REGIONAL SEAS

UNITED NATIONS ENVIRONMENT PROGRAMME

Pollution and the marine environment in the Indian Ocean

UNEP Regional Seas Reports and Studies No. 13

PREFACE

The Regional Seas Programme was initiated by UNEP in 1974. Since then, the Governing Council of UNEP has repeatedly endorsed a regional approach to the control of marine pollution and the management of marine and coastal resources and has requested the development of regional action plans.

The Regional Seas Programme at present includes eleven regions [1/] and has over 120 coastal States participating in it. It is conceived as an action-oriented programme having concern not only for the consequences but also for the causes of environmental degradation and encompassing a comprehensive approach to combating environmental problems through the management of marine and coastal areas. Each regional action plan is formulated according to the needs of the region as perceived by the Governments concerned. It is designed to link assessment of the quality of the marine environment and the causes of its deterioration with activities for the management and development of the marine and coastal environment. The action plans promote the parallel development of regional legal agreements and of action-oriented programme activities.

Five of the regions in the UNEP programme include in their geographic scope coastal waters of the Indian Ocean or of the seas on it's periphery. These are the East Africa, East Asian Seas, Kuwait Action Plan Region, South Asian Seas, and Red Sea and Gulf of Aden.

The present report was prepared with the aim of assessing the present level of pollution in the Indian Ocean and the extent of information available on the marine environment and pollution in the area. In addition to the States of the East African Region (Comoros, Kenya, Madagascar, Mauritius, Mozambique, Seychelles, Somalia and the United Republic of Tanzania), the study covers Bangladesh, Burma, India, Pakistan and Sri Lanka. In its preparation, information was obtained from most of the marine institutes of the States mentioned above. In addition, many useful documents were made available by the Library of the Oceanographic Museum at Monaco and the Library of the Marine Biological Association of the United Kingdom in Plymouth. The assistance and co-operation received from these institutes as well as from Governments and University sources is gratefully acknowledged.

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PART I

THE MARINE ENVIRONMENT

1.0 INTRODUCTION

This report attempts to provide a general idea of the sources, levels and effects of marine pollutants in the Indian Ocean as well as the existence and extent of marine pollution monitoring systems at present available in the area. It is intended to serve as a source document for eventual programmes relating to pollution monitoring and its combatting in the Indian Ocean Area.

This paper has been divided into two parts. Part one deals with the introduction and description of the area. It provides information on the physiography of the region which covers the physical aspects of the ocean such as current systems and water-mass movements: the geological features of the ocean bed; and the meteorology related to the area. Marine chemistry, marine biology and fisheries of the area are also included.

Part two deals with the pollution problems of the area and covers industrial pollution, pollution from municipal and domestic sources, oil contamination, radioactive pollution and pollution related to agricultural activites.

The information in this overview has been obtained from papers and documents provided from several research centres located in the countries bordering the Indian Ocean as well as from the references listed in the bibliography.

2.0 DEFINITION OF THE REGION

For the purpose of this report, the Indian Ocean has been defined as follows: Western Boundary, 77°E and to the southern border of Mozambique; Eastern Boundary, 112°E (to the western coast of Australia); Southern Boundary, 30°S, from Durban on the South African Coast to Green Horn on the West Australian Coast. The two major basins included within these limits are the Bay of Bengal and the Arabian Sea. The area covered by these boundaries is of the order of 70 million square kilometres and the average depth of the ocean is 3800 metres. Seas opening into and forming a part of the Ocean but not treated specifically are, the Persian Gulf, the Red Sea, the Gulf of Oman, the Gulf of Aden, the Timor Sea and the Malacca Straits (see fig. 1).

Countries having borders on the area under survey are Mozambique, Tanzania, Kenya, Somalia, Pakistan, India, Bangladesh and Burma. Islands within the area are Madagascar, Sri Lanka, the Seychelles, Mauritius, the Comoro Islands and the Maldives as well as the territorial islands (see fig. 2). Despite the aforementioned boundaries, the oceanography studied will cover the whole area of the Indian Ocean so as to facilitate the presentatation of features such as currents and water mass movement and hence the southern boundary will extend to Antarctica.

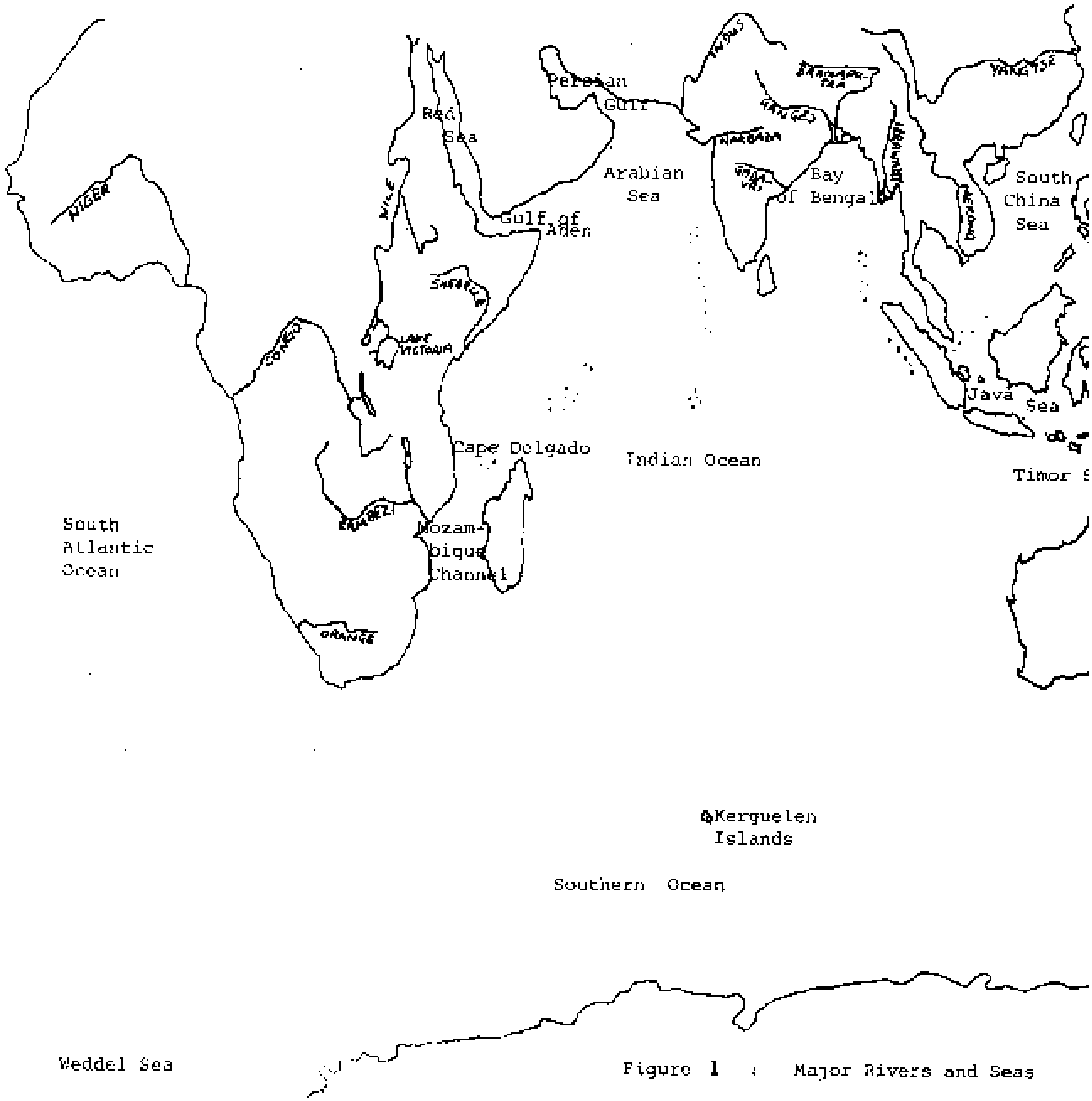


Figure 1 : Major Rivers and Seas

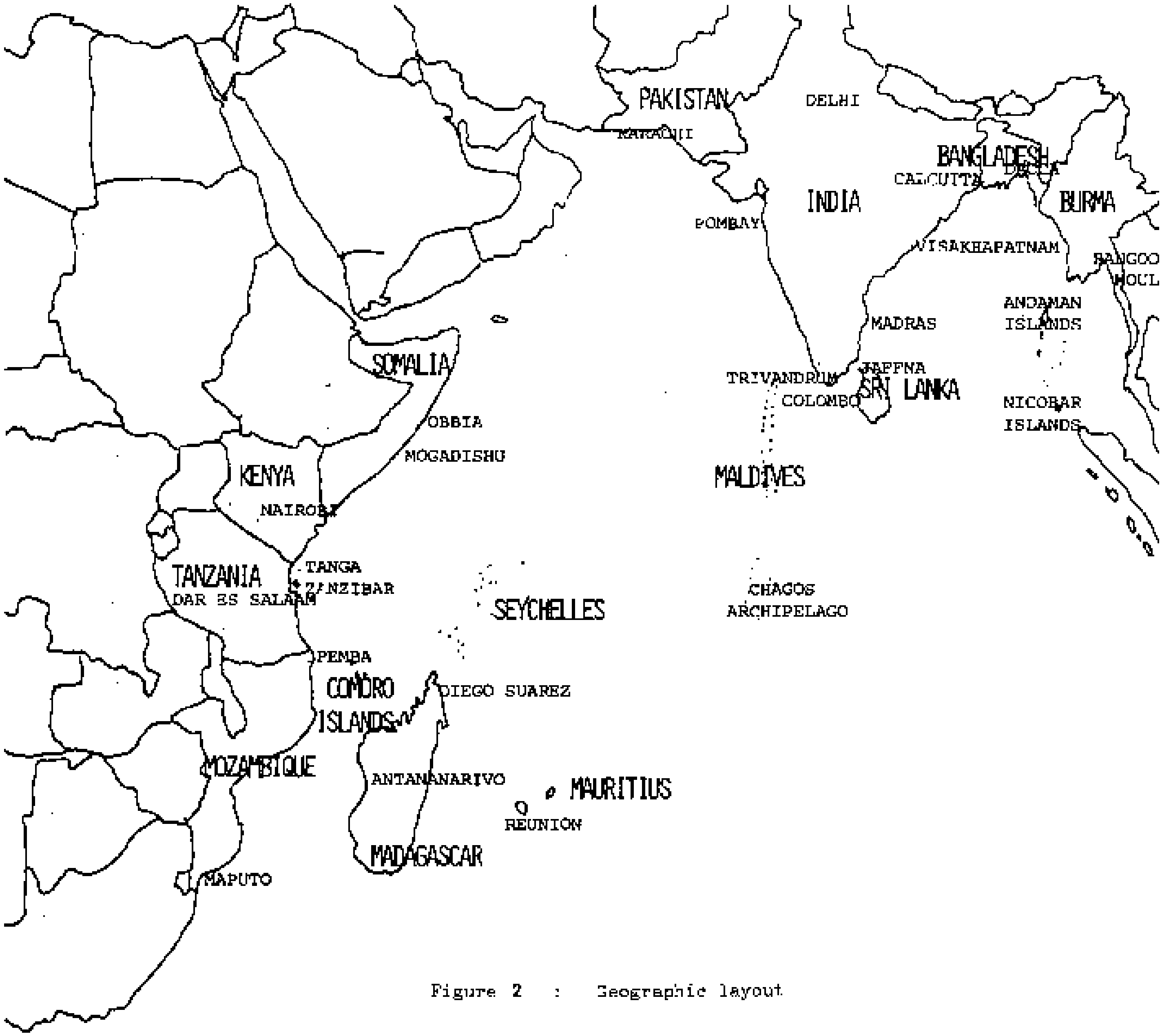


Figure 2 : Geographic layout

3.0 PHYSIOGRAPHY OF THE INDIAN OCEAN BASIN

3.0 Introduction

The Indian Ocean is the smallest of the three major oceans. It has unique features in it's dynamic oceanography, meteorology and geology. There is an overall negative water balance in the Indian Ocean. The Bay of Bengal, on its own, has a positive water balance due to the input by precipitation and run-off exceeding evaporation. The dynamic oceanogrphy is influenced to a great extent by the meteorology especially in the Northern Hemisphere. These inter-related effects give rise to the seasonal monsoons and monsoonal currents.

3.2 The Current Systems

3.2.1 Surface Currents

The current system in the Southern Hemisphere of the Indian Ocean does not change much from season to season and is dominated by the South Equatorial Current and Westwind Drift (see fig. 3). There is a large anticyclonic gyre, the southern-most part of which is the Westwind Drift lying between 38°S and 50°S with a width of 200-240 nautical miles. It can reach a speed of 20-30 NM per day near the Kerguelen Islands, is normally dependent on the wind and is seasonally and regionally variable. In winter it turns north before Australia and joins the current coming from the Pacific via Southern Australia. In summer it joins the south-bound current west of Australia and flows to the Pacific via the southern ocean.

The West Australia Current reaches 10-15 NM per day north of Equatorial Current at 23°S due to the effect of the Southeast Trade winds. In the southern summer the flow becomes eastward and shifts southeast. The current is reinforced in the winter by a flow from the Pacific via the Arafura Sea and reaches up to a 1 knot velocity. It divides into three branches before Madagascar; one branch flows northward around the Island at 50-60 NM per day and then turns east, the second branch runs north and the third turns south and becomes the Mozambique and later the Agulhas Current.

In the Northern Hemisphere, currents are greatly influenced by the monsoons which give rise to the Southwest and Northeast Monsoon Drifts. North of latitude 10°S, surface currents very with seasons. During the Northeast Monsoon, the well-developed Northeast Monsoon Drift or North Equatorial Current, flows west and southwest. In February, the southern boundary shifts 5-7° south and turns north in March disappearing as the Southwest Monsoon Drift begins. The narrow Equatorial Counter Current sets in as a result of the southwest flowing Somali Current and a northward flow from Cape Delgado. In November, it reaches speeds of 40 NM per day and in February, also shifts south, then back north and disappears.

As the Southwest Monsoon begins, the Southwest Monsoon Drift appears and flows eastward, south of India, reaching up to 3 knots south of Sri Lanka. It's branches flow clockwise in the Arabian Sea and the Bay of Bengal. The southeast flow reaches 30-42 NM per day off the west coast of India. The East African Coastal

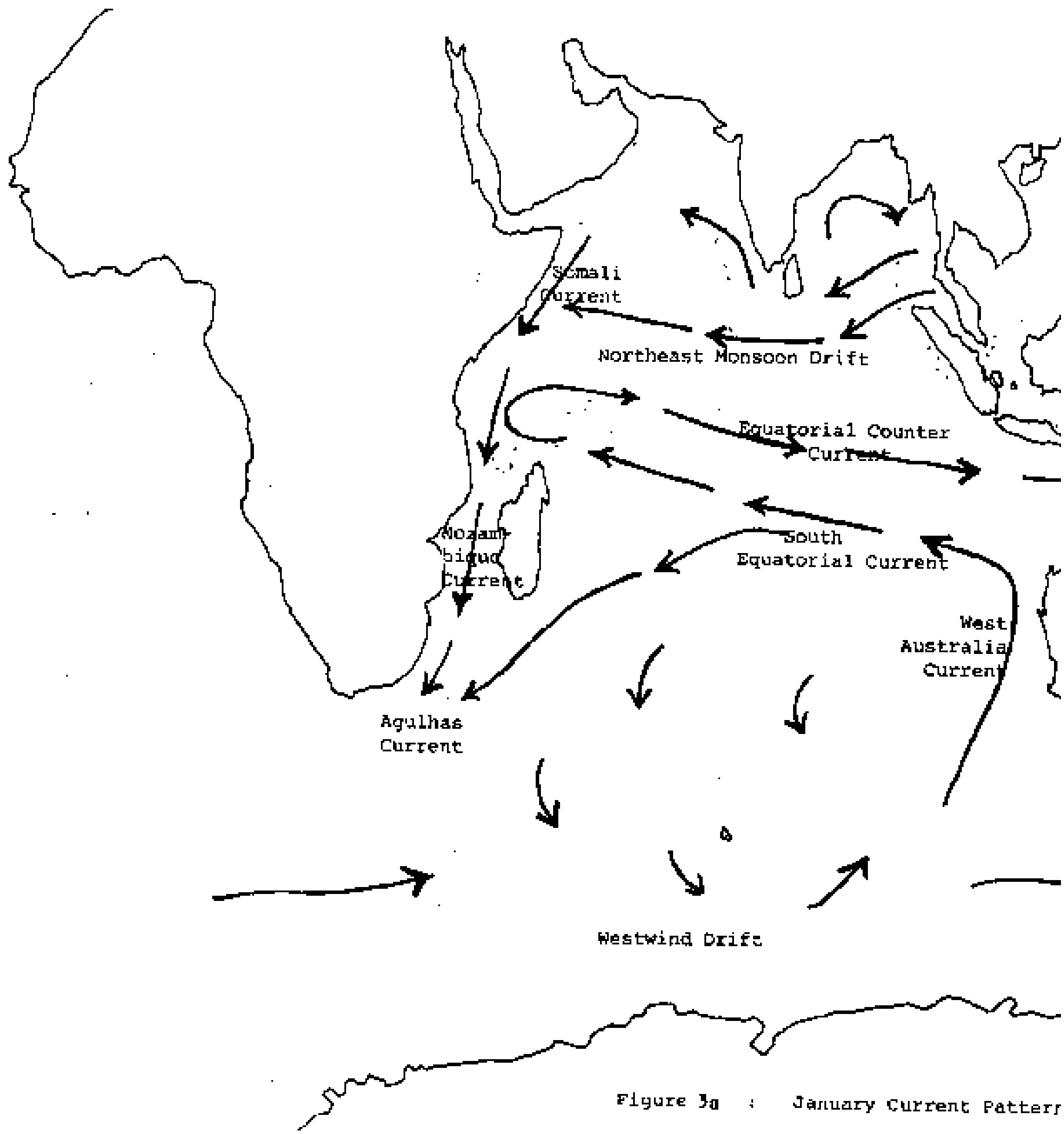


Figure 3a : January Current Pattern

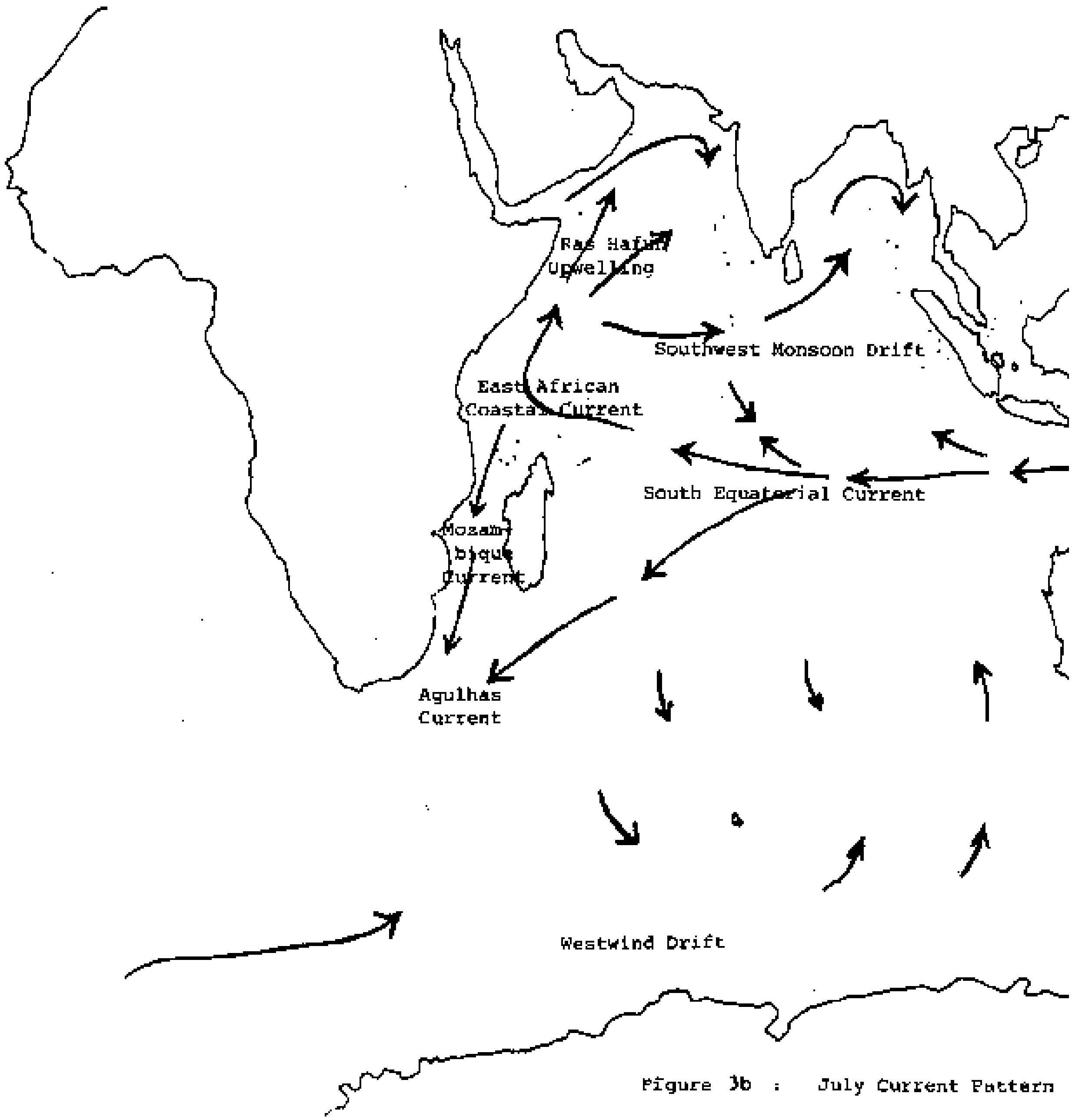


Figure 3b : July Current Pattern

Important local currents are the Mozambique Current, the Agulhas Current, the Equatorial Current, the Somali Current and the West Australian Current.

3.2.2 Sub-surface Currents

Subsurface current measurements show that, at a depth of 15m, the pattern does not change much except for the Equatorial Counter Current which starts at 60°E and is narrower and more southerly than at the surface. At a depth of 200 m, currents south of 5°N are reversed under the North and South Equatorial Currents and under the Countercurrent east of 70°E. At a depth of 500 m, between 5°N and 10°S, currents are eastward with a clockwise gyre around a centre at 5°S and 60°E.

At a depth of 1500 m, an anticyclonic gyre is formed by a broad eastward flow south of 10°S which merges with a southerly current at 80°E and then turns north at 95°E to eventually degenerate into smaller eddies. A slower branch flows south at 70-80°E and 20-25°S. At a depth of 2000 m, the same current, between 15°E and 73°E, is slower and a branch flows northward at 65°E. A current from the Bay of Bengal meets a flow from the east at the equator and turns northward to the Red Sea. At a depth of 3000 m, there is an eastward flow between 20°E and 23°E and a cyclonic gyre appears between 25-35°E and 58-75°E.

The Scripps Institute of Oceanography made some direct current measurements from 1°N to 2°S in July-September 1962 and February-March 1963 as shown in table 1. The undercurrent was stable for several weeks as measurements over a further 3 weeks proved.

At the equator, between 79°E and 92°E, the thermocline thickness was at a maximum as shown by measurements of the distance between the 15°C and 25°C isotherms. High salinity and low oxygen were noted at the point of maximum eastward flow.

3.3 Water Masses

There are 3 major water masses in the Indian Ocean: the Indian Ocean Central Water (IOCW), Equatorial Water (IOEW) and Deep Water (IODW) and two transition types the Antarctic Intermediate Water (AIW) and the Red Sea Water. The IOCW lies between 35-40°S and 15-20°S and is formed by sinking at the subtropical convergence. The salinity ranges of the IOEW are larger than those of the IOCW due to mixing of the high salinity Red Sea Water and the low salinity coastal water.

The subantarctic water (SW) is a low salinity water mass formed by mixing and vertical circulation between the subtropical and Antarctic convergences and is distinct from the AIW which originates with a salinity of 33.80 ppt and sits along a well defined belt around the Antarctic Continent. After sinking, the SW spreads north to mix with waters above and below it and forms a minimum salinity water mass, with low temperatures and high oxygen content, at a depth of 200-700 m between the Antarctic and subtropical convergences. North of the latter convergence, it sinks to a depth of 800-1500 m, then rises to a depth of 500-900 m near 10°S where salinity increases. West of Australia, it spreads northeast between 100-110°E until 15°S at a depth of 600 m and northwest 90-100°E

Table 1: Current measurements (by Scripps Institute of Oceanography)

LATITUDE	MONTH	SPEED	FLOW DIRECTION
79°E	September	60 cm/sec	eastward 0° latitude
89°E	September	50 cm/sec	eastward 0° latitude
90°E	April	80 cm/sec	westward 0° 100 m deep
61°E	March	38 cm/sec 57 cm/sec	0° latitude
53°E	May August	-	no current, westward flow meridonial
62°E	August	-	no current, westward flow meridonial
85°E	February	5 cm/sec	eastward flow

From: The Encyclopaedia of Oceanography
R. W. FAIRBRIDGE (1966)

From the Banda Sea comes the low salinity Banda Intermediate Water (BIW) which spreads west, south of Indonesia, and southwest off Australia below the AIW at depths of 1000-1400 m. The high salinity Northwest Indian Intermediate Water (NIIW) lies above the BIW, 10-20°S and 700-1000 m deep and mixes with the AIW. Highly saline waters originate from 5 areas and are shown in table 2.

Within the three major water masses of the Indian Ocean are found five smaller deep water masses. These are the Circumpolar Deep Water (CPDW) from the South Atlantic Ocean, the Antarctic Bottom Water (ABW) from the Antarctic continental slope, the North Indian Deep Water (NIDW), the North Indian Bottom Water (NIBW) and the South Indian Deep Water (SIDW). The CPDW flows eastward between 65-75°S and is fairly warm. It enters the Indian Ocean at 35°S and 20°E below 2000 m depth and reaches 20-22°S and 30-45°E. It meets the SIDW at 35°S and moves south. The latter forms at 10-16°S at a depth of 1500-3500 m from the NIDW, Subantarctic Intermediate Water (SIW) and ABW and predominates east of 115°E. The NIDW forms in the Arabian Sea from the highly saline Red Sea waters and moves east and southeast. Although the temperatures decrease the salinity does not change much and the water thus sinks to a depth of 2000-2500 m north of the equator. Between 10°S and 16°S it mixes with the SIW and ABW and is transfered into the SIDW.

The ABW forms through mixing with the ASW and CPDW. The west half of the Indian Ocean is dominated by water from the Weddell Sea while the east half receives those from east of 90°E. Shelf water forms bottom water when the density is greater than 27.87 gm/cm^3 with temperatures of -1.8 - 1.9°C and a salinity greater than 34.58 ppt which occurs during ice formation (1.5 - 2.5 m thick). In winter, the bottom water lies at a depth of 500-800 m, 60-80 NM from the shelf and 3000-3500 m deep north of the Antarctic zone. In the summer, it sinks to a depth of 1200 m near the shelf and becomes the NIBW between 16°S and 10°S where its characteristics change. Figures 4 a, b and c show the vertical and horizontal position of some of the water masses whilst table 3 gives some of their characteristics.

3.4 Tides

The tides are both diurnal and semi-diurnal with the former dominating on the west coast of Australia and southern Java and the latter concentrating on the east coast of Africa. When disturbances due to shelf are neglected, variation in phase of semi-diurnal tides are very small. The mean range of spring tides along the northern coast of the Arabian Sea is 2.5 m at Aden, 5.7 m at Bombay and 1.1 m at Cochin. On the west coast of the Bay of Bengal and on the east coast of Sri Lanka, the mean spring tide range is about 1 m but the north and east coasts have 4.5-5.2 m ranges due to shallow depths. The Rangoon spring tides exceed 7 m. In the Mozambique Channel, values of 3-4 m are recorded and from 6-12 m along the northwest coast of Australia.

3.5 Waves

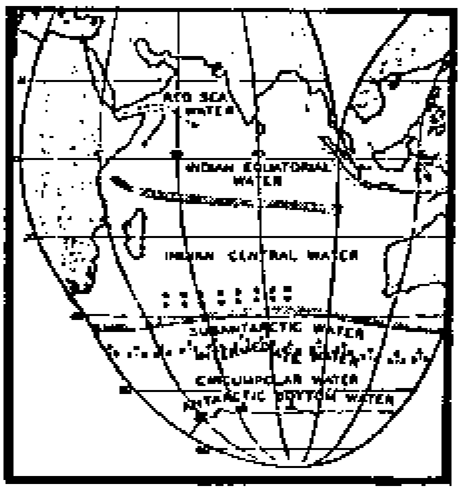
In winter, in the Northern Hemisphere, the Northeast Monsoon only causes small waves below 1 m but in summer, especially from June to August, the Southwest Monsoon generates waves higher than 2 m. Over the Kerguelen Islands these have been seen to reach 15 m heights with wavelengths of 250 m. Swells of 7.5 m in height, 341.7 m in length and 14.5 seconds in periodicity have been recorded in the

Table 2 : Characteristics of Waters Entering the Indian Ocean Basin (Saline Waters)

Originating from	Salinity ppt	Depth m	Densit
Red Sea	36.30 - 34.90	600 - 900	27.30 -
Persian Gulf	36.10 - 35.00	300 - 400	26.40 -
Northern Arabian Sea	36.50 - 35.00	100 - 200	24.90 -
Arabian Sea	36.60 - 35.20	0 - 100	23.80 -
Equatorial Indian Ocean	35.80 - 35.20	0 - 110	23.00 -

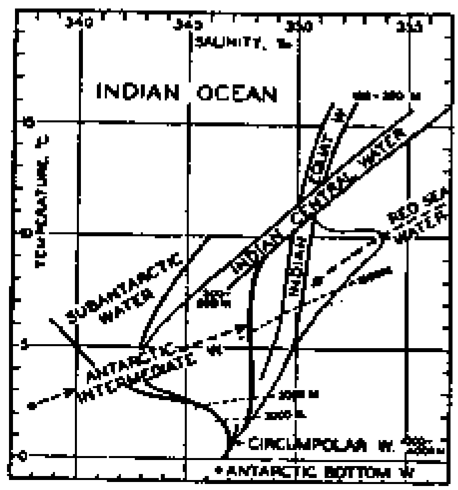
From: The Encyclopaedia of Oceanography
R. W. FAIRBRIDGE (1966)

Figures 4 : Water Mass Characteristics, Indian Ocean



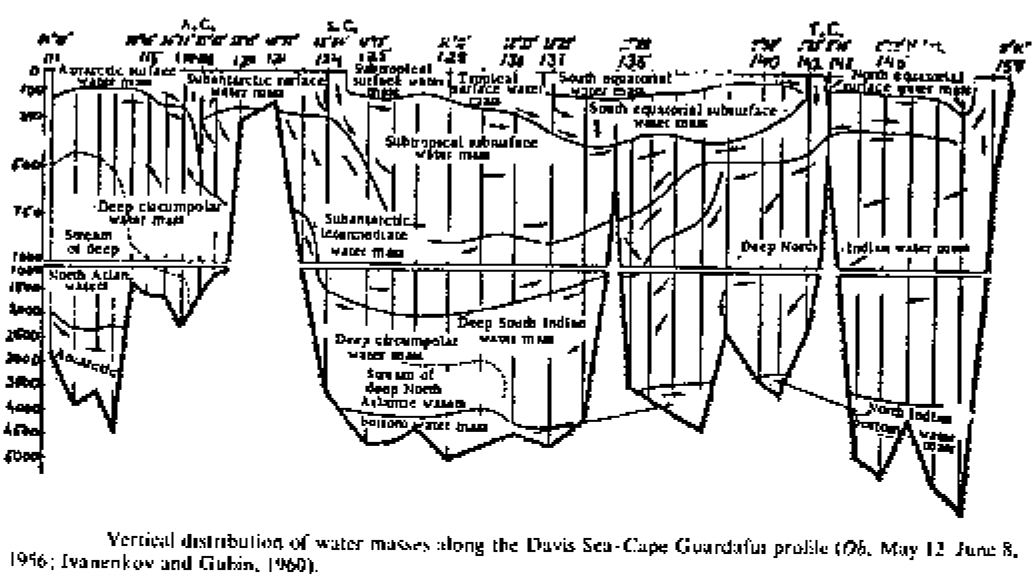
(a) Approximate boundaries of Indian Ocean water masses (Sverdrup *et al.*, 1942). (By permission of Prentice Hall, N.J.)

(a)



(b) Temperature and salinity of Indian Ocean water masses (Sverdrup *et al.*, 1942). (By permission of Prentice-Hall, N.J.)

(b)



Vertical distribution of water masses along the Davis Sea-Cape Guardafui profile (*O6*, May 12 June 8, 1956; Ivanenkov and Gubin, 1960).

(c)

Table 3 : Characteristics of Water Masses in the Indian Ocean

Water Mass	Temperature °C	Salinity °/oo	Depth m	Density
Indian Central Water	8 - 15	36.60	500 - 600	
		35.50	1000 - 2000	
Equatorial Water	4 - 18	34.90 - 32.25		
Antarctic Intermediate	2.2	33.80		27.2 -
Formed from Antarctic Intermediate	3.4 - 4.0	34.20 - 34.50	200 - 700	
		34.75	500 - 900	
Banda Intermediate	4.0 - 5.0	34.60 - 34.70	1000 - 1400	
Northwest Indian Intermediate	7.0 - 8.0	34.70 - 34.90	700 - 1000	
North Indian Deep	1.0 - 2.5	35.50 - 34.80		
Antarctic Surface	0	34.58 - 34.62		
Circumpolar	0	34.76 - 34.70		
North Indian Bottom	1.5 - 1.7	34.74 - 34.76		
Antarctic Bottom Water	-0.9 - 0.0	34.66 - 34.69		27.87

From: The Encyclopaedia of Oceangography
R. W. FAIRBRIDGE (1966)

3.6 Salinity

Maximum salinity values occur west of Australia and in the Arabian Sea. Low salinities are recorded in the eastern side of the equatorial zone at the transition between the Southwest Trade Winds and the monsoon, and extend south to 10°S (see fig. 5 a & b). In the northern ocean the salinity values vary seasonally. In the summer it is very low in the Bay of Bengal and very high in the Arabian Sea. Low salinity is due to the heavy fresh water run-off mainly via the Ganges, Bramaputra and Irrawaddy Rivers. The rise in salinity in winter is due, in part, to the dry season and in part to the upwelling of high salinity water in the western Bay of Bengal which then follows a northerly flow.

3.7 Density

Density values correspond to salinity and temperature and show a low density area between 0° and 20°S (23g/cm^3) and off Java and Sumatra (21.5 g/cm^3). In the Southern Hemisphere, summer surface density values decrease northwards from 27 g/cm^3 at latitudes 53-54°S to 23 g/cm^3 at 17°S. With the advent of summer, density values in the Northern Hemisphere are from 22 g/cm^3 in the southern part to below 19 g/cm^3 in the north-western part of the Bay of Bengal and above 24 g/cm^3 in the Arabian Sea. Figure 6 shows some density values for the Indian Ocean.

3.8 Temperature

The western half of the ocean is warmer than the eastern half at the same latitude due to the ocean circulation pattern. In February, the Southern Hemisphere is in summer and temperatures above 29°C are recorded off Australia. Isotherms run from WSW to ENE turning southeast when they are between 25°C and 27°C. Between 40°S and 50°S a 12°C difference is noted and is a result of the transition zone between middle latitude water and polar water. With the change of monsoon seasons, temperatures above 29°C are seen in most parts of the Northern Hemisphere in May. By August, these temperatures have dropped again and, as a result of the upwelling caused by the Southwest Monsoon off Somalia, values below 25°C are noted between the Somali Coast and the southeast coast of Arabia. In November, the surface temperature is near the annual mean and north of 10°S the range is between 27°C and 27.7°C only.

3.9 Pressure

The pressure values of the sea surface increase as one progresses eastward. Figure 7 shows the dynamic topography at the ocean surface.

3.10 Climatology

The climate in the Indian Ocean Area is influenced by and influences both the land and water and is characterized by its monsoon seasons. The meteorological and thermal equator over the Indian Ocean lies slightly south of the geographic one in January and north of it, on the Asiatic Continent, in July. This divides the Northern and Southern Hemispheres into distinct meteorological provinces. The winds in this area undergo a complete shift between January and July resulting in the Northeast Monsoon in the former and the Southwest Monsoon in the latter (see figs. 8 a & b). This annual cycle is dominated by the heating and cooling of the Asiatic Continent. A low pressure area over the Persian Gulf during the summer causes wind systems over the North Indian Ocean to blow from the southwest whereas in winter, the northeast wind comes from the high pressure zone over the Tibetan Plateau. Pressure and temperature patterns over

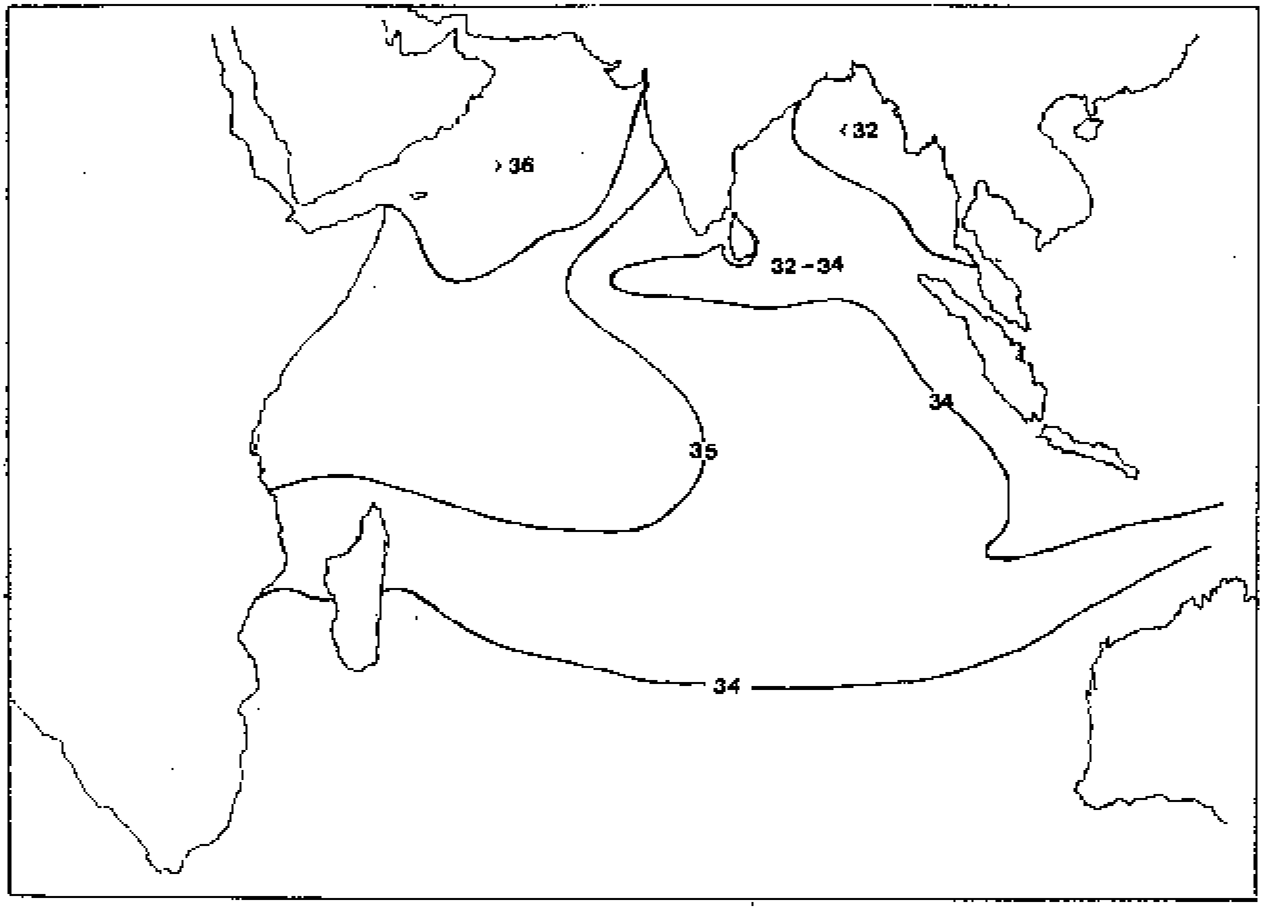
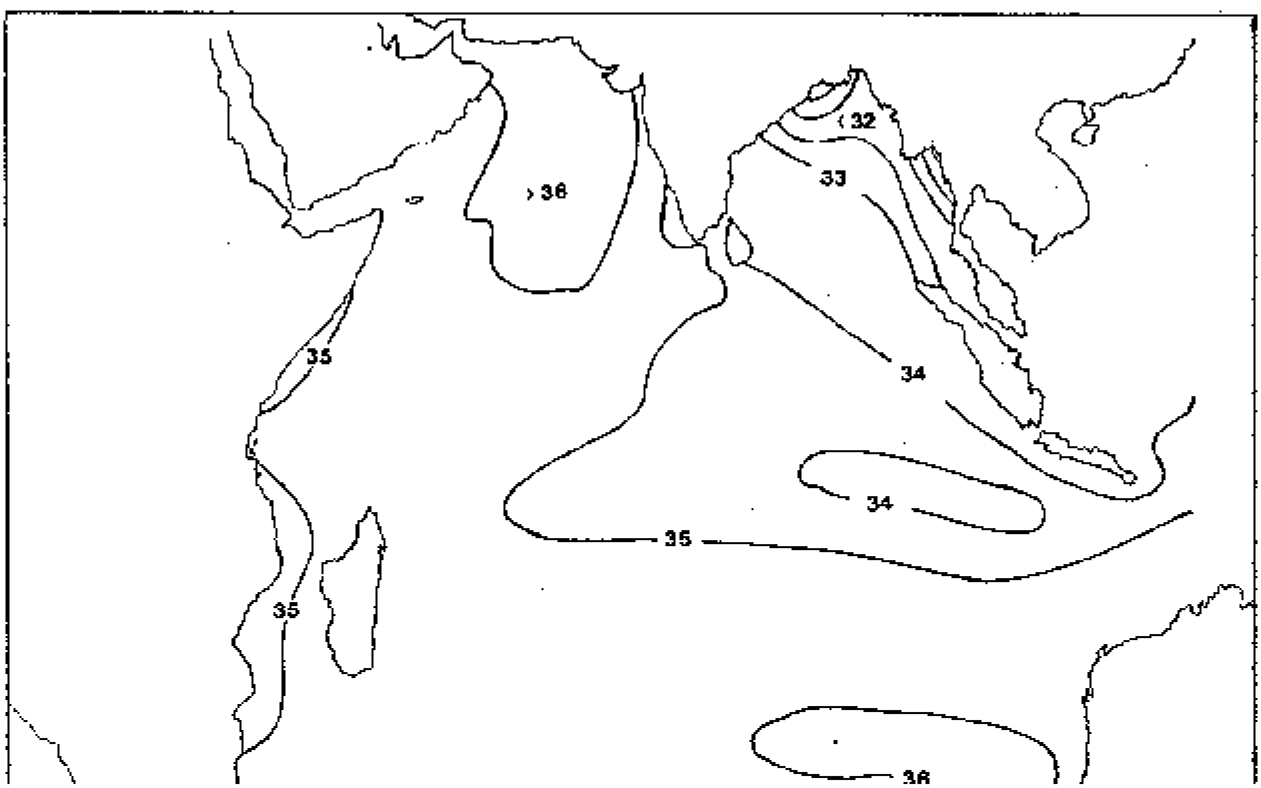


Figure 5a: Surface salinity - February

Figure 5b: Surface salinity - August



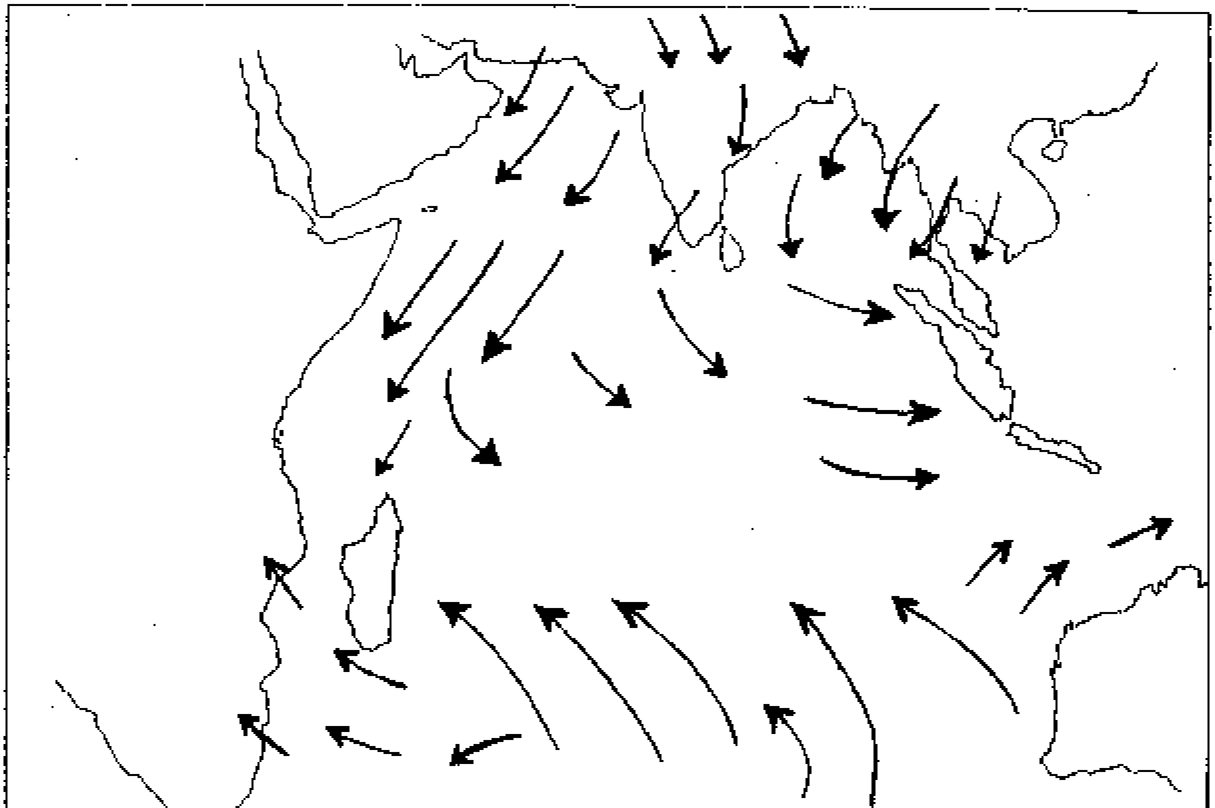


Figure 8a: Prevailing wind pattern in January

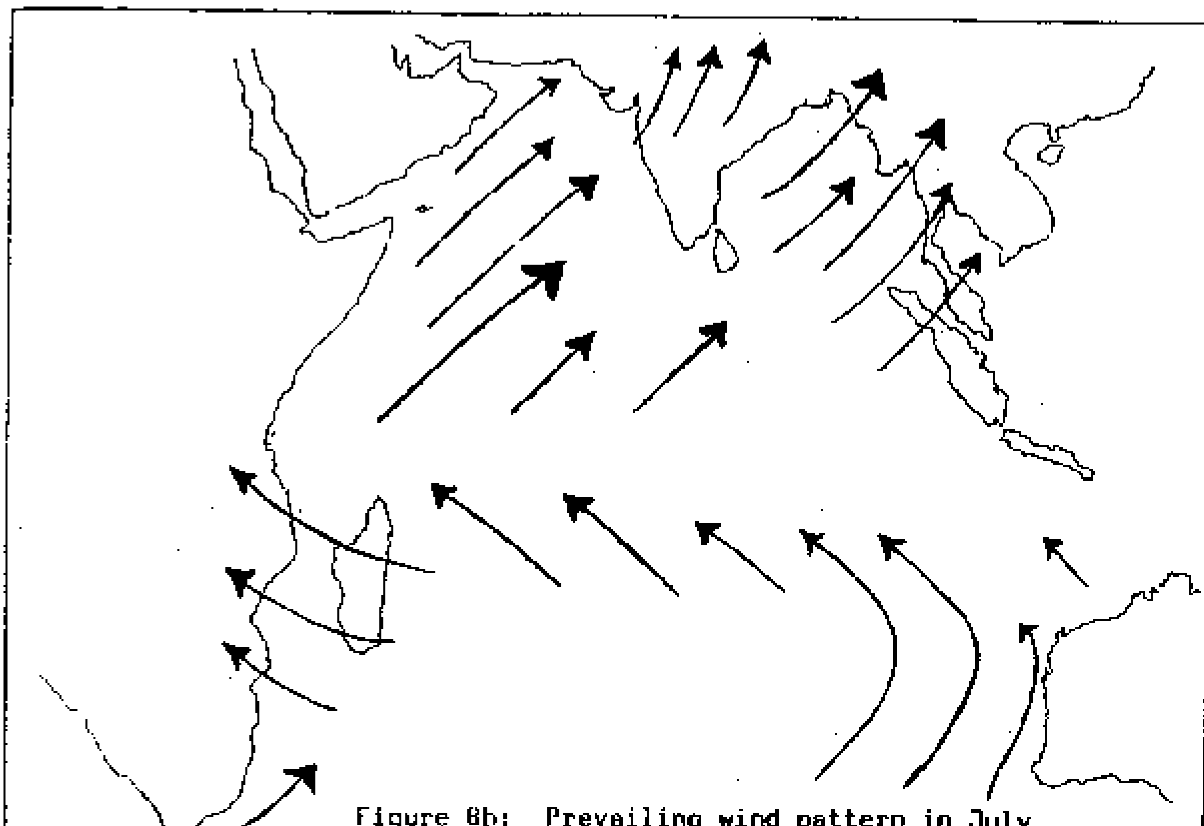


Figure 8b: Prevailing wind pattern in July

Figure 9a: Temperature and pressure patterns over the Indian Ocean (January)

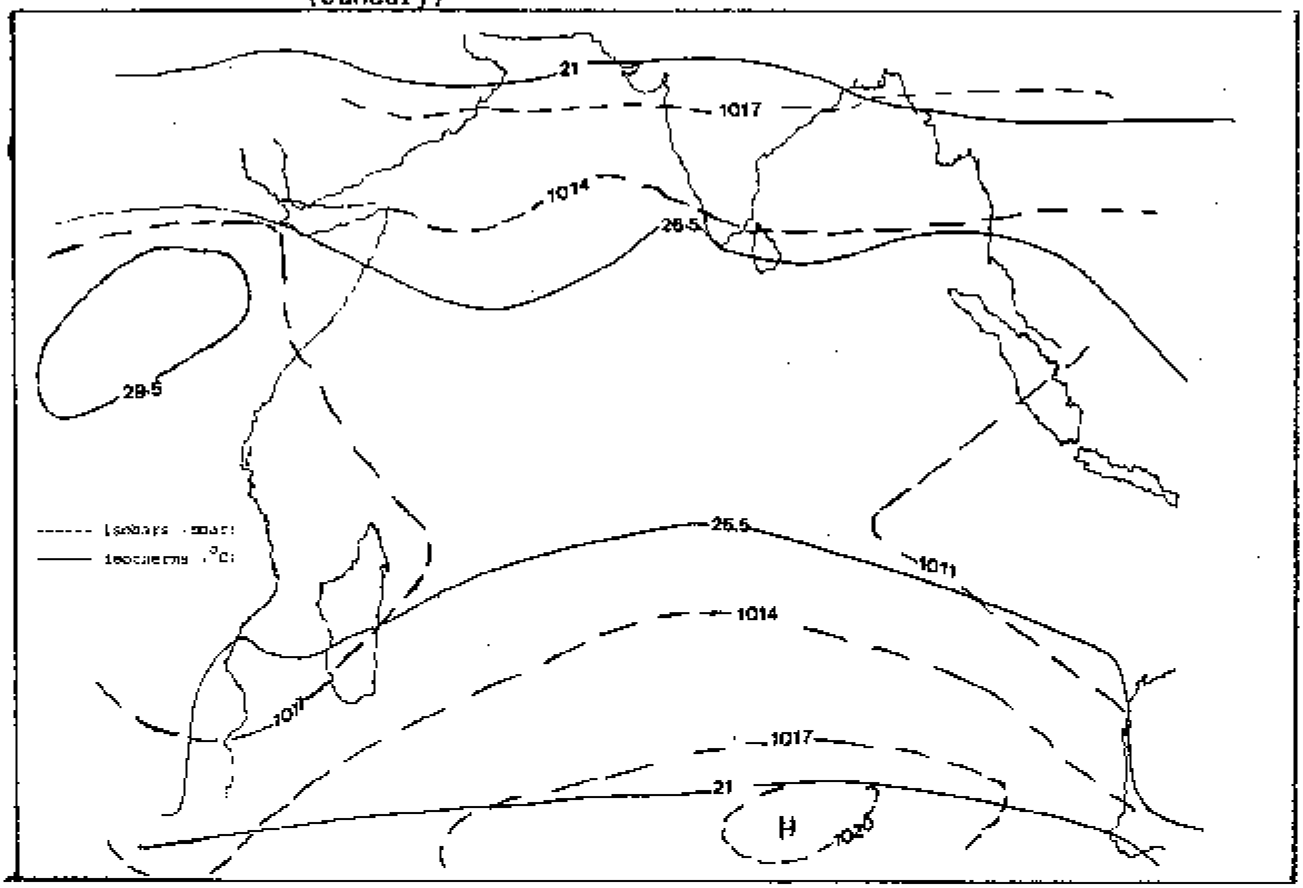
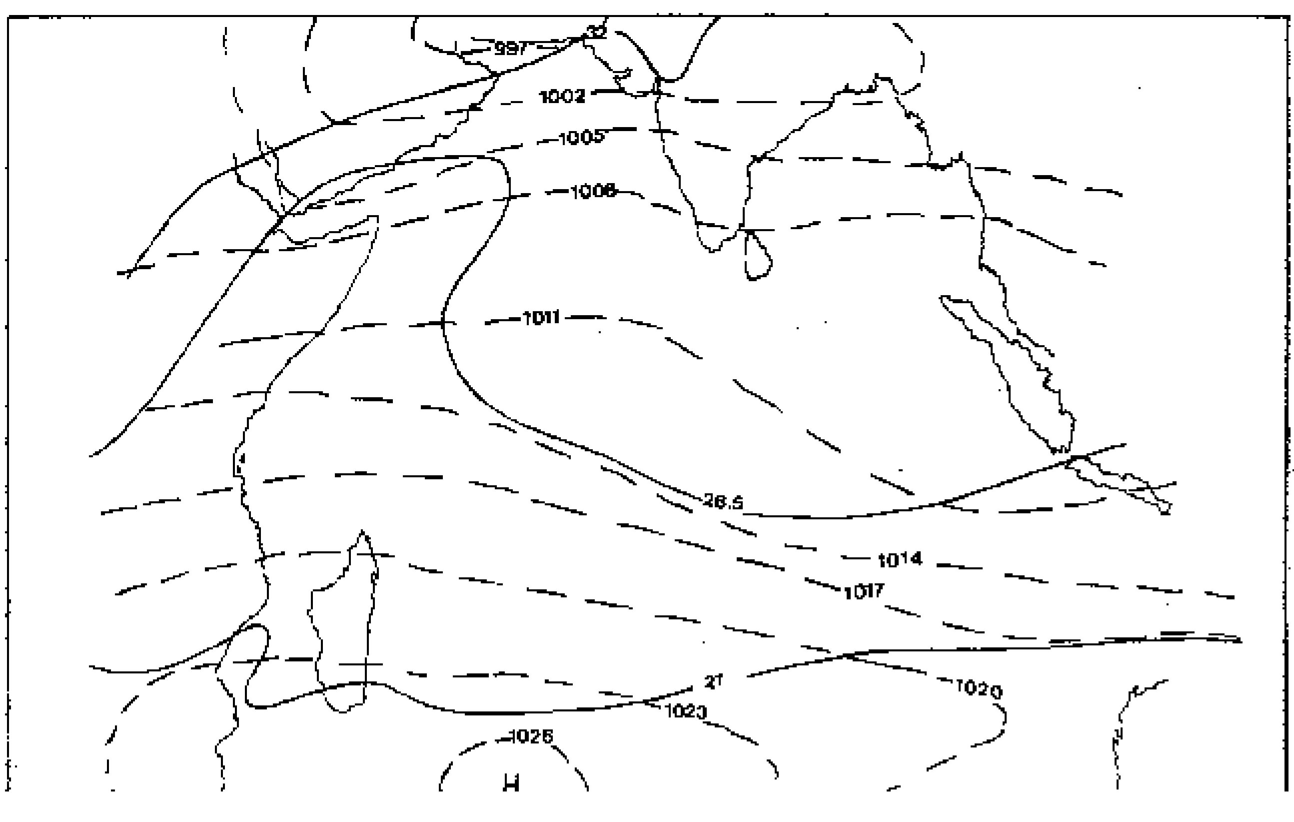


Figure 9b: Temperature and pressure patterns over the Indian Ocean (July)



The moderating effect of the ocean results in little change of pressure and wind between January and July in the middle and high latitudes of the Southern Hemisphere. Storm winds, above 7 on the Beaufort scale, are dominent in the northern summer leaving a calm zone between 1°S and 7°N west of 78°E. The northern winter is calm with an occasional tropical cyclone around 10°S and 85°E-95°E arising between November and April. In the Southern Hemisphere, southward from 15°S, storm winds are seen more frequently.

Cloud cover is highest during the Southwest Monsoon in the Northern Hemisphere but although this clears during the Northeast Monsoon, the Southern Hemisphere remains overcast throughout the year. Sea fog is frequent during the summer off the coast of Somalia and south of the Arabian Peninsula. This condensation is due to cooling of air temperatures by the lower seawater temperature and is stimulated by dust coming from inland deserts. The dust loading over the Northern Indian Ocean averages 1.2 microgram per m^3 of air. The Northeast Monsoon transports dust from the Rajastha desert region at one order of magnitude greater than those of the Southwest Monsoon over the open ocean areas. The southern Indian Ocean averages 0.68 micrograms per m^3 of air with values in the East being higher due to the influence of the Arabian deserts.

The total annual precipitation is high, more than 3000 mm in the central equatorial belt and more than 1000 mm in the western zone of the Southern Hemisphere. Between 20°S and 35°S, up to a northern boundary of 17°S-15°S and particularly off the west coast of Australia, it is fairly dry with precipitation below 500 mm. The equatorial wet zone, lying between the equator and 10°S from the Sunda Sea to the Seychelles, is a result of the boundary area between the northern and southern wind systems. The eastern part of the Bay of Bengal, paricularly off Malaysia, has a high precipitation in contrast to the west side of the Arabian Sea which is very dry. Maximum rainfall in the wet areas occurs 10°S to 25°S between December and February and from 5°N to 10°S between March and April. These maxima occur during the northern summer in the western side of the Bay of Bengal whereas there is heavy precipitation during most months in the wettest area between 5°N and 10°S, east and west of Sumatra.

In winter, when the sun's altitude is highest in the Southern Hemisphere, heat is provided in all but the northern-most parts of the ocean. The maximum heat gain reaches 17 kcal/cm^2 per month in the 40°S area, decreases to the north and is zero around 18°S in the south equatorial current where evaporation is strongest. It then increases again to reach 4 kcal/cm^2 per month at 5°S becoming negative north of 4°N and reaching a maximum heat loss of 6 kcal/cm^2 per month at 20°N. The evaporation at the South Equatorial Current caused by the Southwest Monsoon becomes more conspicuous in February causing a heat loss zone at its western side while the maximum heat gain zone shifts south by 4° latitude. In the north, the heat loss area occurs only in a small area of the northern part of the Bay of Bengal.

In April, the heat loss maximum lies over the Agulhas Current and covers the Southern Hemisphere, while areas of heat gain occur north of 10°N. The heat gain area reduces further to the northern parts of the Arabian Sea and the Bay of Bengal whilst heat loss reaches a maximum of 12-14 kcal/cm^2 per month between Java and Madagascar. The heat gain area north of the equator starts increasing again in August whilst the area of large heat loss lies southwest of India. Maximum heat loss in the Southern Hemisphere occurs at about 22°S but does

On an annual basis, the strongest heat loss area occurs over the South Equatorial Current between Madagascar and Java and the Agulhas Current south of Africa. Maximum heat gain lies around 45°S and a zone of weak heat gain is seen between Tanzania and Sumatra. In the Bay of Bengal and Arabian Sea the southern parts show little heat loss whilst the northern parts have large heat gain. Differences between the annual heat balance are accounted for by horizontal heat transport by the ocean currents. This heat flux appears as a change in surface temperature with a delay of about 2 months and effects the layers above the thermocline, below which seasonal changes in temperature are negligible.

7.11 Geology

The Indian Ocean is the smallest of the three great oceans and geologically speaking the youngest. It has existed since Permian times (late Paleozoic) when Gondwanaland, the land mass formed by Africa, India, Australia and Antarctica, was thought to have broken up as a result of continental drift (see fig. 10).

The bed of the Indian Ocean has five distinct features: the Continental Margin, the Ocean Basin Floor, the Microcontinents, the Mid Oceanic Ridge and the Fracture Zones.

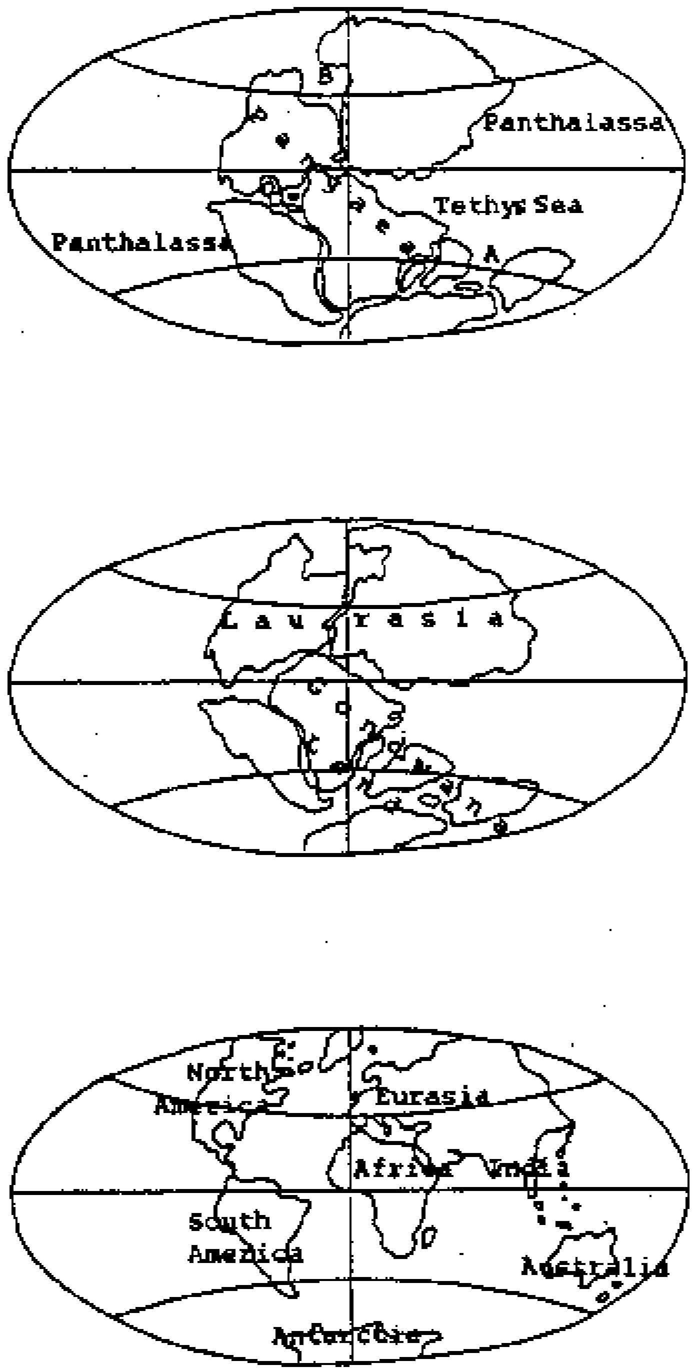
The continental shelves range in width from a few hundred metres to more than 200 km, for example off Bombay. Numerous submarine canyons mark the continental slope notably near the Ganges and Indus Rivers. Large sediment accumulations forming abyssal cones are also associated with these rivers. The continental rise averages a gradient of 1:40 at the base of the slopes to 1:700 at the abyssal plain boundaries and occasional sea mounts, sea knolls and canyons may be seen locally.

The Java Trench bordering Sumatra and Java forms a boundary for the Indian Ocean between Burma and Australia. The ocean basin floor is noticeable for it's abyssal plains. These flat surfaces have gradients from 1:1000 to 1:7000 with occasional peaks, not exceeding 1-2 m, characteristically lying on the seaward side. The plains are extensively well-developed in the northern and southern parts of the Indian Ocean but are poorly developed off Australia.

Aseismic microcontinents, running north-south, are a striking feature of the Indian Ocean and tend to be higher and more akin to sqare blocks with lower local relief, than the mid-oceanic ridges. Notable among these, from west to east are, the Mozambique Ridge, the Madagascar Ridge, the Mascarene Plateau, the Chagos-Laccadive Plateau and the Ninetyeast Ridge - the longest and straightest ridge yet discovered. In addition to these north-south running microcontinents the more east-west trending Broken Ridge, Diamantine Fracture Zone and Kerguelen Plateau may be seen.

The mountainous mid-oceanic ridge, lying in the center similar to an inverted Y, is the most conspicuous feature of the Indian Ocean contrasting with the smooth continental rise and flat abyssal plains. Starting from the Carlsberg Ridge in the Arabian Sea it is thought to separate two distinct crustal regions. Along its axis is found a seismically active rift valley which is cut by several fracture zones, of which, the most prominent are the Owen,

Figure 10: Sketch illustrating the theory of continental drift



A Sinus Australis
B Sinus Borealis

From: Times Atlas of the World (1980)

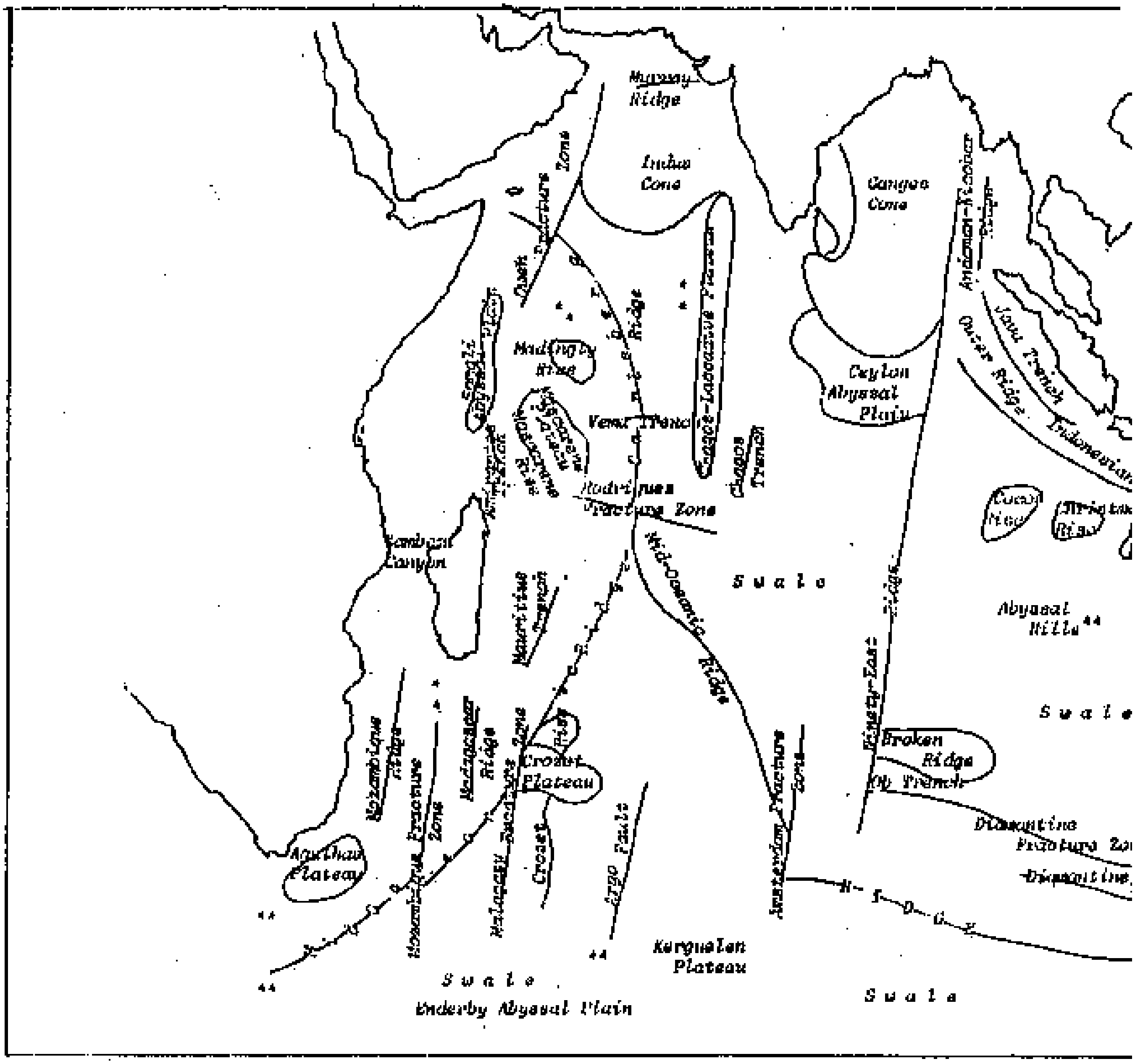


Figure 11 : Major geological features

The pelagic sediments of the Indian Ocean floor are made up of red clay, which covers 25% of the total area (fig. 12). Calcareous ooze covers 54% of the ocean floor and diatom ooze 20% of the area occuring in localized patches. Red clay is seen between 10°N and 40°S in the eastern ocean, away from islands and continents and right up to the continental rise of West Australia, owing to the semi-arid nature of this region. Towards the tropics the red clay merges with radiolarian ooze. Where the depths are not excessive in areas of warmth and high productivity, between 20°N and 40°S, calcareous ooze mainly Globigerina species is found with pteropod dominating in small patches off North Western Australia. Diatom ooze is seen mainly in the sub-polar region beyond 50°S.

Terrigenous sediments, mainly kaolinite in the tropical areas, are found close to land. In the mid-ocean volcanic areas, lava and ash accumulations with occasional fine tuffs and pelagic oozes are found. The zeolinite mineral, philippsite, is characteristic near marginal volcanic zones. Coral limestones are seen occasionally. Near the circumpolar belts, melting of ice floes and icebergs provides fine and coarse tillite sediments up to 500 km north of Antarctica although deposits have been seen as far as 7000 km north of the continent. In the western Indian Ocean, 15°N to 20°S, coral reefs and biothermal facies are seen. These are not associated with submerged volcanic cones but with microcontinent type mid-oceanic submarine plateaus. In the northern part of the Indian Ocean, transport of sediments occurs by turbidity currents, volcanic action and submarine slumping.

4.0 MARINE CHEMISTRY

Oxygen content is usually large at the surface and increases with decreasing temperature and hence the surface layer of the Antarctic region is richest in oxygen with values above 7.5 ml/l. The northern Indian Ocean has low oxygen values which can reach as little as < 0.05 ml/l.

This oxygen rich water is carried north by the Subtropical Subsurface Water, the Intermediate Antarctic Water and the Antarctic Bottom Water. In the South Equatorial Current the oxygen content of the 100-300 m layer is less than 2.5 ml/l due to the stability of the surface which prevents oxygen exchange at the sea-air interface as it has no contact with the atmosphere. The North Indian Deep Water is poor in oxygen and forms an oxygen minimum layer between the oxygen rich bottom and intermediate water masses down to 40°S.

Biological Oxygen Consumption rates estimated in different areas of the Indian Ocean show the center of the North Indian Deep Water, from 600-1200 m, to have the highest consumption rate at 1.5-2.0 ml/l. The biological oxygen consumption rates of all equatorial regions, 100-300 m deep, the Antarctic Shelf, 0-400 m deep, and the North Indian Bottom Water more than 2000 m deep were valued at 1.5 ml/l, 0.37 ml/l and 0.04 ml/l respectively.

pH distribution determination was carried out for some regions as seen in table 4. The Antarctic Surface Water shows a low pH due to cessation of photosynthesis in the early winter (May). pH values of the subsurface and intermediate waters depend on the rate of oxidation and the supply of carbon dioxide-rich waters. Deep water pH values are affected by the dissolution of

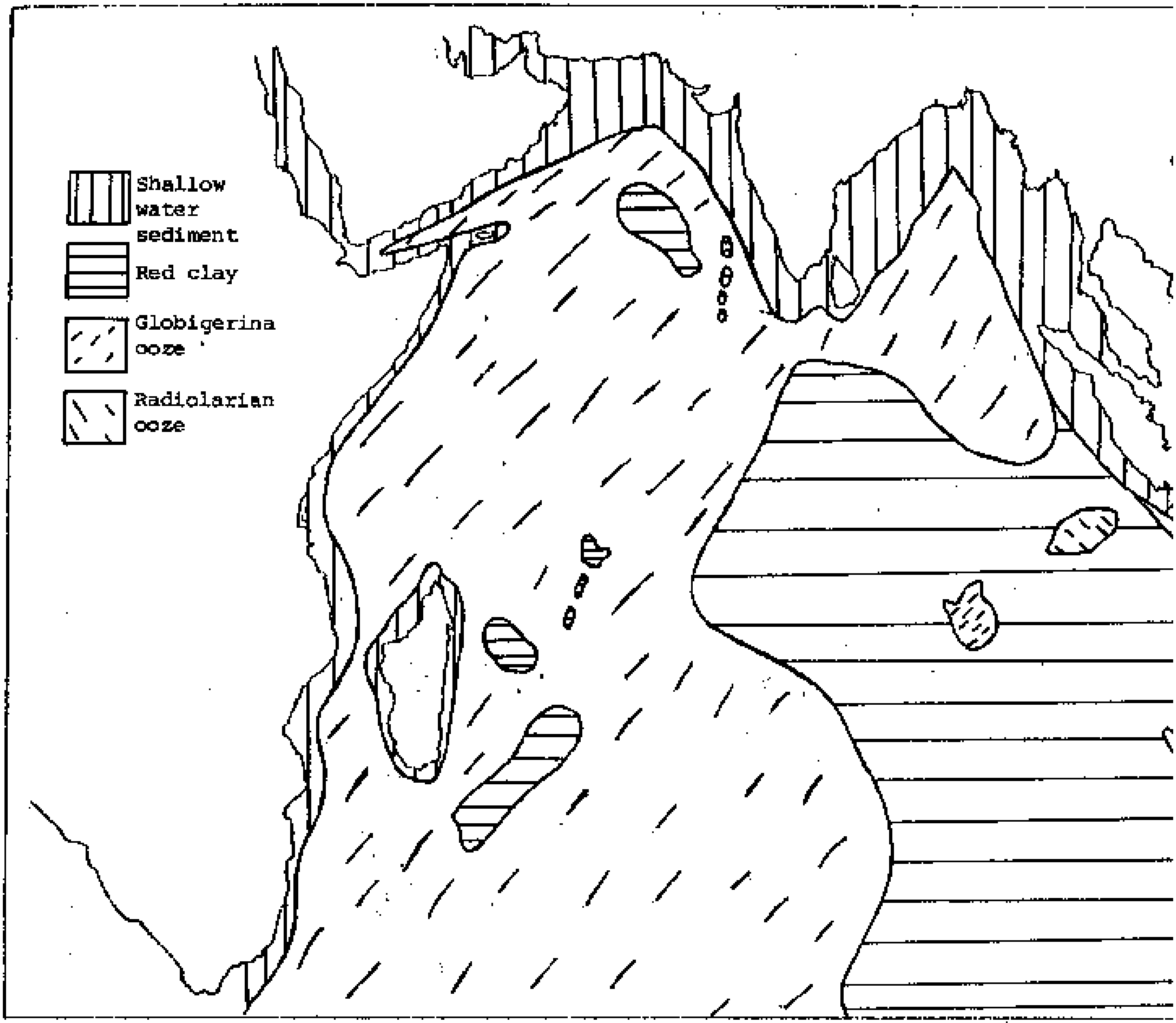


Figure 12: Sediment distribution

Sharp increases in phosphates from the surface to 100 m in the equatorial water are due to the general upwelling in the area. The highest values found in the North Indian Deep Water are an effect of mixing with phytoplankton-rich intermediate waters which originate from the Red Sea Water.

Although the Antarctic zone is rich in silicate consuming diatoms, the silicate values for the area are high due to mixing with deep water whereas north of the subtropical convergence uniformly poor silicate values of 5-10 mg at/m^3 are due to stable stratification preventing mixing with deep water.

In the Antarctic zone, nitrites are found only in summer in the 0-25 m layer where intense decomposition of unstable organic matter occurs. The maximum value in the upper layer of the sub-tropical convergence in the Subantarctic zone was found to be 8-10 mg at/m^3. No nitrite is found north of this convergence in the southern winter and none is present in the North Equatorial Water but values of 10-10.5 mg/m^3 are seen in the pycnocline.

Nitrate maxima of 110-220 mg/m^3 are found in the Antarctic and Subantarctic zones with an overall maximum value of 320 mg/m^3 at 12°S in the North Indian Deep Water. The Circumpolar Current has values of 200-210 mg/m^3 whilst the Subtropical Convergence shows no evidence of nitrate presence.

Organic phosphorous values averaging 0.20-0.30 mg at/l were found on the southern boundary of the South Equatorial Current, the Equatorial Divergence and the boundary between the Countercurrent and the North Equatorial Current. Maxima in the vertical profiles lay at 1000 m probably as a result of the salinity minimum of the Antarctic Intermediate Water. Conditions of some waters of the Indian Ocean may be seen in table 4 and figs. 13 a and b.

5.0 MARINE BIOLOGY

5.1 Introduction

Most of the work carried out on the biology of the Indian Ocean has been done in connection with the results obtained from the International Indian Ocean Expedition which began in 1959. The area contains both tropical and temperate marine life, the majority of which is concentrated around the coastal regions. The tropical Indian Ocean is considered the richest in shallow tropical marine fauna. The least productive of the ocean areas is the south central Indian Ocean which is oligotrophic as compared to the rest of the ocean area which is fairly eutrophic. The Indian Ocean has a lower biological productivity than the Pacific or Atlantic Oceans due, in part, to its relatively smaller continental shelf area. The shelves off India, Sri Lanka and Pakistan are prominent on the western coast whereas the eastern coasts and East Africa have narrow shelves fringed with mangroves and coral reefs. The region of maximum biological use to men is found in the continental shelf area. The islands have volcanic and coral type reefs.

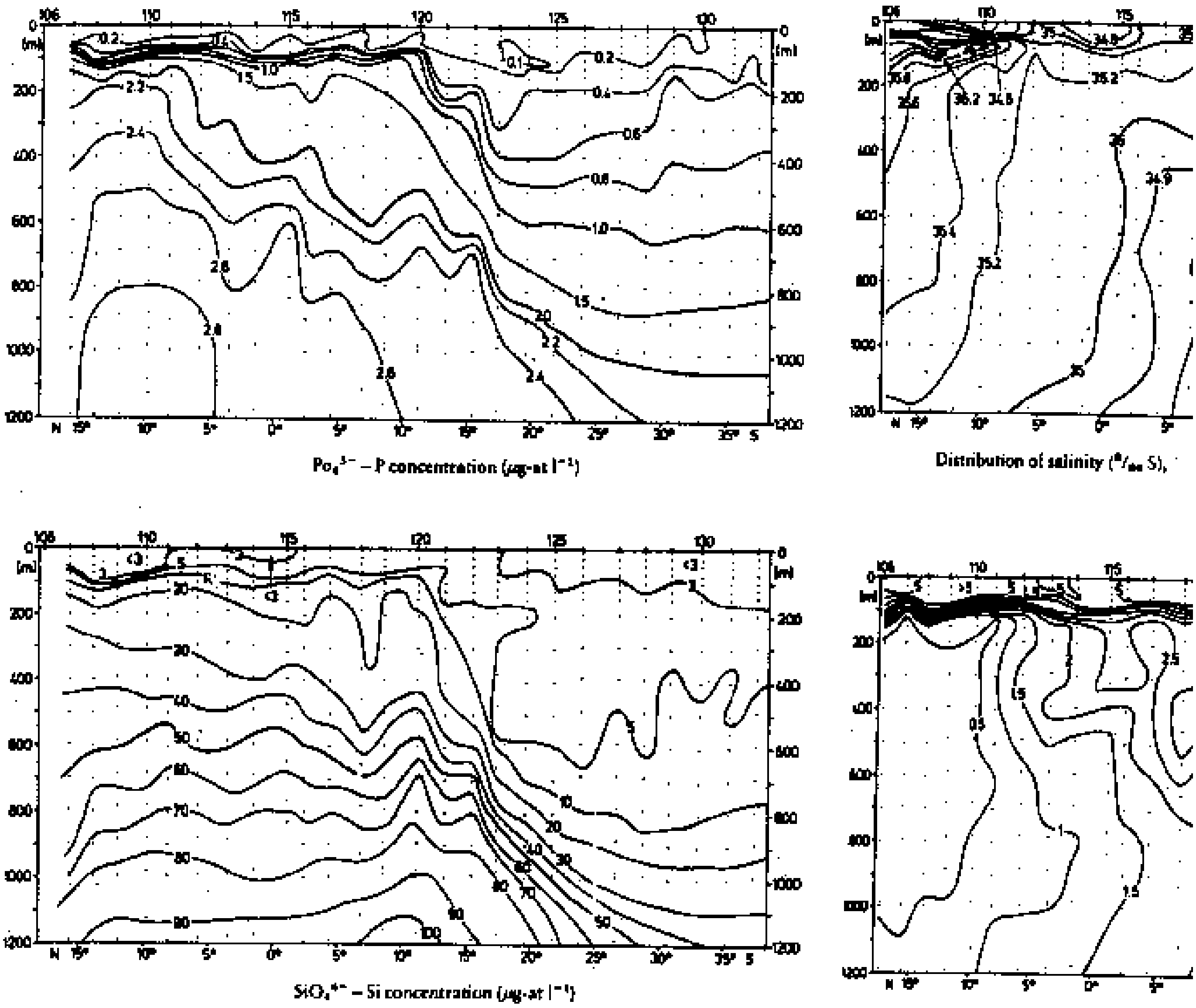
The Arabian Sea has the potential of being an exceptionally fertile area, especially during the southwest monsoon, due to upwelling induced by wind stress. In the Ras Hafun area, upwelling results in water rich in nutrients with temperatures well below 20°C but lacking in the fertility apparent in more stable upwelling areas. Turbulence results in replenishement of nutrients and waters rich

Table 4 : Conditions of some waters of the Indian Ocean

WATER MASSES	Latitude	Depth (m)	pH	Phos (mg
SUBTROPICAL SURFACE		(surface) 200		0.8 - 1.
SUBTROPICAL SUBSURFACE	40-16 ° S		8.0 - 8.1	
EQUATORIAL SURFACE		(surface) 100		0.2 - 1.
EQUATORIAL WATER	6-10 ° S	120 - 300 300 - 500	7.81 - 7.86	
EQUATORIAL BOTTOM				
ANTARCTIC SURFACE		0 - 100	7.93 - 7.98	
ANTARCTIC SURFACE CONVERGENCE				1.5 -
ANTARCTIC INTERMEDIATE		upper band middle band lower band		1.2 - 1.8 -
ANTARCTIC BOTTOM				
CENTRAL		800		
CIRCUMPOLAR				1.8 -
NORTH INDIAN DEEP DEEP				2.6 -

From : The Encyclopaedia of Oceanography
R. W. FAIRBRIDGE (1966)

Figure 13 : Some vertical distribution characterisitics in the Indian Oce



PO_4^{3-} – P concentration (µg-at l^{-1})

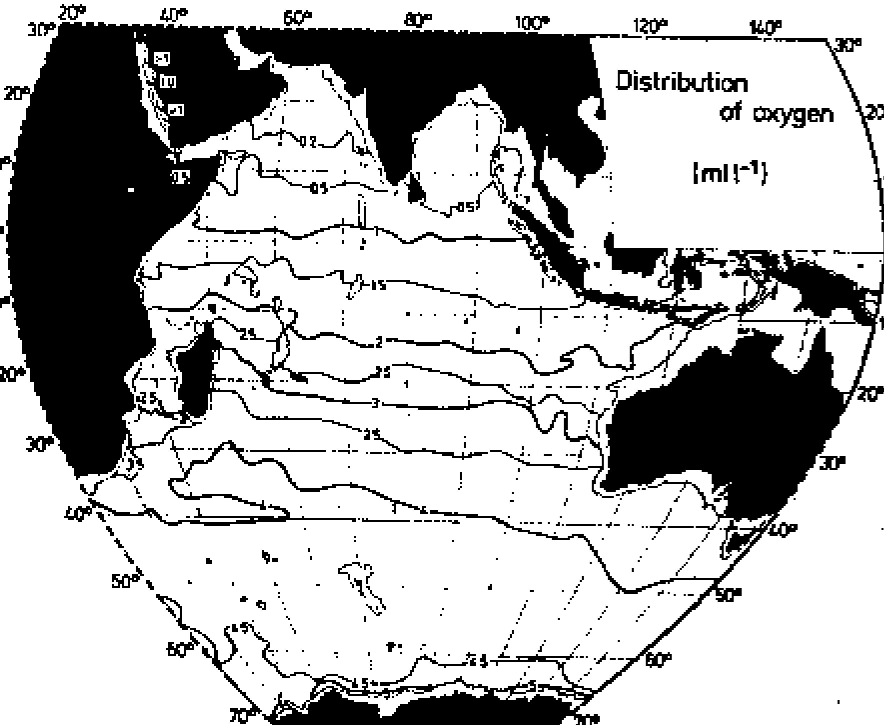
Distribution of salinity (‰ S),

SiO_4^{4-} – Si concentration (µg-at l^{-1})

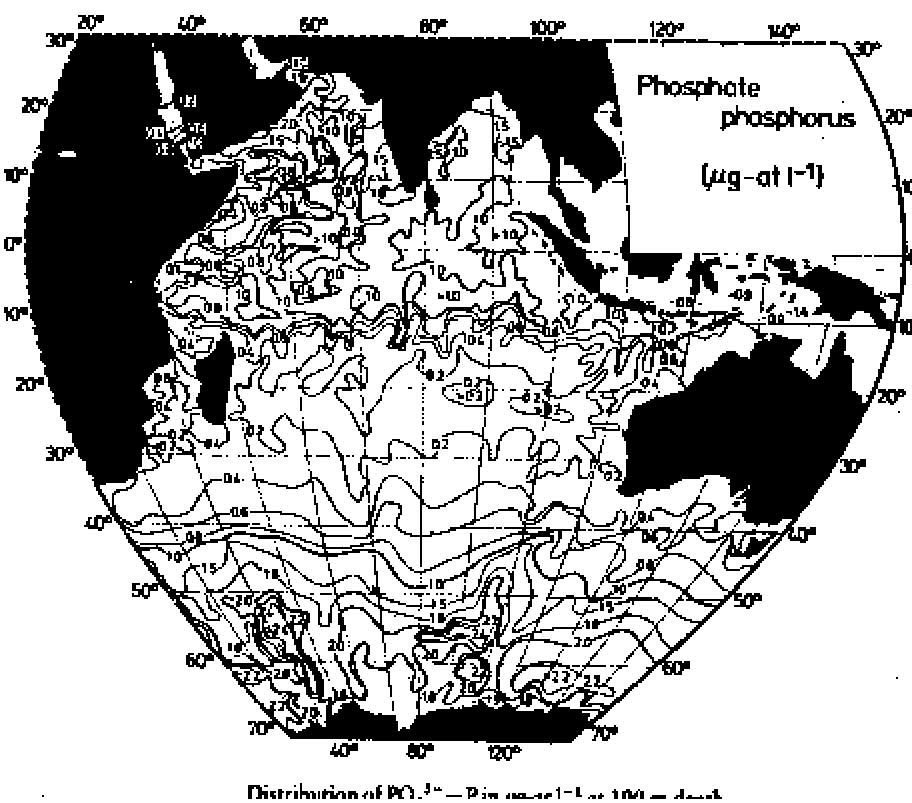
O.

From: Physical Oceanography in the Indian Ocean
K. WYRTKI (1973)

Figure 13b : Oxygen and phosphate distribution in the Indian Ocean



Distribution of O_2 content in the deep oxygen minimum in ml l^{-1}. The 1000 m depth contour is shown



Distribution of PO_4^{3-} — P in µg-at l^{-1} at 100 m depth

The effect of river discharge is also important in the Bay of Bengal for example, there is a high inflow of mud from the Ganges river. The discharge from the turbid rivers is picked up by the Northeast Monsoon Current and taken along the East Coast during the Northeast Monsoon. The Southwest Monsoon, with its heavy rains, causes an increased flow of fresh water from the rivers with an increased sediment load entering the water. Increased sediment reduces light penetration and transparency and results in a decrease of plankton as measured in dry weight per m^3. The sharply stratified low salinity at the surface, due to high fresh water from the Ganges and Irrawaddy rivers, is the cause for the relatively poorer fertility seen in the Bay of Bengal as compared to the Arabian Sea.

Gentle downwelling in parts of the East African Coast around Kenya and Tanzania prevents nutrient enrichment of surface waters. The coastal areas off Tanzania and Kenya are, therefore, less productive than the coastal areas of the rest of the Indian Ocean.

5.2 Bacteria

The microbial distribution in the Indian Ocean is closely linked to that of the primary productivity. The microbiomass is greater near the Equator away from the African Coast. It is also greater in the northern parts of the Bay of Bengal and the Arabian Sea and off the Indian Coast at Goa.

Detritus is found in large quantities near the coast and is especially abundant near the river mouths due to run-off. The increased quantity of organic matter accounts for the high bacterial counts found in the northwestern parts of the Arabian Sea. These bacteria are mainly proteolytic types with about 10% being of the luminescent variety.

5.3 Primary Productivity/Phytoplankton

Although primary productivity is measured as a rate of energy storage, and standing crop as energy present at any given time, the two may be compared to obtain a general view of primary production. Primary production values can indicate the fertility of various regions of the ocean and the variations in productivity with season. In general in the northern Indian Ocean, the Southwest Monsoon period is more productive than the Northeast Monsoon period. In the Northern Hemisphere, for example off the East Coast of Somalia during the Southwest Monsoon, production is 1.0 gC/m^2/day and in the Northeast Monsoon it is 0.3 gC/m^2/day. Further south, few values are noted. Measurements of chlorophyll 'a' concentrations of the standing crop show the northwest Arabian Sea to be fertile (> 0.5 mg/m^3) but the rest, again, is not so fertile. Tables 5 a & b show primary productivity ranges for various types of waters. The tertiary production shows a similar pattern to the primary with 2-4 million tonnes C wet weight per 5° square during the Southwest Monsoon period and 1-2 million tonnes wet weight per 5° square during the Northeast Monsoon period.

<u>Trichodesmium erythraeum</u> is a blue-green alga endemic to the Indian Ocean and often causes blooms where nutrient-rich waters are found. Some Indian Ocean blue-green counts are recorded in table 6. Spatial distribution of some phytoplankton are seen in table 7.

Table 5a : Primary production in different waters of the Indian Oc

TYPE OF WATER	AVERAGE PRODUCTION in mgC/m^2 per day	LIMITS in mgC/m^2 per day	TOTA AREA 10^3k
OLIGOTROPHIC CENTRAL SUBTROPICAL	70	100	1[illegible]
TRANSITION AREAS BETWEEN SUBTROPICAL AND SUBPOLAR REGIONS. PERIPHERAL REGION OF THE EQUATORIAL DIVERGENCE	140	100 - 150	2[illegible]
EQUATORIAL DIVERGENCE SUBPOLAR REGION	200	150 - 250	1[illegible]
COASTAL UPWELLING	340	250 - 500	[illegible]
NERITIC	1000	500	[illegible]

From: Primary Production in the Indian Ocean

J. Krey (1973)

Table 5b : Primary productivity (gCarbon/m^2/day)

AREA	SOUTHWEST	NORTHEAST
ARABIAN UPWELLING	1.16	0.23
ARABIAN SEA	0.76	0.12
JAVAN UPWELLING	0.55	0.28
EAST TROPICAL OCEAN	0.70	0.26
EQUATORIAL REGION	0.40	0.15
EAST AFRICA & MOZAMBIQUE	0.83	0.42
BAY OF BENGAL	not sampled	0.21

From: Production in the Indian Ocean and the Transfer from the Primary to the Secondary Level, D. H. CUSHING (1973)

Table 6 : Blue-green algal counts

AREA	NUMBERS
ANTARCTIC GYRE & WESTWIND DRIFT	1000 - 100,000 cells per liter
ARABIAN COAST UPWELLING	more than 100,000
SOUTHWEST INDIA "	more than 100,000
ARABIAN SEA	app. 10,000
EQUATORIAL CURRENT	app. 10,000
SOUTHERN TROPICAL GYRE	less than 5,000
BAY OF BENGAL	less than 5,000

From: Primary Production in the Indian Ocean, J. KREY (1973)

Table 7 : Phytoplankton predominance in eight phytoplankton geographical regions of the Indian Ocean

Area	Predominance	Secondary Dominance
1. Coastal upwelling areas a. Southern Arabia, b. Western Australia, c. Indonesia	Diatoms	Dinoflagellates, partly Blue-green algae
2. Central Arabian Sea and Bay of Bengal	Dinoflagellates, Blue-green algae	Diatoms, Coccolithophores
3. Somali Current region a. NE section b. SW section	Diatoms	Dinoflagellates, partly Blue-green algae
4. Mozambique Current region	Diatoms	Dinoflagellates, Coccolithophores
5. Equatorial Current region	Dinoflagellates, Coccolithophores	Diatoms, Blue-green algae
6. Southern subtropical gyre between southern subtropical convergence and the southern tropical front	Dinoflagellates	Coccolithophores, Diatoms
7. West-wind drift region	Diatoms	Dinoflagellates, Coccolithophores
8. Antarctic gyre up to the subantarctic convergence	Diatoms	Dinoflagellates, Coccolithophores

From: Primary Production in the Indian Ocean, J. KREY (1973)

Table 8 : Counts of total abundance and percentage of chaetognath species found in the Arabian Sea

Species	Total Abundance	Percentage
Eukronnia	7	negligeable
Krohnitta	14,627	1.3 %
Pterosagitta	48,319	5.1
Sagitta	[illegible]	[illegible]

5.4 Zooplankton

The copepod populations follow a trend of increased numbers in the northwestern regions. They are associated with productive waters. Amphipods are found in large numbers in the southern central and central Arabian Sea. Fair numbers are seen in the east and west southern Indian Ocean in the equatorial zone. The Somali and Arabian coasts have a high density of amphipods and the Bay of Bengal has a high concentration in its northern part. Increased numbers are noticed in upwelling regions, in areas of river drainage and at night due to vertical migration. Euphausid concentrations also follow a similar pattern. Zooplankton volumes are highest in the Arabian Sea with values of 54.7 ml/m^2. A general idea of the different species of chaetognaths present is shown in table 8.

Detritus feeders are dominant nearest the surface followed by seston and predators. At a depth of 200 m seston feeders become dominant.

14 species of Hydromedusae have been recorded in the Arabian Sea of which 4 were also seen in the Bay of Bengal where they tolerate low salinity. Half of the species present there are neritic. Inshore and in upwelling areas, their numbers are low, the greatest numbers coming from the boundary zones and discontinuity layers and where there is a large food supply. Some deep water species are also present. The dominant species found are <u>Aglaura hemistoma</u> and <u>Lyriope tetraphylla</u>. These are warm water, holoplanktonic, oceanic, surface species.

5.5 Benthos

Benthic biomass generally decreases with increasing depth. The abundance of benthic organisms is linked with the presence of food. Areas rich in detritus and phytoplankton are favourable to colonization by benthos as these regions are rich in nutrients. Phytoplankton numbers are at a minimum at the tropics with higher densities towards the two poles. The benthos is thus richer in the temperate regions near the coast. Some concentrations of benthic organisms are listed in table 9 and their spatial distribution is shown in figure 14.

The major part of the benthos consists of polychaetes at depths. Crustacea and Tanaidacea are common in shallow regions and sponges are seen at great depths along with echinoderms. Molluscs are not very common.

A few cumacea have been noted near the coasts of Gujarat and Southwest India. The species recorded include <u>Sympo dammatide</u>, <u>Bodotriida</u> spp. and <u>Lerconida</u> spp. Specimens of cumacea have also been seen in the nearshore waters off Pakistan, India and East Africa. Cumacea are usually rare in open waters and are present in waters of low oxygen content. <u>Compulsspis</u> spp. have been found at great depths off Madagascar.

Rivers carry pollutants and detritus to the sea, sometimes in the form of nutrients. At the point where these rivers flow out nutrients enrich the waters and this often leads to some eutrophication. The effects of this river discharge and run-off on the fauna and flora is very localized.

5.6 Representative Biotopes

The major ecological systems present in the Indian Ocean are the coral reef, coral-free/inter-reef areas, mangrove swamps and open ocean. The Somali upwelling

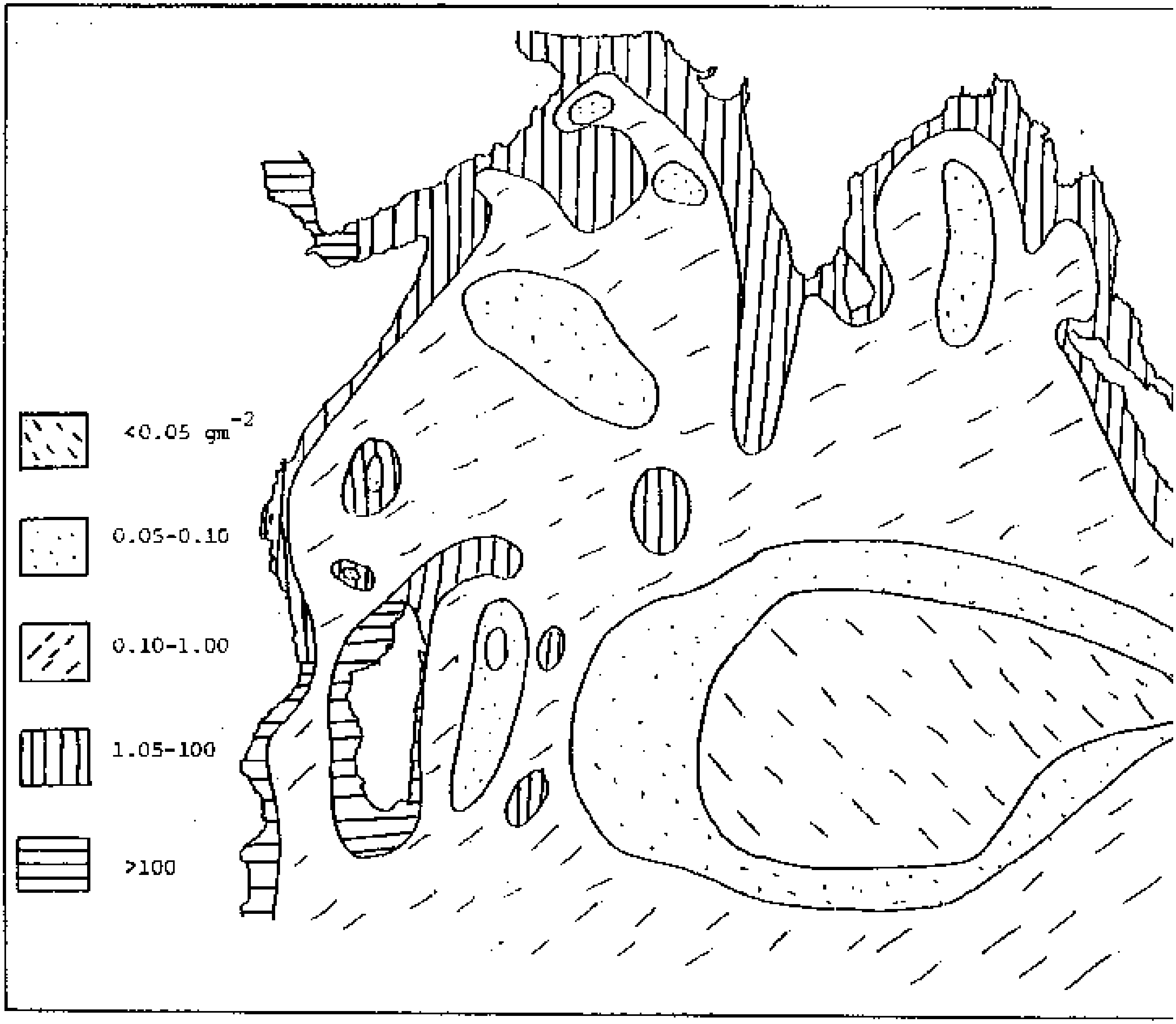
Table 9 : Numbers of benthic organisms found in some regions of the Ind.

AREA	NUMBERS
NORTH ARABIAN SEA	more than 500 g/m^2 averaging
ARAB PENINSULA	15 - 20 to 3 - 5 (up to Mozam
WEST COAST OF INDIA	25 - 30 to 5
BAY OF BENGAL & ANDAMANS	0 - 10
COASTAL TROPICS	less than 10
GANGES MOUTH	42.8
OPEN OCEAN	less than 0.2
WEST OPEN OCEAN	less than 0.1
EASTERN OPEN OCEAN	less than 0.05

Richest at 25-75 m; poor at 80-150 m due to low oxygen a

From: Some Patters of the Distribution of Bottom Fauna in the Indiar
A. A. NEYMAN, M. N. SOKOLOVA, N. G. VINOGRADOVA & F. A. PASTERN

Figure 14: Distribution of benthic biomass in the Indian Ocean



5.6.1 Coral Reefs

One of the main focii of marine life in the tropics is the coral reef which extend to a depth of approximately 15 m. The coral reef is made up of calcareous skeletons, living and dead, onto which coral polyps are attached. In the shallow regions of the coral reefs (2-3 m deep), the substratum is made up of sand, coral and encrusting algae and colonized by angiosperms and turtle grass. The 20°C isotherm is a rough indication of the lower limit of coralline growth. The numbers of coral genera present in certain designated areas is shown in table 10 and the corresponding diversity contours are shown in fig. 15. In Mozambique, most of the corals are found in the north from Preimeiras Islands to the Rovuma and are rich in neritic molluscan fauna. These areas support commercially important fish and crustacea. The shelf region to a depth of 120 m has mainly coral rubble in it but some fauna is present.

5.6.2 Mangroves

The estuarine regions of most rivers of the area have extensive mangrove growths. Mangrove vegetation extends along the coasts of Mozambique, Tanzania, Kenya and the southern part of Somalia with some mangrove forests found in the Northern Madagascar Coast. In India, an area just under 700,000 hectares is covered with mangroves. Rhizophora mucronata, Avicennia officinalis, Sonneratia acida and Excoeccina agallochra are the dominant species present. The mangrove area is economically important for firewood, tanin medicinal products, pulp and paper, timber and aquaculture. They are also important spawning, nursery and feeding grounds for commercially important fish and shellfish species. Oysters, mangrove crab, mullet and penaid shrimp are found here. The mangroves have a distinct ecological character of their own. Due to heavy demands on land a large number of mangrove areas are being deforested. This activity combined with siltation is seriously affecting fisheries and environmental conditions in some of the areas of the region.

6.0 FISHERIES

6.1 Introduction

The Indian Ocean contains between 3000 and 4000 species of fish. The dugong or sea cow is an aquatic mammal peculier to tropical waters. The numbers of these animals are on the decline as are those of the sea turtles.

The western and eastern extremities are fairly distinct in species composition with the Arabian Sea being slightly more productive than the Bay of Bengal. Due to areas rich in chlorophyll, nutrients, organic production and zooplankton, biomass should sustain large stocks of fish. In the countries of the Indian Ocean, fish forms an important source of food. Fisheries contribute in a major way to the economy of the majority of these countries. Most fishing methods are fairly simple, and fishing by large vessels using advanced technology is somewhat restricted to the foreign presence in the area. The main species of fish found in the Indian Ocean are listed in tables 12 and 13. The distribution of fish larvae in the Indian Ocean is shown in fig. 16.

Comparing potential yield values estimated in 1973 with actual catches in 1979, the Indian Ocean area still appears to be underfished (see tables 14 &

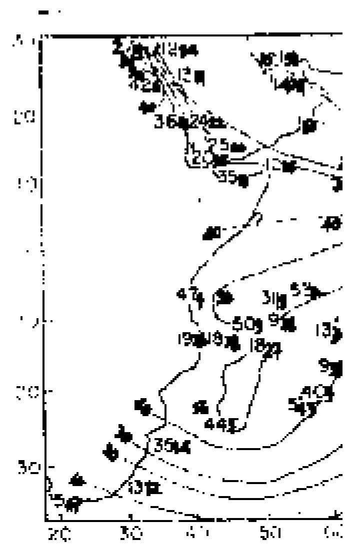
Table 10 : Distribution of reef coral genera in the Indian Ocean (nos. of genera)

COUNTRY	SURFACE	18-91 m	91-146 m	146- m
MALDIVES	59	49		
SEYCHELLES	53	27		
ALDABRA - GLORIOSO	50	29		
EAST AFRICA	47			1
MADAGASCAR (southwest)	44			
MALDIVES	40	17		
CHAGOS	40	3		
MAURITIUS	40		1	
SRI LANKA (south)	37	1		
MERGIN	37	1		
MOZAMBIQUE (south)	35			
MINIKAI	32			
SRI LANKA (north)) INDIA (south))	32	2		
AMIRANTES	31	19	3	
COCOS-KEELING	25			
ANDAMANS	24	1		
RODRIGUEZ	21			
MOZAMBIQUE (north)	19	3		
MADAGASCAR (northwest)	18			
COMORO ISLANDS	18			
FLORES (south)) TIMOR (west))	13	8		
SAYA DE MALHA	13	12	1	1
AQABA	12	1		
FARQUHAR - PROVIDENCE	9	7	2	
CARGADOS CARAJOS	9	6		
LACCADIVES	9			
REUNION	5			
NICOBARS	3			
SAVAQUIRAH BAY	1			

Table 10: Distribution of reef coral genera in the Indian Ocean (nos. of genera)

COUNTRY	SURFACE	18-91 m	91-146 m	146- m
MALDIVES	59	49		
SEYCHELLES	53	27		
ALDABRA - GLORIOSO	50	29		1
EAST AFRICA	47			
MADAGASCAR (southwest)	44			
MALDIVES	40	17		
CHAGOS	40	3		
MAURITIUS	40		1	
SRI LANKA (south)	37	1		
MERGIN	37	1		
MOZAMBIQUE (south)	35			
MINIKAI	32			
SRI LANKA (north), INDIA (south)	32	2		
AMIRANTES	31	19	3	
COCOS-KEELING	25			
ANDAMANS	24	1		
RODRIGUEZ	21			
MOZAMBIQUE (north)	19	3		
MADAGASCAR (northwest)	18			
COMORO ISLANDS	18			
FLORES (south), TIMOR (west)	13	8		
SAYA DE MALHA	13	12	1	1
AQABA	12	1		
FARQUHAR - PROVIDENCE	9	7	2	
CARGADOS CARAJOS	9	6		
LACCADIVES	9			
REUNION	5			
NICOBARS	3			
SAVAQUIRAH BAY	1			

Figure 15 : Coral di
Indian O



Reef coral records and di
line d, Table I. Symbols: *—locality d
1968. Suffixed numbers give locality

From: Bl
B.

From: Biology of C

Table 11 : Some species of algae found in Kenya

Algae marked x are not in previously published records for Kenya.

	Species	Stations 1	2	3	4	5	6
	Rhodophyceae						
	Acrocystis nana Zanardini					X	
	Amansia glomerata C. Ag.		X				
	Amphiroa fragilissima (L.) Lamouroux		X				
x	*Amphiroa rigida* Lamouroux					X	
x	*Bostrychia radicans* Montagne				X		
	Bostrychia tenella (Vahl) J. Ag.				X		
x	*Caloglossa leprieurii* (Mont.) J. Ag.				X		
	Carpopeltis rigida (Harvey) Schmitz	X					
	Catenella opuntia (Goodenough & Woodw.) Grev.				X		
	Centroceras clavulatum (C.Ag.) Montagne					X	X
x	*Ceramium brevizonatum* Petersen					X	
x	*Ceramium masonii* Dawson		X				
x	*Ceramium taylorii* Dawson		X				
x	*Champia irregularis* (Zanard.) Hauck			X			
	Champia parvula (C.Ag.) Harvey		X				
	Chondria armata Okamura	X					
	Chondrococcus harveyi J. Ag.		X				
	Chondrococcus hornemanni (Lyngb.) Schmitz		X				
x	*Dasya elongata* Sonder		X				
x	*Endosiphonia clavigera* (Wollny) Falkenberg		X				
x	*Galaxaura obtusata* (Ell. & Soll.) Lamouroux		X				
	Galaxaura tenera Kjellman		X				
	Galaxaura subverticillata Kjellman		X				
	Gelidiella acerosa (Forsk.) Feldmann & Hamel	X				X	
x	*Gelidiella tenuissima* Feldmann & Hamel				X		
x	*Gelidium* cf. *heteroplatos* Börgesen						X
	Gracilaria corticata J. Ag.	X	X				
x	*Gracilaria fergusonii* J. Ag.					X	
	Gracilaria salicornia (J. Ag.) Dawson	X			X	X	
x	*Griffithsia tenuis* C. Ag.		X				
	Haliptylon subulata (Ell. & Sol.) Johansen		X				
	Halymenia venusta Börgesen		X				
	Hypnea cornuta (Lamour.) J. Ag.			X			
	Hypnea esperi Bory		X	X			
	Hypnea hamulosa (Turn.) Montagne		X				
	Hypnea musciformis (Wulf.) Lamouroux		X				
x	*Hypnea pannosa* J. Ag.	X					
	Jania adherens Lamouroux		X				
x	*Laurencia intermedia* Yamada					X	
	Laurencia papillosa (Forsk.) Greville		X			X	
	Leveillea jungermannioides (Mart. & Her.) Harvey		X	X			
	Liagora mauritiana Börgesen		X				
x	*Lophosiphonia reptabunda* (Suhr) Jaasund						X
	Lophosiphonia sp.				X		
x	*Polysiphonia crassicollis* Börgesen		X				
x	*Spyridia hypnoides* (Bory) Papenfuss		X	X			
	Spyridia filamentosa (Wulf.) Harvey			X			
	Yamadaella cenomyce (Decaisne) Abbott					X	

	Species
	Phaeophyceae
	Cystoseira myrica (Gmelin) C. Ag.
	Cystoseira trinodis (Forsk.) C. Ag.
	Dictyota cf. *pardalis* Kützing
	Dictyota bartayresii Lamouroux sensu Vick
x	*Ectocarpus rhodocortonoides* Börgesen
	Hydroclathrus clathratus (Bory) Howe
	Padina boryana Thivy (= *P. commersonii* Bo
	Padina gymnospora (Kütz.) Vickers
x	*Sargassum aquifolium* (Turn.) J. Ag.
x	*Sargassum* cf. *binderi* Sonder
	Sargassum duplicatum J. Ag.
	Sargassum ilicifolium (Turn.) J. Ag.
	Sargassum spp.
	Spatoglossum asperum J. Ag.
	Sphacelaria sp.
	Stoechospermum marginatum (C. Ag.) Kutzi
	Turbinaria conoides (J. Ag.) Kützing
	Turbinaria decurrens Bory
	Turbinaria kenyaensis Taylor
	Chlorophyceae
	Caulerpa fastigiata Montagne
	Caulerpa serrulata (Forsk.) J. Ag. em. Borge
	Chaetomorpha crassa (C. Ag) Kützing
	Chlorodesmis fastigiata (C.Ag.) Ducker
x	*Cladophoropsis sundanensis* Reinbold
x	*Codium dwarkense* Börgesen
x	*Codium geppii* Schmidt
	Dictyosphaeria cavernosa (Forsk.) Börgesen
x	*Enteromorpha kylinii* Bliding sensu Dawson
	Halimeda discoidea Decaisne
	Halimeda incrassata (Ell.) Lamouroux
	Halimeda macroloba Decaisne
	Halimeda opuntia (L.) Lamouroux
	Halimeda renschii Hauck
	Ulva fasciata Delile
x	*Ulva pulchra* Jaasund
	Ulva reticulata Forsskal
	Ulva rigida C. Ag. f. tropica

From: Notes on Littoral Algae from Mombasa, Kenya

J. KNUTZEN (1979)

Table 12 : Presence of different species of marine organisms in various ecosystems in the Indian Ocean

Species	Lagoon Boat channel	Reefs	Shelf	Coastal Pelagic	Small Schooling	Large Schooling	Coral Reef 0 - 20 m	Coral Reef 20 - 100 m	Coral Reef 100 m	Mangroves	Epipelagic	Meso/Bathy Pelagic	Deep Ocean	Other
Siganidae	+													
Mugilidae	+													
Lethrinidae	+	+						+						
Lutjanidae	+	+	+					+	+					
Mullidae	+						+	+		+				
Scaridae	+	+												
Labridae	+													
Nemipteridae		+					+	+						
Acanthuridae		+												
Serranidae			+					+	+					
Carangidae	+	+	+	+	+	+	+		+		+			
Clupeidae				+	+						+			
Scombridae				+	+	+					+		+	
Sphyraemidae				+		+	+							
Leiognathidae					+									
Rachycentridae						+								
Trichiuridae							+							
Synodontidae								+	+					
Sparidae								+	+					
Engraulidae											+			
Myctophidae												+		
Apogonidae												+		
Diodontidae														+

Table 12 (cont'd) : Presence of different species of marine organisms in various ecosystems in the Indian Ocean

Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Sepioidae													+	
Sepiidae													+	
Portunidae														+
Penaidae														+
Chelonidae														+
Ostraidae										+				
Paniluridae	+	+					+							
Octopoda	+													
Rays							+							
Sharks			+				+		+					
Cetacea													+	+

Key:

1 Lagoon Boat channel
2 Reefs
3 Shelf
4 Coastal Pelagic
5 Small Schooling
6 Large Schooling
7 Coral Reef 0 - 20 m
8 Coral Reef 20 - 100 m
9 Coral Reef more than 100 m
10 Mangroves
11 Epipelagic
12 Mesopelagic / Bathypelagic
13 Deep Ocean
14 Other

Table 13 : Fish species present and approximate distribution

Estuaries: Penaids

Mangroves: Penaids, mullets, crabs, oysters

Reefs: Lethrinids, scolopsis, scarids, lutjanids, caesio, carangids, panulirus

Coral-free Reefs: Rays, sharks, breams, penaids

40 meters: Scavengers, snappers, sharks, rays

Coral rubble & rocky bottom: Lutjanids, serranids, sharks, denticids, carangids, caesio, spiny lobsters

Smooth Sea Floor: Mullidae, nemipterus, sauridae, sparids, lutjanids, serranids, lethrinids, sand lobster, portunid crab

more than 100 m: Pristipomoides, carangids, panulirus, scuridae, polysteganus, sparids, epiniephelids, sharks

Deep ocean waters: Tuna, billfish, squids, cuttlefish, sharks, skipjack, dolphin fish, auxis, euthynnus, scomberomorus, acanthocybium, clupeoid, carangids, baraccudas

Epipelagic: Sardines, scombroids, carangids, scads

Mesopelagic/Bathypelagic: Lantern fish, gonostomidae

Others: include red oceanic swimming crab, mantis shrimp, porcupine fish, dolphins, marine turtles

East-West Distribution of Major Species

Pelagic: Oil sardine *, lesser sardine +, other clupeoids +, Bombay duck *, half beaks, gar fishes, carangids, flying fish, ribbon fish +, mackeral *, seer, tunny, Indian pellona, leiognathidae

Demersal: Elasmobranchs +, eels, catfish +, tuna, perches, lizard fish, anchovy, red mullet, polynemids, sciaenids +, silver bellies +, lactarius, pomfrets, soles, prawns *, shellfish, cephalopods, crustacea, Pomadasyidae

* Dominant on the West Coasts

+ Dominant on the East Coasts

Figure 16 : Distribution of total fish larvae in the Indian Ocean

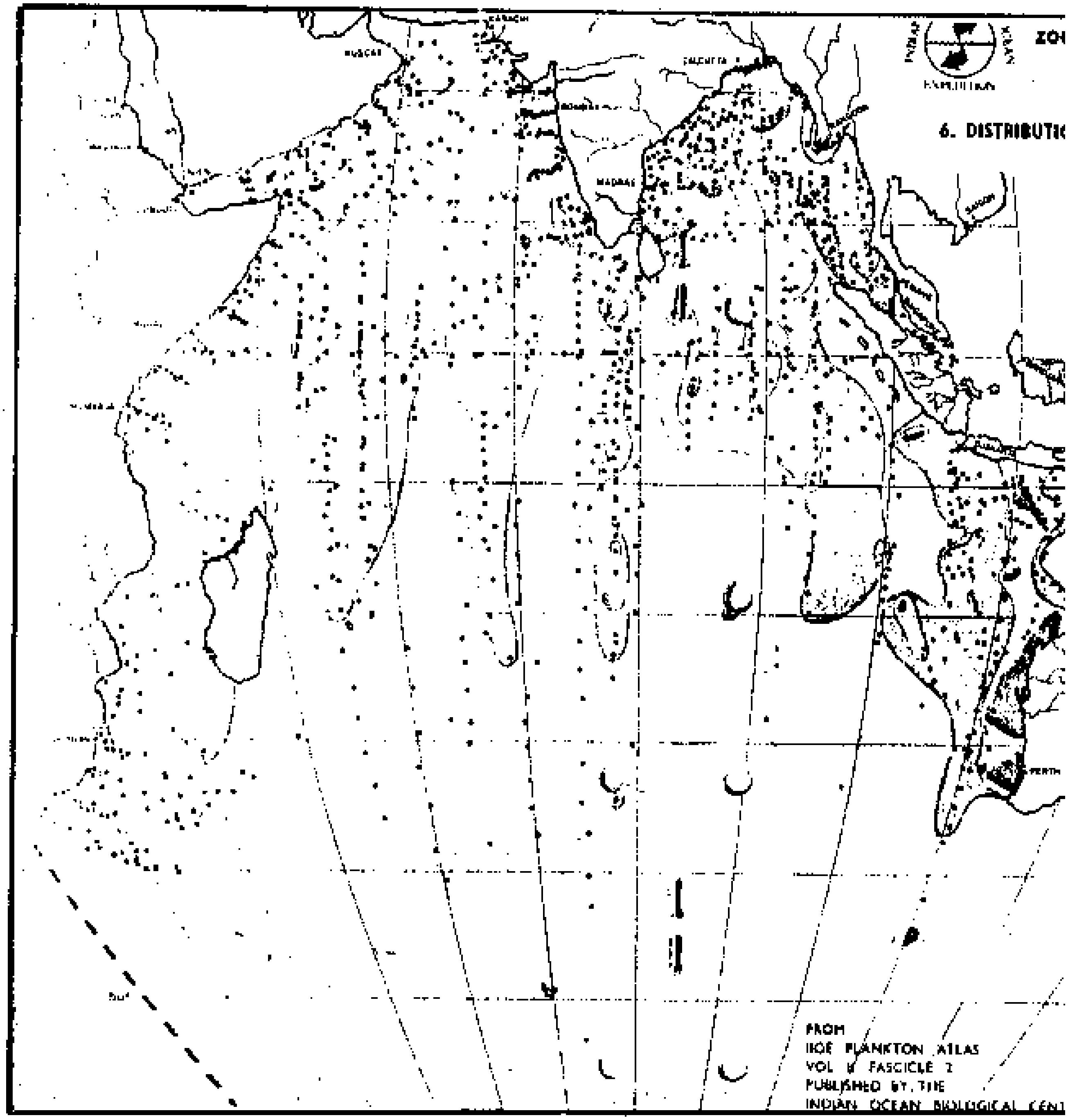


Table 14 : Potential yield in thousands of tons

ZONE	DEMERSAL & CRUSTACEA	PELAGIC	TOTAL
EAST AFRICAN COAST	120	5	125
EAST AFRICAN OFFSHORE	3000	-	3000
SOMALIA	–	–	–
WEST PAKISTAN	160	90	250
INDIA, WEST COAST	580	1020	1600
MALDIVES, LACCADIVES, CHAGOS	7	23	30
INDIA, EAST COAST	143	672	815
EAST PAKISTAN	98	250	348
SRI LANKA	52	90	142
ANDAMAN & NICOBAR ISLANDS	4	8	12
OCEANIC (Tuna)			[illegible]

Table 15 : Total catches of fish 1975 - 1979 (in tonnes) fresh water and mar

Country	1975	1976	1977	197
Bangladesh	823,000	826,000	835,000	640
Burma	485,140	501,560	518,700	540
Comoros Islands	3,850	3,500	4,000	4
India	2,265,875	2,173,926	2,311,869	2,306
Kenya	27,341	41,021	42,779	46
Madagascar	55,800	54,950	56,040	54
Maldives	27,900	32,300	26,400	25
Mauritius	7,038	6,660	7,668	7
Mozambique	17,490	19,900	18,950	17
Pakistan	195,039	206,659	269,958	293
Seychelles	3,950	4,010	4,600	5
Somalia	32,600	32,600	32,600	32
Sri Lanka	124,681	135,853	138,747	156
Tanzania	195,581	239,194	288,084	294

From: FAO Yearbook of Fisheries (1980)

6.2 Pelagic and Demersal Fish

The demersal fish catches are rich in northwestern parts of the Bay of Bengal but pelagic fisheries are negligible in comparison with those of the Arabian Sea. In the Bay of Bengal, the major part of the catch taken by Burma is mainly through the use of primitive craft with simple nets. Mechanisation of the techniques using purse seines and side trawlers is, however, becoming more prevalent. In the latter manner, mackerel are caught off Sri Lanka, the Maldives and Bangladesh, of which the last has the most primitive fishing methods. India and the Maldives are nett exporters of fish whereas Sri Lanka still imports some of her needs.

On the East African Coast, the trawlable ground is fairly unproductive. The potential yield is probably 10,000-20,000 tons. The most common fish appearing in the trawls are Carangidae (scads, horse mackerels), Lethrinidae (emperors, scavengers), Lutjanidae (snappers) and Serranidae (groupers, basses). Scombroidae, too, is fairly common. Elasmobranchs (sharks, rays) comprise an important part of the catch. Coral-free areas such as the North Madagascar and North Kenya Banks, the Zanzibar and Mafia Channels, the Somali Coast and the Gulf of Aden are important as trawlable grounds.

Large tuna such as yellowfin, bigeye, albacore and southern bluefin are the most heavily exploited pelagic fish with 100,000-150,000 tonnes being captured, whereas skipjack is lightly exploited mostly around the Maldives and Sri Lanka. Billfish stocks are overfished by longline techniques. Exploitation of other species has not been assessed.

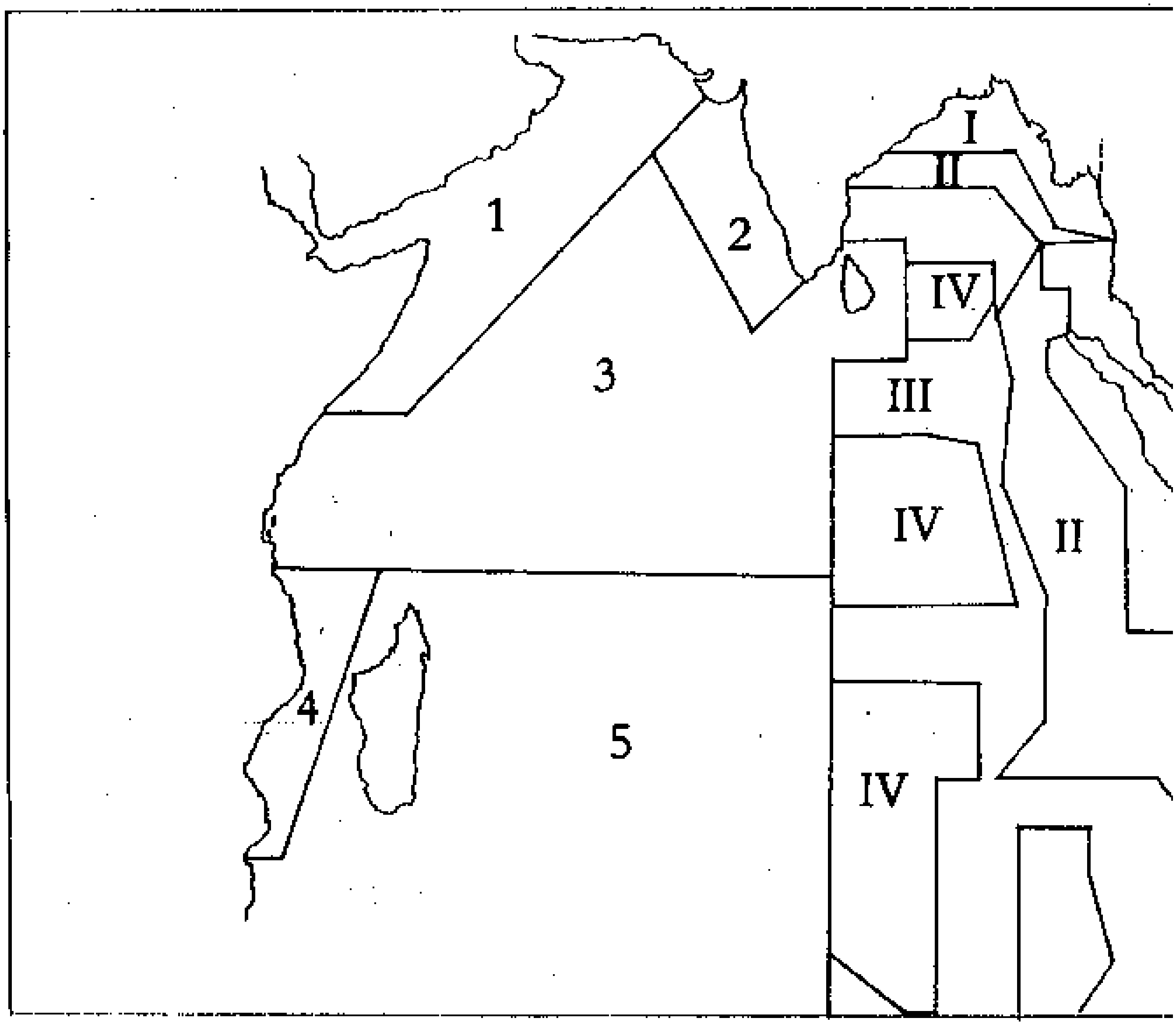
From Mogadiscio to the Indo-Pakistan border, purse seining for schools of herring species and scad is common. Off Pakistan, in the 10-30 m depth layers, anchovies are found in abundance especially from the Sind coast of Pakistan to the Ras Hafun-Ras Asir coast of Somalia. Catfish (Ariidae), snappers, groupers, hairtail (Trichiuridae), croakers (Sciaenidae) and grunt (Pomadasyidae) are an important part of the demersal fish community. In Kenya and Tanzania, fishing is still mainly concentrated inland. The coastal areas are poorly fished probably due, in part, to the poor fishing technology existing at present.

6.3 Mesopelagic Stocks

Preliminary calculations show approximately 2 million tonnes of mesopelagic fish to be present with maximum concentrations of 10-30 g/m^2 just off the shelf from 150-700 m deep. The catch rates are highest in the northern Arabian Sea with Myctophidae and Gonostomidae being the main species found. Off Pakistan one finds mainly _Benthosema pterotum_ followed by _B. fibulatum_, _Diaphus perspicillatus_ and _D. watasei_. The species composition is more diverse further south (see fig 17 and tables 16 a & b). In the eastern Indian Ocean, Gonostomidae (_Cyclothone alba_ and _Gonostoma elongatum_) and Myctophidae (_Benthosema suborbitale_ and _Diogenichthys atlaticus_) are still dominant. The Arabian Sea seems to hold the largest stock of mesopelagic fish of the world but estimates vary from 60 million to 150 million tonnes whether due to natural fluctuations in the stock size or sampling variation.

Fish larval counts are 25/m^2 for East Africa, 27/m^2 in the open ocean and 9/m^2 on the Indian West Coast which were sampled using shallow nets. From Cape Guardafuil to Mombasa, a large variety of scarce fish larvae are seen (175 species), and these are possibly coral fish as there is a narrow shelf here. These fish were mainly man-of-war fish, cardinal fish and lantern fish (28 larvae/m^2). The

Figure 17: Subdivisions of mesopelagic fish



From: A Review of the World Resources of Mesopelagic Fish, J. GJØSAETER & K. KA

Table 16 : Mesopelagic fish stocks

Area	Size ($m^2 \times 10^{11}$)	Biomass (g/m^2)	Stock (metric tonnes)
Western Indian Ocean			
1	17	60	100
2	5	30	15
3	95	0.5	20
4	3.5	6	2
5	184	0.5	90
Total	305.5		257
Eastern Indian Ocean			(1KMT-10 ft)
I	34	4.7	16
II	75	3.8	29
III	122	3.1	38
IV	59	1.8	11
Total	290		94

Table 17 : Species collected in the larval state in different coastal regions of the Indian Ocean

Area	Species
Somali coast	*Metapenaeopsis andamanensis* *Penaeopsis rectacuta* *Parapenaeus* sp. *Penaeus* sp.
Gulf of Aden	*Penaeopsis rectacuta* *Metapenaeus dobsoni* *Penaeus* sp. *Metapenaeopsis andamanensis*
Saudi Arabian coast	*Metapenaeopsis coniger* *Penaeopsis rectacuta*
Bombay and Ratnagiri coast	*Metapenaeus affinis* *Penaeopsis rectacuta*
South west coast of India	*Penaeopsis rectacuta* *Parapenaeus* sp. *Metapenaeus* spp. *Metapenaeopsis andamanensis* *Penaeus indicus* *Trachypenaeus curvirostris*
East coast of India (off Madras to Orissa)	*Penaeopsis rectacuta* *Parapenaeus* sp. *Metapenaeopsis andamanensis* *Metapenaeus* spp. *Penaeus indicus* *Parapenaeopsis* sp.
Rangoon coast	*Penaeus* spp. *Metapenaeus* sp. *Penaeopsis rectacuta* *Parapenaeus* sp.
South of Andaman and around Nicobar Islands	*Penaeopsis rectacuta* *Metapenaeopsis* spp. *Penaeus* sp. *Metapenaeus* sp. *Parapenaeopsis* sp. *Trachypenaeus* sp.

From: Abundance and Distribution of Penaeid Larvae as an Index of Penaeid Prawn Resources of the Indian Ocean
V. T. PAULINOSE & M. J. GEORGE (1976)

6.4 India

In India, with a coastline of 5650 km, the major fishing ground lies off Kerala followed by Maharashtra and Tamil Nadu. Major potential still exists for catches of catfish along the northwest coast; deep sea lobsters from the southwest coast and upper continental slope off Quilend; squid off the southwest and southeast coasts along Gujarat and Maharashtra. Lantern fish (Myctophidae), a mesopelagic species providing vitamin A and about 110 litres of oil per ton, are found off the Bombay shelf and Angina Baka. Grenadiers (Lutjanidae) and macurids are found off the west coast; swimming crab off the northeast and east coast and prawns off Kakinada.

India has extensive molluscan resources which are neglected in some regions and overexploited in others. The more important species are mussels, oysters, clams, pearl oysters, squids, cuttlefish and sacred chank (gastropod). Indian mussels attain sexual maturity very early and grow rapidly to marketable size and they should, therefore, be profitable. However, there is little demand in India for edible bivalves, although pearl culturing is viable. Cephalopods, too, are still underfished.

Bottom trawling provides an average of 200 kg per hour of which 24% are elasmobranchs, 17% congers, 14% catfish, 16% croakers and 5% pomfret (Stromateidae). Pelagic trawling is most profitable off Dwarka followed by Veraval and Goa. Here, 834 kg per hour has been recorded (60% horse mackeral, 18% ribbon fish (Trachipteridae), 5% elasmobranchs 3% catfish, 6% pomfret and 2% eels). In each case the remaining percentage is made up of diverse other species.

6.5 Pakistan

Large resources of anchovy and whitebait (Clupeidae) are found on the west coast. They are found between 25-35 m from October to May. From the data of cruises in 1969, the potential yield of pelagic fisheries to a depth of 150 m, was estimated at 3-4 times the present catch. In 1978, the standing stock for demersal inshore fisheries was 43,500 tonnes and up to 125 m offshore, 4,200 tons. For both, the annual sustainable yield is estimated to be 41,000 tons. The inshore waters were found to be exploited but the offshore waters were not.

6.6 Sri Lanka

Sri Lanka has a coastline of 1,770 km with a wide continental shelf. The expected yield is 260,000 tons. There are 1000 fishing villages with approximately 47,000 fishing households. During the southwest monsoon, fishing takes place on the north and east coast and during the northeast monsoon, on the south and west coasts. The fishermen migrate to obtain maximum fishing time. 30-40 km offshore, roughly 6000 tonnes tuna and skipjack are caught by gill-netting from deep sea vessels. Coastal fisheries form 90% of the total, with commercial fishing using mainly beach seines and drift nets. Purse seines are coupled with light attraction techniques to increase catches of small pelagic fish. On the west coast, sardine, herring, redbait and anchovy are caught, but only sardine and herring are caught on the east coast. The main period of fishing is from November to April in the west and from May to October in the east. Shrimp, crab and lobster are

6.7 The Comoro Islands

The four Comoro Islands have mainly rocky coastlines with a scattering of sand beaches. The 139 fishing villages provide an annual catch of 3000 tonnes of which more than 50% is tuna. The Saya de Malha is one of the biggest fishing areas. This is mainly a subsistence fishery using stationary lines or simple troll lines close to shore, as the main transport is by engineless canoes. Sale of the catch is local but good catches are often lost due to lack of a market.

6.8 Kenya

Kenya has just over 500 km of coastline with fringing coral from 16-40 m deep. There are approximately 6000 fishermen and 10% of the boats are mechanized. Fishing is mainly within the 12 mile zone using beach seines, gill nets and bottom lines. The most productive zones are from 25-200 m offshore and on the North Kenya Banks. In one month's trawling an average of 7000 kg shrimp and 14 kg fish may be obtained. Restrictions are enforced on the export of marine shells and corals. Commercial exploitation of marine turtles and sea cows has also been banned. Swimming crabs are common off the Kenyan coast although they are not exploited. The main species of crustacea found off the Kenyan coast is shown in table 17. The existing fish stock is underutilized and Kenya imports some of its needs.

6.9 Madagascar

The major part of the fish catch in Madagascar comes from the inland fisheries. Local marine fisheries appear to be concentrated on the west coast catching mainly shrimp, whereas offshore foreign vessels are dominant. Prawn larvae are located nearshore and open waters support few varieties. The biggest shrimp fisheries, however, occur in Madagascar and Mozambique and are fully exploited there.

6.10 Mauritius

Mauritius has a fringing coral reef which slopes to 150 m deep. There are over 3000 fishermen using mainly basket traps, lines, drag seines and gill nets. The lagoon stocks are constantly replenished but the demersal fish are associated with coralline and sponge areas and hence trawling is not possible as the hydrogeography is poor for fishing, and growth and recruitment of stocks is slow. Coral reefs are heavily fished off Mauritius where crustacea are abundant with spiny lobsters and crab being the primary catch. There is some oyster harvesting on the west coast in the vicinity of the mangrove swamps and a small tuna fishery.

6.11 Mozambique

Mozambique has 4020 km of coastline with a northern rocky coralline zone, central loamy shore with mangroves and a southerly sandy zone with consolidated dunes. 80% of the 120,000 km^2 shelf is in the central area. Subsistence fishing exists along the entire coastline. There are important pelagic fisheries (Sofala Bay) and shallow water shrimp fisheries (Maputo Bay) along the coast with clupeoids being found in large quantities in the estuaries. The spiny lobster is common at 100-400 m depths from the southern border to the Bazaruto

6.12 The Seychelles

The Seychelles are made up of 92 islands with flat areas between that permit trawling. The north, west and east edges have coral and the northwest edge has sea knolls. Handline, trap and beach seine are used catching mainly jacks (Carangidae) but with fluctuations due to adverse weather conditions and migration. Various catching methods are used to catch different species.

6.13 Tanzania

Tanzania has 800 km of coastline with 6-60 km of shelf. 80-90% of the fishing is artisanal using outrigger canoes, hooks, lines and nets. Pemba and Zanzibar Islands and the shallow channels between the latter and Mafia Island contain some of the more important fish stocks of sardine and other filter feeding clupeoids of the East African coast. 75% of the fish catch is small pelagic fish and 25% demersal, the catch being made up of sardinella, sharks, rays, small prawns, lobsters, tuna, billfish, kingfish, groupers, barracudas and snappers. About 7000 individual fishermen exist using purse seines, gill nets, traps and hand lines. Stocks are still underfished.

6.14 Somalia

The Somali coastline has good fish resources north of 15°N but the rest is fairly unproductive. There are commercially viable grounds for tuna fisheries. Mackerel is an important species along the edge of the continental shelf 5-10°N. The northeast coast has a fairly high abundance of small pelagic fish: Indian oil sardinella, round herring and scad. Some export of dried and/or salted fish to neighbouring countries is underway.

PART II

POLLUTION

7.0 INTRODUCTION

GESAMP, the Joint Group of Experts on the Scientific Aspects of Marine Pollution, has defined marine pollution as "the introduction by man, directly or indirectly, of substances or energy into the marine environment (including estuaries) resulting in such deleterious effects as harm to living resources, hazards to human health, hindrance to marine activities including fishing, impairment of quality for use of sea water and reduction of amenities."

The Indian Ocean region, especially in the Bay of Bengal area, is one of the most densely populated in the world (see table 18). With progressive urban and industrial growth, pollution in the countries bordering the Indian Ocean Basin is becoming a major source of anxiety but is only just being documented as experience, funds and technology with which to tackle the problem become more prevalent. The primary sources of pollution are industrial and municipal effluents, oil spills or leakages, river run-off including agricultural wastes, and the adverse effects of coastal development, for example from blasting and dredging.

Until recent oil pollution scares and the increased publicity given to pollution effecting coastal areas, research in the countries in this region, especially the islands, has tended to concentrate on development and exploitation of fisheries resources. This occurs for two main reasons. Firstly, the countries are dependent on fish as a source of food as well as income from exports; hence improved fishing technology is potentially important to the national economy in many cases. Secondly, these nations are developing countries and industrialization is not far advanced. Many of the countries are primarily agricultural and with increasing populations and urbanization, the problems of pollution from domestic and municipal wastes and from agriculture are the first to cause concern. Although industrial technology and the number of factories being built have been growing very rapidly, the adverse effects of this development are only just being studied, and research is now being carried out on factory effluents. In addition, oil contamination studies receive priority due to the heavy tanker traffic going through the Indian Ocean to the Far East. Some details on growth and development, industrialization, major resources and major produce are seen in tables 19-29.

7.1 East Africa

Little information is available concerning pollution of the East African Coast. The main threat is from oil contamination but otherwise pollution does not appear to cause much concern. Coastal and coral reef damage is one of the major problems in East Africa. The reef is close to the shore and vulnerable to pollution and silting. Coral has been dynamited and used to construct breakwaters, and burnt for the production of lime to be used in building construction. This destruction of the coral reef system has caused several marine species to disappear including starfish and sea-urchins. Artisanal fisheries are concentrated on well-developed fringing coral reefs and their lagoons. The reef area is productive and local fishing is intensive. The use of dynamite and poisons for fishing is now banned Kenya and Tanzania but has already destroyed fish cover and caused severe damage in the coral reefs which are slow to re-form. In Tanzania, a

Table 18 : Population figures for the countries of the Indian Ocean basin (1979)

Country	Population	Area (km^2)
Bangladesh	86,062,000	142,776
Burma	34,434,000	678,031
Comoro Islands	328,000	2,274
India	678,255,000	3,287,593
Kenya	15,780,000	582,644
Madagascar	8,511,000	587,042
Maldives	145,000	298
Mauritius	976,000	1,865
Mozambique	10,199,000	789,961
Pakistan	79,838,000	803,941
Seychelles	64,000	443
Somalia	3,542,000	637,539
Sri Lanka	14,608,000	65,610
Tanzania	17,382,000	939,762

Table 19 : Growth of consumption and investment

COUNTRY	AVERAGE ANNUAL GROWTH RATE AS A PERCENT					
	PUBLIC CONSUMPTION		PRIVATE CONSUMPTION		GROSS DOMESTIC INVESTMENT	
	1960-70	1970-78	1960-70	1970-78	1960-70	1970-78
BANGLADESH	-	-	3.4	3.1	11.1	-1.4
BURMA	-	-	2.8	3.7	3.6	4.2
INDIA	-1.7	4.2	4.2	3.0	5.6	6.1
KENYA	10.0	8.7	4.6	6.2	7.0	2.3
MADAGASCAR	-	-1.4	-	-2.2	-	-2.5
MOZAMBIQUE	6.8	-4.6	4.4	-2.7	8.3	-9.6
PAKISTAN	7.3	3.9	7.1	3.8	6.9	4.8
SOMALIA	3.7	11.7	-0.5	2.7	4.3	8.5
SRI LANKA	-	-	1.9	2.5	6.6	3.6
TANZANIA	-	-	5.2	5.8	9.8	1.0

From: World Development Report, 1980

Table 20 : Growth of production as an average annual growth rate

(PERCENT)

COUNTRY	GDP		AGRICULTURE		INDUSTRY		MANUFACTURING		SERVICES	
	1960-70	1970-78	60-70	70-78	60-70	70-78	60-70	70-78	60-70	70-78
BANGLADESH	3.6	2.9	2.7	1.6	7.9	5.9	6.6	5.3	3.8	4.7
BURMA	2.6	4.0	4.1	3.6	2.8	4.5	3.3	4.2	1.5	4.2
INDIA	3.6	3.7	1.9	2.6	5.5	4.5	4.8	4.6	5.2	4.6
KENYA	6.0	6.7	-	5.5	-	10.4	-	11.7	-	6.0
MADAGASCAR	2.9	-0.7	-	-0.3	-	-	-	-0.4	-	-1.4
MOZAMBIQUE	4.6	-3.2	2.1	-1.8	9.5	-5.1	6.6	-6.1	6.4	-3.7
PAKISTAN	6.7	4.4	4.9	1.9	10.0	4.8	9.4	3.5	7.0	6.2
SOMALIA	1.0	3.1	-1.5	2.7	3.3	-2.6	14.3	-	2.5	6.8
SRI LANKA	4.6	3.4	3.0	2.3	6.6	3.0	6.3	1.2	4.6	4.3
TANZANIA	6.0	5.0	-	4.5	-	2.3	-	4.5	-	6.4

Table 21 : Industrialization

COUNTRY	DISTRIBUTION OF VALUE ADDED (percent) Food and Agriculture 1976	Textiles and Clothing 1976	Machinery and Transport Equipment 1976	Chemicals 1976	Other Manufacturing 1976	Value added in Manufacturing (millions of dollars) 1970	1976	Gross manufacturing output per capita (1970 dollars) 1970	1976
BANGLADESH	-	-	-	-	-	324	320	11	13
BURMA	40	20	-	-	40	225	271	-	-
INDIA	15	29	13	12	31	7093	8973	51	62
KENYA	18	13	19	8	42	174	190	-	98
MADAGASCAR	95	-	-	-	5	118	112	40	44
MOZAMBIQUE	68	13	-	4	15	104	82	28	-
PAKISTAN	46	35	-	9	10	1462	1757	-	-
SOMALIA	-	-	-	-	-	11	17	6	12
SRI LANKA	17	23	-	9	51	321	346	-	-
TANZANIA	-	-	-	-	-	116	156	27	-

Table 22 : Production and capacity of energy sources (1974)

Countries	Petrol ($x 10^3$ tonnes)	Natural Gas (tetra cals)	Petroleum Distillation Capacity	Coal ($x 10^3$ tonnes)
Bangladesh	-	6720	1680	1471
Burma	1163	1425	1320	13
Comoros Islands	-	-	-	-
India	8659	10630	31960	100870
Kenya	-	-	4750	-
Madagascar	-	-	750	60
Mauritius	-	-	-	-
Maldives	-	-	-	-
Mozambique	-	-	800	371
Pakistan	305	40140	3690	1349
Seychelles	-	-	-	-
Somalia	-	-	-	-
Sri Lanka	-	-	1850	-
Tanzania	-	-	850	1

Table 23 : Production and consumption of energy in millions of metric tonnes

Country	Production	Consumption	Hydro-electric Capacity	Hydro-eletric production	Total capa-city	Total produc-tion
Bangladesh	1.14	2.63	110	505	915	1710
Burma	1.78	1.51	181	470	441	968
Comoros	-	0.02	-	1	-	3
India	121.09	132.92	9029	34827	13684	95335
Kenya	0.09	2.10	171	694	284	1119
Madagascar	0.02	0.55	40	248	95	343
Mauritius	0.01	0.35	25	55	143	378
Mozambique	0.56	1.25	680	1510	793	1915
Pakistan	8.33	13.11	2236	4920	2236	10876
Seychelles	-	0.03	-	-	11	33
Somalia	-	0.15	-	-	18	45
Sri Lanka	0.14	1.45	335	1134	421	1202
Tanzania	0.06	1.07	-	-	160	685

From: United Nations Statistical Yearbook (197[illegible])

Table 24 : Major resources

Burma - Copper Petroleum Water Power Tin Tungsten Zinc Lead Silver	Bangladesh - Coal Petroleum Water Power Mozambique - Beryl Water Power Madagascar - Graphite Uranium
India - Uranium Titanium Magnesium Mica Bauxite Iroh Ore Chromium Asbestos Gold Manganese Coal Water Power Salt Copper	Pakistan - Graphite Lignite Chromium Water Power Petroleum Salt Coal Sri Lanka - Graphite Tanzania - Diamonds Soda Ash Water Power Salt

Table 25 : Major mineral resources (in thousands of metric tonne

Countries	Fe ore	Cr	Bauxite	Cu	Pb	Magnesite
Bangladesh					1	
Burma					38	
India	27430	195.5	1448	28.8	12.8	320
Kenya				0.1		
Madagascar		87.7				
Mozambique			5	2		
Pakistan		5.1				8

From: United Nations Statistical Yearbook (1978)

Table 25 (cont'd) : Major mineral resources (in metric tonnes)

Countries	U	Au	Ni	Ag (kg)	Sn (concentrates)
Burma			20	22	750
India	29800	2211		3	
Kenya		1			
Madagascar		5			
Pakistan					

From: United Nations Statistical Yearbook (1978)

Table 26 : Some goods being manufactured at present (1977)

Countries	Milk	Meat	Butter	Sugar	Salt	Eggs	Wheat Flour
Bangladesh	1092	169	14	110	784	27.0	-
Burma	273	172	5	80	132	23.0	53
India	25632	646	575	5039	4076	85.0	1666
Kenya	1007	181	4	182	14	18.7	138
Madagascar	28	132	-	114	27	28.0	-
Mauritius	-	-	-	731	6	-	-
Mozambique	67	46	-	220	28	9.2	65
Pakistan	9932	570	250	677	578	61.3	-
Seychelles	-	-	-	-	-	-	-
Somalia	731	113	2	40	2	-	-
Sri Lanka	229	21	-	24	140	17.5	94
Tanzania	750	161	3	110	22	21.1	72

From: United Nations Statistical Yearbook (1978)

Table 27 : Industry in the Comoros Islands

The principal exports of the Comoro Islands are ylang-ylang oil (for perfumes and soaps), vanilla, copra, cloves, and to a smaller extent, coffee, cocoa, rice, maize, manioc and livestock.

Commodity	Year	Quantity
Ylang-Ylang	1974-1977	300 tonnes
Vanilla	1970-1974	300 tonnes
Cloves	at present	150,000 trees
Copra	" "	50,000 tonnes

Coconut production is high ; more than 60% of the production is used for domestic purposes and less than 40% goes towards the production of copra.

From: Comoros - An Island Nation in a Difficult Economic Situation (1981)
The Courier : Africa-Caribbean-Pacific

Table 28 : Number of livestock in thousands of animals

Countries	Cattle	Sheep	Horses	Pigs	Asses	Mules
Bangladesh	26,500	1200	43			
Burma	7,696	205	105	1,800		9
Comoro Islands	75	8	-		3	
India	181,092	40,187	900	8,732	1,000	125
Kenya	9,100	3,980	2	65		
Madagascar	8,886	607	2	557	1	
Mauritius	54	4		6		
Mozambique	1,350	95		100	20	
Pakistan	14,901	20,546	452	94	2,226	63
Seychelles	2			11		
Somalia	3,950	9,800	1	8	22	21
Sri Lanka	1,690	27	2	36		
Tanzania	14,817	3,000		25	160	

From: United Nations Statistical Yearbook (1978)

Table 29 : Wood and cement production (in thousands of metric tonnes)

Countries	1974 Roundwood	1976 Sawnwood	1976 Cement
Bangladesh	10700	291	160
Burma	21100	335	233
India	124200	3561	18684
Kenya	13600	173	987
Madagascar	6400	44	70
Mozambique	9100	193	-
Pakistan	9000	293	3196
Somalia	3100	14	-
Sri Lanka	4600	37	336
Tanzania	35400	67	244

From: United Nations Statistical Yearbook (1978)

Some coastal regions have been dredged and blasted to create space for berthing and manoeuvring of larger ships and tankers. For example, in Tanzania, the expansion of the Dar es Salaam port is in the process of destroying shellfish spawning areas at the south end of the creeks. In Tanzania, the coastal area is densely populated and, as a result, most of the pollution is localized and tends to be domestic. Although industry in Tanzania and Kenya is developing at a rapid rate in both coastal and inland areas, pollution studies tend to be concentrated inland especially around Lake Victoria where many industries are located. Both studies and effects of pollution are very localized and usually concern fresh water problems.

Somalia, where industrial development is still at an early stage, nevertheless has oil contamination problems. In Mozambique, research has been carried out on pollution in the heavily populated Lourenço Marques Bay which receives municipal and industrial effluents. However, studies usually deal with fisheries and coral reef investigations. At Inhaca Reserve, coastal erosion management and control are also under observation.

7.2 The Islands

In the islands of the Indian Ocean, industrial development is slow and the effects of related pollution not readily apparent. There is concern about the possibility of oil pollution as occasional coastal contamination is seen. As in the case of East Africa, coral reef damage is a major concern in the islands notably in the Maldives, Mauritius and Sri Lanka. In Madagascar, pollution problems are, again, primarily related to fresh water. Some problems are specific to certain areas. An example of this is found in Mauritius where the leaves from the Aloe fibre tree have destroyed the aquatic fauna in parts of the island. Significant damage has been recorded in the fisheries and oyster beds due to the toxic effects of these leaves.

7.3 The Asian Sub-continent

Pakistan's recent intensive industrial development is localized and causes increased pressure on the existing domestic and municipal sewage systems around Karachi. Although some preliminary investigations have been carried out and increasing attention is being given to the state of pollution, the amount of research done is minimal and as yet, the information seems to be restricted to the ecology of the coastal area.

Most information on pollutant levels and pollution research in the Indian Ocean concerns work done in India. Coastal and inland aquatic pollution research is fairly advanced and information may be obtained as to the effects of pollution along most of the coastline. The conditions of some estuaries in India which are affected by pollution are seen in table 7C.

Little documented information is available on pollution problems from Bangladesh or Burma. There is some concern about the effects of river run-off from the Ganges and the Brahmaputra in the former, especially around Chittagong Harbour, and from the Irraweddy River in the latter.

Table 30 : Conditions of some estuaries in India

Kulti Estuary:	polluted by Calcutta sewage. 48 km of septic tank os in tidal waters without dissipation. Dissolved oxyge are subnormal. HT: DO 0.8 - 3.2; pH 7.1 - 8.0 LT: DO 1.5 - 3.6; pH 7.1 - 7.8) mg/1 Fish fauna are almost completely gone in heavily pol waters.
Cooum River, Madras:	Normally separated from the sea by a bar which is op of sea. Washings from slums, cattle yards overflow a pumping station wastes from automobile workshops and factories. Upper zone devoid of fish. Major part of is septic.
Adyar Estuary, Madras:	Not much pollution is seen.
Pinnakayal Channel:	In Tamil Nadu. Discharge of caustic soda plant destı fish fauna near it. Significant quantities of chlori
Cochin Backwaters:	The main pollutants are domestic sewage, coconut hus retting waters and small industries.
Chaliyar Estuary:	In Kerala State. Pollution from Rayon factory, 13 kr Beypore. High BOD values as go down the estuary. Pr lysate contributes major part of BOD load and waste mortality is caused by oxygen defficiency, effluent decomposition of organic matter creatin g near anae conditions.
Bombay Bay Region:	More than 100 industries discharge via creeks into via Kalu River mainly. Acidic block in river preven migration of Hilsa ilisha. Putrid smell apparent.

8.0 INDUSTRIAL POLLUTION

8.1 Introduction

The countries around the Indian Ocean are all developing countries, and there is a basic need to improve industrial technology. The rate at which industries are being set up is steadily increasing. At present there are few major industrial sites along the coasts (see fig. 18). Marine pollution problems resulting from this development are, thus, restricted to small areas of the coastline such as the Bombay region in India or the area around Karachi in Pakistan. As industrial development is still fairly recent, there is little evidence of documentation on related pollution problems.

8.2 East Africa

Coastal industrial developement is at a very low level in East Africa and industrial pollution is not very apparent off the coastline. In Tanzania and Kenya, for example, many industries are situated around Lake Victoria and pollution is mostly of the fresh water type.

In Somalia, industry is negligible and as yet, does not constitute a major source of pollution. However, of particular interest are the slaughter houses situated along the coast at Marka and Mogadishu. At Marka, wastes are discharged directly into the sea which has an unpleasant smell and attracts sharks to the nearshore area. At Mogadishu, effluent is drained into a sump pond. There is probably some leaching from the pond into the sea as before the slaughter house existed there were no sharks in the region. Mats and tools used in the trade are cleansed directly in the sea.

In Kenya, industrial wastes from Nairobi drain into the river passing the city which eventually discharges directly into the Indian Ocean via the Athi River. The Athi River carries with it wastes from slaughter houses, cement factories, tanneries and coffee factories from the industrial sector in the Kiambu district. Effluent enters the town sewers but sometimes this is untreated and released directly into natural waters. Examples of these are sugar wastes from untreated molasses entering Lake Victoria and the waters south of Mombasa, which have a deleterious effect on the survival of fish. Wastes from dairy processing plants and slaughter houses are released from Mombasa and Kisumu and cement and fertilizer factory effluents from Kilindi Harbour. Tanneries at Kisumu discharge large amounts of chrome salts and solids which increase the Biological Oxygen Demand (BOD) load. When the BOD load is increased, the oxygen content in the water is depleted due to it's use for the degradation of such pollutants as has been introduced into the environment. Other effluents include cyanide from mining and smelting operations, heavy loads of organic wastes from coffee and sisal industrial plants and wastes from pulp and paper mills. Heavy-metal pollution is a potential problem arising from the use of zinc to coat iron sheets used for roofing. Another potential pollutant in Kenya is mercury. About 25,000 tonnes per annum of mercury compounds are used here as seed dressing.

In Tanzania, however, organic waste from a diversity of small industries is apparent, especially in and around Dar es Salaam. These include soap factories (Mwanza and Dar es Salaam), sisal (Tanga), sugar mills (Bukoba), cotton seed processing plant (Mwanza), plastics (Dar es Salaam), wood processing and super-phosphate plants. Textile and fishnet industries at Dar es Salaam discharge

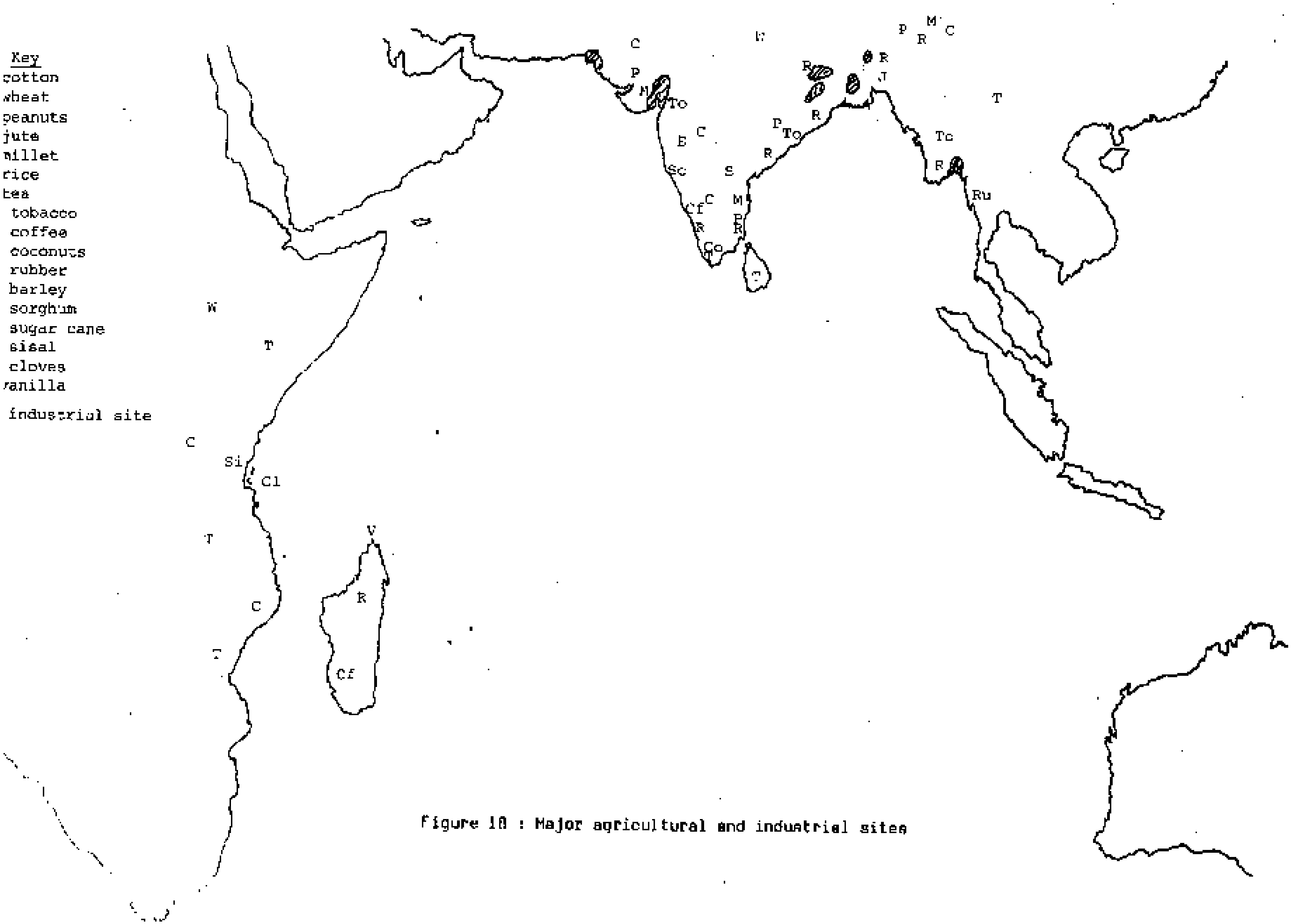


figure 10 : Major agricultural and industrial sites

Waste effluents from several industries, for example breweries at Ilala and industries in Ubungo are discharged into the Msimbazi Valley Estuary. The water is very alkaline with pH values of 11 and above and has a soapy texture. The dissolved oxygen concentration is near zero and wastes are mainly from dyes and chemicals used in textile processing. Effluent from the breweries is acidic with 1-5% solid waste which is mostly organic is nature. There is a flushing system in the industry but it is hindered by sand bars and during high tide, waters sometimes overflow into the mangrove system. The low oxygen waters and organic wastes mix to form an anaerobic environment but stagnation is prevented by the flushing system. The increasing population in the area has increased the pressure on the system.

In Maputo in Mozambique, the Lourenço Marques Bay is a busy harbour. Wastes from the city and port drain directly into the Bay (see C7 in fig. 30) and effluent comes from, e.g. cotton and textile factories. There are two ports, one at the junction of the inner and outer bays catering to general cargo and minerals, and the other at the west of the inner bay handling iron ore and hydrocarbons in bulk. High values of iron and copper are noted due to the use of a new method for loading. This involves a sedimentation process where the supernatant rich in heavy metal content (311.4 micrograms/l iron and 8.2 micrograms/l copper) is dumped into the bay. In windy conditions, even normal loading procedures result in high values of iron and copper downwing. A large part of the tide flows back to the inner bay on tide reversal and therefore not much of the water is renewed. However, the shallow depth and geometry of the bay create a self-clearing process by adsorption of metal ions onto the mud of the bay. Increases in iron, copper, lead and nickel are short-lived due to the natural cleaning process in the bay. However, metal ion accumulation could occur in, for example, bivalves and shrimps which are capable of ingesting and concentrating these ions in their flesh.

8.3 The Islands

In Madagascar, wastes from similar industries to those found in Kenya could effect the shrimp fisheries on the southern and western coasts. Examples of these are sisal and sugar cane at Diego Garcia, Nosy Be, Port Dauphin and the Marudrari River. Near Tananarive, effluent from tanneries, plastics, textiles and paper industries have already been noted as causing some pollution problems. Mining industries (mica, chromium) are potential polluters but without severe effect to the fisheries as the they are situated on the East Coast.

In Mauritius, a particularly high BOD load (4,600 lbs) is caused by wastes from the 20 odd sugar mills found on the island. Effluent containing bagasse (crushed cane fibres), ash, soot and molasses can cause total oxygen depletion up to 3-4 km downstream. This is accompanied by a sludge layer and mass mortalities of fish and invertebrates. Between January and June, factories do not operate and some organisms, thus, have time to recolonize. Parts of the south coast beach are blackened and local fishermen complain of a decrease in catches and fouling of fish traps by bagasse. There is a major industrial drain from Port Louis which carries effluent from the industrial estate at Carmandel.

Effluent from industries in the Seychelles is negligeable. Discharges consist of caustic soda from the cleaning of vats in the local brewery and sawdust

Some local pollution is seen from industrial and port activity in Colombo, Sri Lanka. Copper values of 0.133 ppb and 2.0 ppb were found in the industrial effluent in Colombo which has a direct effect on the drinking water. Many industries are situated on the banks of the Keleni River which then passes through the city of Colombo and out to the sea.

8.4 The East Asiatic Sub-Continent

On both the eastern and western coasts of India, there are regions of intense industrial development. One of the most important on the East Coast is the Hooghly Estuary region. The Hooghly Estuary is formed from three branches of the Ganges and is very important for port facilities and commercial fisheries. The estuary has large rivers discharging into it and many industries are situated along the banks of these rivers. The lower part of the estuary has multifarious industries: paper, textiles, chemicals, pharmaceuticals, plastics, shellac, food, leather, jute, tyres and cycle rims. It also receives drainage from the Bagar and Reighland canals which have sewage oulets. The data suggest that the river is polluted before it receives the industrial wastes. Despite the heavy sewage and industrial pollution in the river and canals, the estuary itself is not too badly polluted due to the effect of mixing and dispersion by high tides and turbulence. The estuary has a high salinity, a high turbidity factor and is well supplied by the monsoon. The tidal range is large and its impact can be felt up to 300 km inland.

About 250 million gallons of waste water are discharged per day of which 30.6% is industrial. The total solid waste is of the order of 1060 tonnes and the BOD 110 tons. The BOD value it has is equivalent to that caused by a population of about 735,000. An example of waste from a chemical factory is seen in table 31. This factory lies about 18 km north of Calcutta and produces heavy chemicals, paints, varnishes, plastics and rubber chemicals. Some characteristics of waters from textile, vegetable oil and paper and pulp factories are seen in table 32. These are found in the Rishar region in Tiribeni, Titaguth and Palta.

Between the 92 km from Dumurdahe to Birlapore, 95 factories are found of which 55 are jute mills. The bulk of the effluent, however, comes from five paper and pulp mills. The fresh water supply is slow and the condition of the water is deteriorating. Sulphite, sulphate and soda processing methods are used in the mills. The characteristics of the effluent from these mills is seen in table 33. For 75,000 tonnes of paper produced, along a 50 km stretch, the total pollution load is 60,000 lbs BOD (population equivalent of 400,000) and 260,000 lbs suspended solids (population equivalent of 1,320,000). In summer this load is heavier. Due to the use of jute and salar grass for raw materials, the effects of pollution from paper and pulp factories in India is higher than from other countries using different raw materials. 80% of the effluent is discharged untreated into the Hooghly Estuary. One of the major components of the waste water is lignin which is toxic to the fish stock. Up to 3.5 km below the confluence of the Hooghly and the Bagar Canal, conditions are not congenial to the sustenance of fish life.

A comparison was made between the polluted Hooghly and the unpolluted Matlah Estuary. The former is a tidal estuary with fresh water, gradient and tidal/marine conditions. The tidal/marine is only seen in the summer in the lower

Table 31 : Effluent from a chemical plant near Calcutta

Plant	Nature of Discharge	
Chlorine Plant	Weak Sulphuric Acid	
	0.05% Solution Hydrochloric Acid	
	Bleach Liquor	4-5 g/l calcium oxide
		40-45 g/l available chlorine
		200 g/l calcium chloride
	Brine sludge	calcium, magnesium and sodium insoluble salts
	Benzene	
	Caustic soda	
Paint Plant	Caustic soda	
Polythene Plant	100% Alcohol in 5-10% solution	
From all three	Oil from the machinery	

From: Observations on Estuarine Pollution of the Hooghly by the Efflu
Chemical Factory Complex at Rishra, West Bengal, India.
B. B. GHOSH and A. K. BASU (1968)

Table 32 : Characteristics of waste waters from different industries

Industry	pH	Lignin mg/l	Suspended matter mg/l	BOD mg/l	Volume m^3/day	Lignir kg/da
Textiles	8.8- 9.1	200	0.905	130	9.120	2.1(
Indian Paper & Pulp	5.8- 6.4	1000	1.990	375	11.400	13.5(
Papeterie Titagurh 2	8.5-10.0	130	1.650	170	27.360	4.2:
Papeterie Titagurh 1	7.9- 8.5	135	1.700	185	26.600	4.2!
Western Indian Match	5.0- 6.5	100	0.600	80	2.280	0.2'

From: Problemes d'eaux residuaires industrielles dans la zone du Hooghly
notamment des fabriques de pate a papier et d'huile vegetale hydro
A. K. BASU (1969)

Table 32 (cont'd) : Characteristics of waste waters from different industri

Industry	Volume of Flux m^3/day	Total Matter mg/l	Suspended Matter mg/l	COD mg/l
Margarine	171 - 247	2.505 - 8.100	1.405 - 5.795	3.850 - ¢
Soap	190 - 228	1.540 - 5.390	0.540 - 2.100	1.416 - 1
Combined Effect (average)	418	8.200	4.460	7.980
Combined Effect (range)		3.460 -12.840	1.480 - 7.440	4.990 -10

From: Problemes d'eaux residuaires industrielles dans la zone du Hooghl
notamment des fabriques de pate a papier et d'huile vegetale hydr
A. K. BASU (1969)

Table 33 : Characteristics of effluent from different mills

Characteristics	Sulphate Mill	Tissue Mill
pH	9.8 - 7.1	9.0 - 8.5
Suspended solids mg/l	1392 - 732	964 - 512
BOD 37°C	552 - 207	610 - 251
COD mg/l	1525 - 792	1234 - 600
Lignin mg/l	116 - 12.4	100 - 33

Table : Criteria for Characterizing Waste

Waste Characteristics	Suspended Solids	BOD
Weak	less than 200	less than 150
Medium	200 - 400	300 - 150
Strong	more than 400	more than 300

From: Characteristics of Wastes from Pulp and Paper Mills in the Hooghly Estuary.
R. S. DHANESHWAR, S. RAJAGOPALAN, A. K. BASU & C. S. G. RAO (1970)

Table 34 : Comparison of Hooghly and Matlah estuaries

Condition	Hooghly	Matlah
Dissolved oxygen rate (mg/l)	3.76 - 5.89	5.62 - 6.00
Zooplankton	Dominant	
Phytoplankton		Dominant
Dissolved Oxygen	Lower	Higher
Temperature	Lower	Higher
Oxygen Consumption	Lower	Higher
Turbidity	Higher	Lower
pH	Lower	Higher
Plankton Numbers	Lower	Higher
Free Ammonia Values	Higher	Lower
Primary Productivity ($mgC/m^3/day$)	negligeable	0.375 - 0.562

Adapted From: Comparison of the Polluted Hooghly Estuary with the Unpolluted Matlah Estuary
A. K. BASU, B. B. GHOSH & R. N. PAL (1970)
and
Observations on the Probable Effects of Pollution on the Primary Productivity of the Hooghly and

Ooty, in the Tamil Nadu region of India, has an industry for black and white photographic film fabrication. The main toxin being washed out is undissociated ammonia. Hydroquinone and metol are also present and these have a synergistic effect on the survival of fish - in the presence of hydroquinone, metol is more lethal. When the two are combined toxicity can be reduced by the presence of thiosulphate, carbonate and sulphate of sodium. Hydroquinone is a powerful reducing agent and depletes oxygen.

The presence of mercury was noted in parts of fish obtained from the Bay of Bengal. Hammer-headed shark and white spot shark showed high values ofmercuty with lower values seen in seer fish and dolphin. The overall values, for example, are lower in the Arabian Sea.

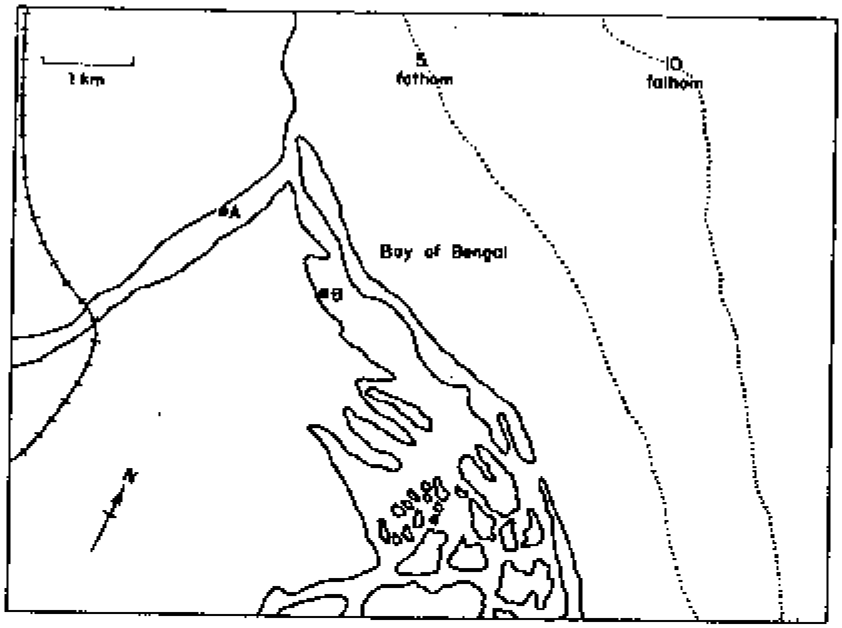
Copper, iron, manganese, zinc, cobalt and nickel in dissolved and particulate fractions of sea water at different depths were estimated from nine stations in the Bay of Bengal. Concentrations of dissolved and particulate iron were fairly high at coastal stations especially at the river mouths. Copper at the nearshore stations was high but there was no marked difference between nearshore and offshore concentrations so as to reflect the possibility of a river input. Dissolved zinc and nickel values were lower at the surface than at the deeper layers contrary to that noted for manganese. Particulate fractions of iron and zinc were significant whilst cobalt and nickel were not significant. Copper and manganese showed intermediate values.

Dissolved copper values are greater in the Arabian Sea than in the Bay of Bengal as are the values for particulate copper and manganese. Zooplankton appear to accumulate higher quantities of metals in the Arabian Sea than in the Bay of Bengal possibly due to the higher quantities of dissolved metals present there. The concentration factor in the Arabian Sea was highest for zinc followed by iron, cobalt, copper and nickel whereas in the Bay of Bengal, the concentration factor was highest for iron followed by cobalt.

Heavy metals in effluent, for example copper, are traced back to pesticides, fungicides, jewellery, copperware and anti-fouling paint. In Vellar Estuary in Porto Novo, South India the effect of copper on Meretrix casta was studied. After acclimatisation and subjection to lethal doses, the bivalve was found to have an LC50 (lethal concentration at which 50% of the population is killed) value of 0.57 ppm Cupric sulphate. Death was caused by asphyxiation due to copper induced mucus coagulating the gills. Bivalves can generally accumulate larger amounts than fish and are thus more tolerant. Studies were carried out on heavy metal concentration by the oyster Crassostrea madrasensis in the Cochin area. High levels of manganese, zinc, iron and copper were noted in December to May whereas the low values from June to November were attributed to the flow of fresh water causing dilution. Oysters can concentrate copper up to 14,000 times and zinc up to 10,000 times. Some results for copper accumulation by various bivalves were also obtained for the Vellar Esturry on the east coast of India (see table 35 and fig. 19).

Natural run-off effects the concentrations of iron found in the Mandovi and Zuari Estuaries, India. Estimation of concentrations were studied for 1 year and values were found to vary from 0-3.6 mg/l. The higher values were attributed to the influence of the river which flows through iron ore bearing terrain. Around other parts of Goa values vary from 0.65-180 mg/l. The decrease

Figure 19 : Geography of Vellar estuary



Vellar estuary—Lat. 11° 29′ N, Long. 79° 49′ E. Location of stations: A, opposite to Marine Research Lab; B, oyster bed at Muzhukkuthurai.

Table 35 : Accumulations of copper in certain bivalves

Experimental concentration (parts/10⁶)	*A. granosa* Length (mm)	*M. casta* Length (mm)	*C. madrasensis* Length (mm)	Copper: dry weight (parts/10⁶) *A. granosa*	Avg.	*M. casta*	Avg.	*C. madrasensis*	Avg.
0·020	26	35	55	19·15	26·44	11·80	18·91	20·38	23·51
	29	39	59	22·72		12·75		23·69	
	32	43	68	25·31		16·23		24·47	
	35	46	78	26·70		16·51		25·50	
	39	49	—	38·30		37·25		—	
0·040	28	36	56	27·79	34·83	17·25	18·42	39·08	39·70
	32	40	60	27·78		21·40		39·05	
	36	44	69	27·58		16·73		40·27	
	41	48	77	33·53		18·28		40·39	
	44	—	—	57·45		—		—	
0·060	29	37	55	32·22	36·42	12·77	20·15	34·58	48·74
	32	41	61	32·66		26·37		45·35	
	36	44	69	30·65		15·70		53·59	
	40	48	79	30·99		25·73		61·44	
	42	—	—	55·58		—		—	
0·080	—	36	56	—		23·50	32·25	48·54	75·36
	—	39	62	—		26·12		56·27	
	—	42	70	—		35·80		99·02	
	—	47	79	—		43·56		97·69	

In the Bay of Bengal studies on arsenic content showed values from <1 to 18.75 microgram/l with an average of 2.55 microgram/l. The highest concentrations were seen in the Gulf of Mannar off the northwest coast of Sri Lanka. Surface waters have <1 to 8.25 microgram/l and bottom waters <1 to 18.75 microgram/l with the oxygen minimum layer carrying the minimum amount. In the fine clay regions of the Bay of Bengal the arsenic was absorbed into the sediment. In the Indian Ocean, arsenic is found mainly as arsenate and it is removed in particulate form.

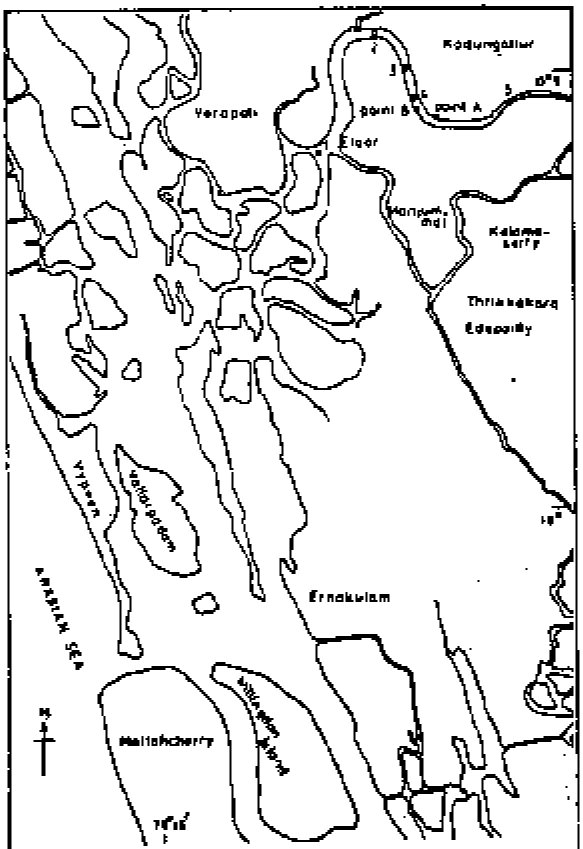
Visakhapatnam Harbour is slightly further south of the Hooghly Estuary and lies half way between Madras and Calcutta along the eastern coast. It is also affected by industrial effluent and receives effluent from fertiliser factories and oil refineries through the Mehedriggeda Stream. The Visakhapatnam coast is rocky with a diverse growth of algae. Industrial, domestic and municipal sewage result in the presence of crude oil, iron ore dust and sulphur. Thermal blue-green algae are found in the thermal effluent of the oil refinery.

In the early mornings of November 1974 and May, September and October 1975, mass mortality of fish occurred. This was thought to be the result of an acidic effluent composed of ammonia, fluorides, phenols and heavy metals such as copper and lead discharged from the fertiliser factory which lowered the already acidic pH in the northwestern arm. About 350 fish, mainly from the species Nematalosa, Megalops and Mugil, per 100 m stretch of canal died. In enclosed harbours, estuaries, lagoons and bays high in bicarbonate content, the addition of strong mineral acids can cause liberation of large amounts of carbon dioxide. This combined with a low dissolved oxygen content level due to photosynthetic inactivity during the night was the probable cause for the fish deaths. Mass mortality of fish due to ammonia poisoning has also been seen in Chitrapuzha, a tidal tributary of the Cochin Backwaters. These kills have been attributed to effluent from two major industrial establishments in the area.

8.5 The West Asiatic Subcontinent

Ammonia is often apparent in effluents. The accepted level of ammonia is 2.5 ppm. In the Cochin Backwaters, the present level is 432-560 ppm. Acids and suspended solids are also present in this region due to industrial pollution. In Kalamaserry this resulted in scattered patches of dead Ambasais gymnocephalus. At point A 12,000 l/day acid is discharged and at point B, 50-60 million l/day alkali (see fig. 20). Some of the conditions of the water in this area and their effects on fish are as follows: high temperature leads to changes in chemical and biochemical processes, an increased turbidity causes choking of the operculum cavity and high ammonia concentrations corrode the gills. Studies on the toxicity of ammonia to various fish species was carried out at Goa. The toxicity of the ammonia depended on the solution it was in; at pH 8 ammonia was more toxic than at pH 7. Similarly a decrease in the dissolved oxygen content increased the toxicity of non-ionized ammonia. Ammonia toxicity affects the growth rate, disease resistance and produces hyperplasia of the gill epithelium. Ammonia toxicity is correlated to the permeability of the gill to it. Often, the fish that are not indigenous to the area may have accidently entered it during feeding movements.

Figure 20 : Geographic location of the Cochin backwaters



— Location of stations in the study area

From: Incidence of Fish Mortality from Industrial Pollution in the Cochin Backwaters
R. V. UNNITHAN, M. VIJAYAN, E. V. RADHAKRISHNAN & K. N. RAMANI (1977)

Table 36 : Characteristics of Cochin backwaters

—Characteristics of Effluents on Enter

Source of effluent	Temp. (°C)	Chlorinity (ppm)	*p*H	Diss. oxygen (ml/l)	Alkalinity (mg $CaCO_3$/l)	Sus soli (mg
Periyar Chem.	33.9	200	8	1.8	117	264
Catalysts & Chem. India Ltd	43.9	310	6	1.4	16.4	184
Cominco Binani Zinc Smelters (1)	35.5	300	2	<0.05	195.8	8
Bleach ,, (2)	32.2	50	2	4.5	157.7	16
Indian Rare Earths Ltd	36	50	6	4.2	10.8	15
FACT	30.2	50	6	4.4	16.3	12
TCC	31	150	7	4.3	16.4	50
Water Sample Upstream	29.5	50	6.5	6.9	18	8

From: Hydrographic Featu
Cochin Backwaters
Pollution.
K. SARALA DEVI, R.
S. LALITHA & R. V.

The majority of the industrial effluent entering the Cochin Backwater stems from Eloor (Uyogamandal) belt which stretches 5 km along the banks. With sewage and industrial pollution causing so much concern in the region, studies on the hydrographic features and water quality of the area have also been carried out. The state of the water is influenced by the monsoonal conditions. Some characteristics of the effluents entering the area are listed in table 36. The major stress is at station 2 (table 37) and diminishes gradually from there both up stream and downstream. High levels of metals are noted particularly iron, manganese, copper and zinc.

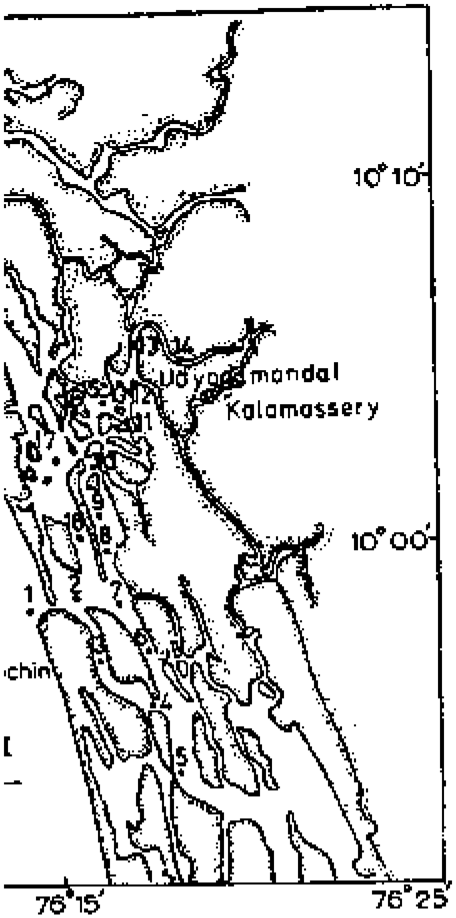
Although all arise from industrial and municipal pollution, the iron concentrations are also influenced by leaching through iron ore bearing terrain. Organic carbon and organic matter levels showed enrichment in the area of a coconut husk retting yard. Bacterial counts are high and the sediments take on a black coloring and are malodorous. Monsoonal dilution and tidal mixing are too low to have any positive effect on the self purifying abilities of the system. The concentrations of some metals at different stations in Cochin are seen in table 37 and comparisons of this data with data from other regions is seen in table 38.

A titanium factory situated 3 km from the Marine Biological Station at Sankhenoghon, Trivandrum in India, discharges an effluent containing sulphuric acid, ferrous sulphate and small scale titanium sulphate. In March and November, the effluent is especially heavy in ferrous sulphate 0.0126 g/l whereas the range at other times is usually 0.0007 g/l - 0.0035 g/l. During these months few interstitial fauna are seen on the affected tropical sandy beach, with none close to the discharge point. This depletion is not due to natural causes. Tests have shown that species of copepod, nematoda, archiannelid and polychaete cannot resist concentrations above 0.0021 g/l at pH 7.1. In May, the maximum number of animals is 21 per 0.5 l of sand but in the other months only 6-18 animals per 0.5 l of sand are found. The animals seen are foraminifera, ciliata, coelenterata, turbellaria, nematoda, gastotricha, ostracoda, copepoda and isopoda. The sand has become a browny colour due to the presence of iron in the discharge. This clogs the interstices and the lack of fauna from the outfall point to 30 metres along the beach is due to this as well as to the reduced oxygen content and pH. From 30-200 m from the outfall, the beach is still moderately effected with some slight effect after a distance of 200 m. Near the titanium plant the nearshore waters of the Kochuveli beach are very polluted due to the daily discharge of 1600 m^3 of wastes. pH can range from 1.4-2.5. Studies on foraminifera show less specimens in the region. When they are found it is often with corroded surfaces due to the acidic nature of the effluent.

Bombay is the second most populated city in India. It has many industries and effluents from these industries are a major pollution problem. About 75 million m^3 of industrial effluent is discharged from Bombay every year. The current measurements for this area indicate that the movement off Bombay is northward in the rising tide and southward in the falling tide. South of the harbour, there are strong onshore and offshore components. Tidal phenomena appear to help dissipate the pollution to some extent in this region.

The mercury content entering the ocean has caused great concern since the Minamata disaster. Some regions of the Indian Ocean have been tested for mercury content as seen in table 39. The mercury concentration is constantly increasing due to its long residence time. It is found mainly in the coastal areas. The content of mercury in various organisms has been recorded. Values for concentrations in food

Table 37 : Concentration of various metals at different sites in the Cochin backwaters



— Concentration of Metals at Various Stations in the Cochin Backwater

Station No.	Depth	Salinity ‰	Suspended matter, mg/litre	Conc., µg/litre Fe	Mn	Cu	Zn
1	S	32.54	32.7	2913	5.7	2.1	11.4
	B	33.24	92.3	9771	40.2	10.5	25.8
2	S	32.1	42.2	4686	26.5	6.8	24.6
	B	32.94	35.1	3312	18.6	4.7	18.5
3	S	31.8	12.5	1257	7.5	3.8	5.7
	B	32.6	42.8	2328	17.7	3.8	16.2
4	S	23.66	17.4	219	10.8	2.6	2.4
	B	28.3	6.4	3177	36.9	13.7	20.1
5	S	20.3	12.3	1644	16.8	2.1	2.3
	B	26.4	28.5	1281	25.2	3.8	12.6
6	S	31.2	14.5	366	12.9	2.1	4.5
	B	32.4	12.5	354	4.8	2.6	3.1
7	S	32.34	18	744	14.1	5.9	13.5
	B	32.6	29.7	2286	16.3	2.6	6.9
8	S	27.75	16.2	219	11.6	2.6	6.9
	B	31.31	46.5	2516	21	7.1	21.4
9	S	24.92	18.3	310	18.7	0.8	13.8
	B	25.6	30.1	1260	32.5	3.4	29
10	S	22.77	12.6	868	19	1.97	9.9
	B	23.84	16	584	13.6	2.8	20
11	S	16.29	12	268	48	2.2	18.2
	B	19.54	10.9	204	39.2	0.8	13.2
12	S	12.86	10	172	50.4	3.1	36.6
	B	18.46	10.2	212	45.2	1.4	15.4
13	S	13.04	9.3	156	64	0.8	34.4
	B	18.46	11	330	59.8	2.8	23.8
14	S	7.57	6.3	288	12	2.8	88.8
	B	13.22	13.8	568	97	4.2	83.6
15	S	14.31	14.4	178	24.6	2.8	113.2
	B	16.47	12.2	352	56.2	3.8	38.1
16	S	17.38	13.4	220	20.4	3.6	35
	B	21.51	19.9	620	24	5.4	57.4
17	S	24.38	12.1	170	12.8	3.2	13.6
	B	24.56	11.5	192	8	2.3	9.4
18	S	24.38	19.8	548	24.4	5.4	23.3
	B	24.38	22	520	26.8	4.3	22.1

S=surface; B=bottom.

From: Particulate Iron, Manganese, Copper and Zinc in Waters of the Cohin Backwater
V. N. SANKARANARAYANAN & R. STEPHEN (1978)

Table 38 : Comparison of data from different areas with respect to Cochin

— COMPARISON OF PRESENT DATA WITH REPORTED DATA FOR WATERS FROM DIFFERENT AREAS

Ranges of conc. in present study (μg/litre) Surface	Bottom	Values (μg/litre) reported earlier	Remarks
		IRON	
1257-4586	2286-9771	10-80	Porto Novo waters[4]. Higher particulate concentration at the bottom also reported
		0·65-180 mg/l	Waters around Goa[6]. Higher iron concentration observed attributed to the mining operation in the area
		MANGANESE	
5·7-64	4·8-97	2-21	Waters of Bombay[4]
		40-42	British coastal waters[11] and Porto Novo waters[4]
		12·5-102·2	Waters of Goa[7]. High content has been explained as a result of minin activity in the area
		COPPER	
0·8-5·9	0·9-13·7	24-78	Waters of English Channel[18] and high value has been attributed to land drainage
		1.45	San Juan Channel[17]
		0·1-4·8	Sargasso Sea water[18]
		—	Av. copper content for river and ocean water, 5 and 3 respectively[19]
		0·5-12	Porto Novo waters[4]
		1·7-7·9	Arabian Sea waters[9]
		ZINC	
2·3-113·2	3·1-83·6	28-35	Bombay waters[4]
		0·8-52·6	Sargasso Sea[18]
		21-38	Oresund[18]. High values due to the influence of sewage effluents
		1·3-47·6	British coastal waters[15] due to terrestrial contamination
		2·8-42·3	Goa waters[7]
		5·5-42·4	Arabian Sea[9]

From: Particulate Iron, Manganese, Copper and Zinc in Waters of the Cochin Backwater
V. N. SANKARANARAYANAN & R. STEPHEN (1978)

Table 39 : Surface samples of mercury from the Indian Ocean

Longitude	Latitude	Date	Mercury ng/l	Weight of Suspended Matter µg/l
18°55.5'S	60°40.0'E	1972-8 Nov.	20	12
06 33.5'S	78 11.0'E	12 Nov.	20	38
30 42.5'S	34 08.5'E	1973-10 Nov.	21	-
27 24.0'S	42 15.0'E	19 Jan.	10	36
25 24.0'S	49 45.0'E	27 Apr.	12	25
14 35.5'S	58 35.5'E	5 Jul.	35	65
12 46.0'S	69 37.0'E	1 May	11	11
07 47.0'E	73 54.0'E	13 Jan.	6	11
06 57.0'S	68 50.0'E	3 Jul.	20	101
01 17.0'S	83 37.0'E	4 May	34	19
06 34.5'S	91 55.0'E	22 Jun.	18	142
01 44.0'N	77 12.0'E	22 Jun.	17	64

From: Observation on the Distribution of Dissolved Mercury in the Oceans.
D. GARDINER (1965)

Table 40 : Mercury concentrations in some fish from the Indian Ocean (μg/g)

Species	Minimum	Mean	Maximum
Pomfret	15	16.5	18
Seerfish	9	12.5	16
Skipjack	6	65.0	124
Jew Fish	16	19.0	22
Sardine	4	6.0	8
Bombay Duck	26	35.5	45
Catfish	5	35.5	62
Eel	8	14.0	20
Ribbon Fish	4	8.0	12
Whitefish	1	3.5	6
Mackeral	2	5.0	8
Sole	12	14.0	16
Cuttlefish	6	23.0	40
Lobster	19	37.0	55
Edible Oyster	9	12.5	16
Sharks	12	40.0	62
Shrimps	5	10.0	30

From: Baseline Study of the Level of Concentration of Mercury in the Food Fishes of Bay of Bengal, Arabian Sea and Indian Ocean.
V. D. RAMAMURTHY (1979)

From studies done along the west coast of India from Bombay to Cochin, concentrations of mercury at different depths are recorded giving lower values as the depths increase, probably as a result of adsorption on to particulate matter. Apart from off Cochin (at station 726 in fig. 21) the average concentration of mercury present, 77 ng/l, appears to correspond with global values (Atlantic Ocean 0.5-225 ng/l Pacific 12-153 ng/l, China and Japan Seas 6-51 ng/l).

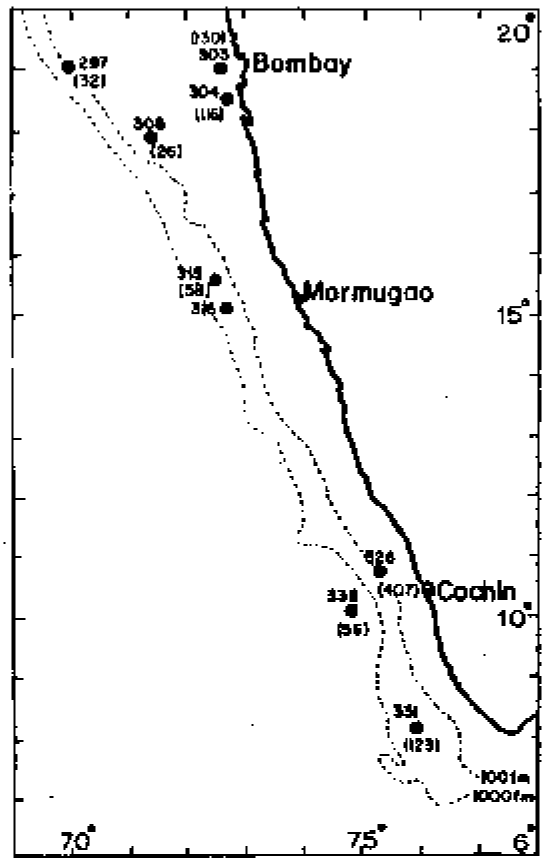
In general the Bay of Bengal is more polluted by mercury than the Arabian Sea except for the region near Bombay and Thana. The mercury content of the water column estimated along Thana Creek/Bombay Harbour (figure 22), gave a value of about 77 kg in excess of the expected background count. Mercury concentrations in sediment from 27 locations varied from 0.17 - 9.21 ppm (dry weight) (see tables 41-43). The highest values were found in the creek region which suggests a substantial input in this area. The mercury enriched layer in the sediment cores (figure 23) has about 10 - 25 cm in the creek region and 0.8 cm in the harbour area. Results obtained from around Bombay at Thane and Colaba markets show the brain of fish to accumulate more mercury than the muscle and the bone (table 44). Measurements of mercury concentrations present in the Laccadive Sea carried out in March 1978, show values ranging from 45 ng/l to 204 ng/l. Values increase from north to south and decrease offshore. Localized high spots probably arise due to leaching from mercury carrying rocks.

Along the coast of Goa, seaweeds were monitored at 5 spots. The specimens showed an ability to bioconcentrate and accumulate trace metals such as cobalt, copper, iron, manganese, nickel, lead and zinc. Results of a study of the effects of different metals on seaweeds of the Goa coast are seen in table 45. Some values for concentrations of trace metals zinc, copper, manganese and iron in fish, prawn and crab are seen in table 46. The effects of trace metal concentrations on different marine organisms along the coast of India are seen in tables 47 and 48. Concentrations of copper, zinc, manganese, cobalt, iron and nickel were measured in particulate and dissolved form in the Arabian Sea. Generally dissolved copper shows a decrease with depth and particulate copper an increase at mid-depths. High values at increased depths are due to accumulation by organisms and sediment. Dissolved iron and manganese showed a noticeable increase at depths of 500m. Iron and zinc values are higher nearshore due to coastal input; nickel and cobalt values were low.

From October 1977 to September 1978, chaetognath fauna were studied in the Bombay region at Thana, Malu, Bombay harbour and Versova. The maximum density of chaetognaths were found in the post monsoon period and the fluctuations in population and species density were greater in the polluted area. Sagitta bedoti was most common of the Sagitta species present.

In Pakistan, industrial development is advancing rapidly. More than half the country's industry is situated around Karachi which has a population of 4.5 million. Sewage running through uncemented drains and linking with bigger drains containing industrial effluent all discharge into the sea. Despite the laws against dumping dangerous industrial wastes, local factories still release untreated mercury, lead compounds, chlorine and hydrochloric acid into the rivers. For example, 70% of the contaminants in the waste water flowing into the River Lyari come from the local factories. BOD values of 1,237 tons/day were obtained from effluent from Karachi of which 84.5% were from industrial wastes. About 800 industries are situated here comprising alimentary products, metal and

Figure 21 : Some values for mercury concentrations along the west coast of India



— TOTAL MERCURY CONCENTRATIONS

Station No.	Depth (m)	Conc.* ng l⁻¹	Station No.	Depth (m)	Conc.* ng l⁻¹
	1	32			
297	100	52			
	150	13			
	1	130			
303	10	71		1	—
	20	84	316	10	187
				65	90
	1	116			
304	10	142		1	407†
	15	32	326	50	181
	1	26		1	123
	25	32	331	500	90
308	50	136		1200	181
	75	84			
				1	58
	1	58	338	500	187
	100	52		1000	110
315	500	26			
	800	39			

*Surface av. 77 ng l^{-1}.
†Excluded from calculation.

From: Total Mercury Concentrations in the Arabian Sea
Waters off the Indian Coast
S. Y. S. SINGBAL, S. SANZGIRI & R. SEN GUPTA (1978)

Figure 22 : Geography of Thana Creek

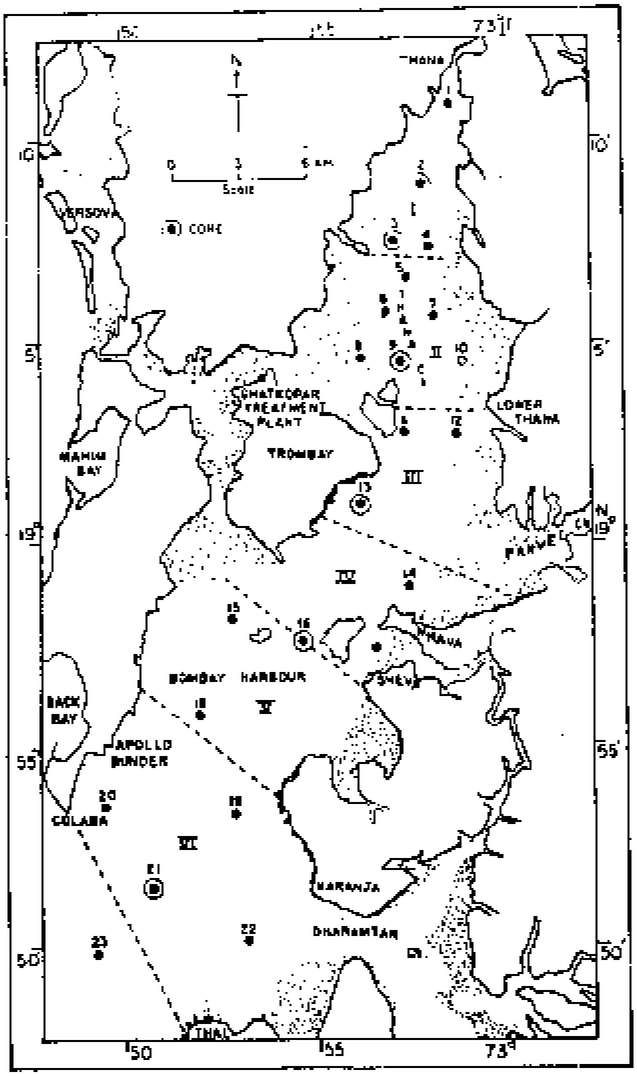


Table 41 : Conditions of surface water

Station	Tide	Salinity (‰) Surface	Salinity (‰) Bottom	Water Dissolved oxygen (Surface	Bo
1	Eb	35.76	36.06	1.8	[illegible]
2	Eb	35.49	35.31	2.8	[illegible]
3	Eb	–	–	–	
4	Eb	36.12	36.14	4.0	4
5	Eb	–	–	–	
6	Eb	37.09	36.89	4.8	5
7	Eb	36.05	36.82	5.1	5
8	Eb	–	–	–	
9	Eb	36.94	37.86	4.2	4
10	Eb	–	–	–	
11	Eb	36.12	36.84	6.5	5
12	Eb	36.04	36.91	6.3	6
13	Fl	37.16	37.09	6.1	6
14	Fl	37.65	38.11	6.3	6
15	Fl	37.31	37.42	5.5	5
16	Fl	37.47	38.14	6.4	5
17	Fl	36.92	37.64	6.0	5
18	Fl	37.21	36.46	6.3	5
19	Fl	36.16	36.46	6.5	6
20	Eb	36.32	36.25	6.0	6
21	Eb	36.40	36.24	6.4	6
22	Eb	36.09	35.80	6.1	6
23	Eb	36.10	36.12	6.7	6

From: Mercury in Thana Creek, Bombay H

M.D.ZINGDE & B. N. DESAI (198]

Table 42 : Mercury levels in water

Mercury in water of Thana Creek/Bombay Harbour

Region	Approximate area (km^2)	Mean water depth (m)	Mass of water (Mt)	Mean Hg concentration in water (μg kg^{-1})	Mass Hg in water (kg)	Excess Hg in water (kg)
I	8	0.3	2.4	0.311	0.7	0.5
II	19	1.2	22.8	0.302	6.9	5.2
III	28	2.1	58.8	0.266	15.6	11.2
IV	34	3.3	112.2	0.186	20.8	12.4
V	53	5.0	265.0	0.240	63.6	43.8
VI	98	5.8	568.4	0.153	86.9	44.3

Table 43 : Mercury levels in sediment

Mercury in sediment of Thana Creek

Segment	Approximate area (km^2)	Contamination depth (m)	Sediment mass (Mt)	Hg (wet weight) (mg kg^{-1})	Estimated sediment mercury (t)
I	29	0.20	8.41	2.5	21
II	61	0.16	14.15	1.0	14.1
III	49	0.10	7.10	0.35	2.5

Figure 23 : Mercury in some sediment cores

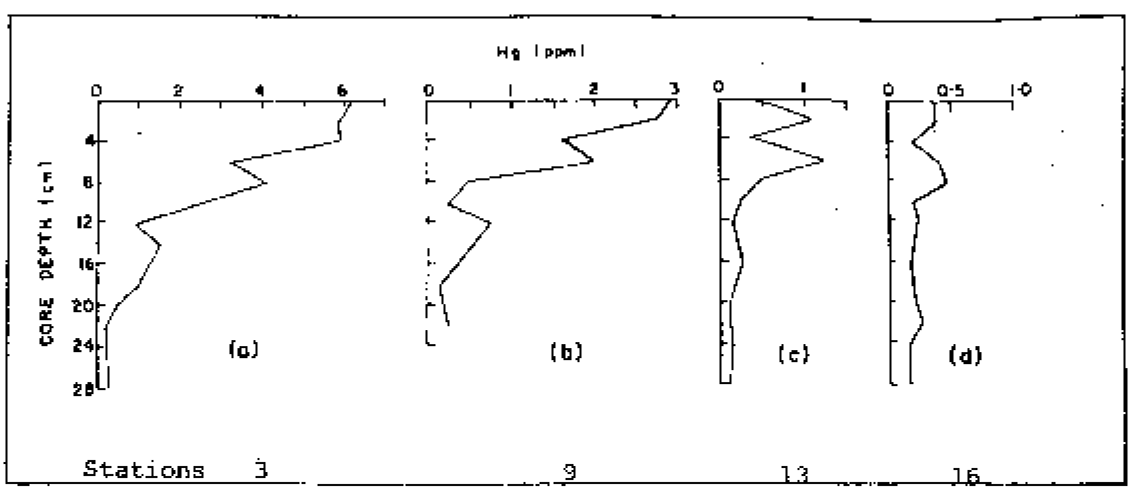


Table 44 : Mercury concentrations in selected species from Thana and Colal
(in ng fresh weight)

Species	Colaba		Thana		
	Muscle	Bone	Muscle	Bone	Bra
Bombay Duck	35±1	122-2	48-2	92-2	
Pomfret	92±4	189-7	124-6	205-4	
Lobster	177±8	-	207-7	-	
Red Prawn	161±6	-	180-7	-	
Salmon	113±4	297-9	109-4	254-3	
Dhoma	56±2	137-6	67-3	111-2	
Sardine	77-3	121-2	66-2	133-4	
Shark	172-8	318-12	160-6	389-14	

From: A Preliminary Survey of Mercury in Fish
from Bombay and Thana Environment
B. M. TEJAM & B. C. HALDER (1975)

Table 45 : Trace metal concentrations in the seaweeds off the Goa coast, India (ppm dry wt.)

Trace Metal Concentration in the Seaweeds of Goa Coast (values expressed in ppm/dry weight)

Station	Sl. No., Name of species	Co	Cu	Fe	Mn	Ni	Pb	Zn
I. Chapora	1. *Enteromorpha clathrata*	15.18	30.23	1292.51	2685.53	34.55	9.17	11.58
	2. *Ulva reticulata*	10.56	13.85	1169.23	1721.04	39.06	17.76	8.89
	3. *Gracilaria verrucosa*	14.52	15.61	1076.77	3420.56	13.52	8.59	11.74
II. Anjuna	1. *Caulerpa sertularioides*	4.35	5.03	587.50	74.58	17.02	14.9	11.07
	2. *Ulva fasciata*	6.07	6.70	722.34	111.25	9.61	15.24	23.80
	3. *Dictyota* ssp.	9.24	5.84	710.20	94.77	9.31	9.51	9.95
	4. *Padina tetrastromatica*	4.35	7.86	1004.53	344.20	10.31	2.95	7.60
	5. *Sargassum tenerrimum*	7.92	4.53	471.93	79.81	7.31	34.73	5.40
	6. *Acanthophora specifera*	7.39	80.41	490.61	90.72	13.62	6.07	12.61
	7. *Gracilaria corticata*	7.92	4.53	564.96	144.86	22.03	11.00	12.27
	8. *Hypnea musciformis*	6.07	6.55	615.82	96.81	9.61	16.04	11.74
III. Baga	1. *Ulva fasciata*	8.58	7.30	353.46	1075.65	7.01	16.04	2.79
	2. *Dictyota* ssp.	5.94	10.32	784.94	153.47	8.01	16.04	7.38
	3. *Padina tetrastromatica*	8.58	4.03	657.81	530.65	8.51	10.89	4.47
	4. *Sargassum tenerrimum*	7.92	5.79	128.09	42.67	3.50	12.61	11.30
	5. *Acanthophora specifera*	7.26	12.59	238.85	63.11	9.51	8.02	11.80
	6. *Gracilaria corticata*	11.88	3.52	261.97	180.19	6.00	9.74	3.69
IV. Dona Paula	1. *Colpomenia sinuosa*	10.56	21.06	1796.22	258.15	23.03	20.06	21.48
	2. *Dictyopteris australis*	3.03	8.36	685.74	131.52	11.31	20.97	21.26
	3. *Dictyota* ssp.	2.64	12.99	582.69	100.39	11.71	14.1	18.19
	4. *Padina tetrastromatica*	5.67	6.70	755.66	418.78	18.33	28.31	11.70
	5. *Sargassum tenerrimum*	4.88	8.96	451.32	140.55	8.71	14.55	6.04
	6. *Acanthophora specifera*	13.20	7.40	796.11	344.16	14.72	17.19	13.80
	7. *Hypnea musciformis*	8.84	8.56	779.74	238.79	12.72	11.80	10.36
V. Cabo-de-Rama	1. *Caulerpa peltata*	9.63	12.59	1596.86	136.24	18.33	19.48	18.19
	2. *Codium elongatum*	8.84	3.82	680.92	72.42	17.72	12.95	11.97
	3. *Dictyopteris australis*	1.32	9.72	492.54	32.98	5.30	14.55	57.44
	4. *Padina tetrastromatica*	4.62	3.17	388.52	205.09	8.01	13.75	9.78
	5. *Sargassum tenerrimum*	1.32	15.46	130.48	43.02	6.31	11.48	38.49
	6. *Spathoglossum asperum*	1.98	5.54	130.40	25.09	0.50	18.34	24.55
	7. *Stoechospermum marginatum*	5.94	33.60	868.16	84.61	15.32	197.52	203.88
	8. *Acanthophora specifera*	1.32	13.45	1012.24	88.20	13.02	13.75	28.71
	9. *Gracilaria corticata*	10.95	9.22	1028.61	159.91	14.32	18.68	15.21

From: Metal Concentrations in Some Seaweeds of Goa.
V. V. AHADI, N. B. BHOSLE & A. G. UNTWALE (1978)

Table 46 : Concentrations of some trace metals in fish, prawn, and crab (µg/g wet weight)

Organism	Zinc	Copper	Manganese	Iron
Fish (Arius species)	9.42	0.88	1.41	11.50
	22.17	2.30	1.80	3.00
	30.55	4.35	3.74	-
Prawns (Ascelis indius)	11.15	11.20	-	15.00
Crab (Scyella serrata)	83.50	23.60	4.76	295.20
	60.70	34.00	–	114.20
Sea Water Average	14.54	5.50	2.78	9.90

From: Distribution of Zinc, Copper, Manganese and Iron in Bombay Horbour Bay.
V. M. MATKAR, S. GANAPATHY & K. C. PILLAI (1981)

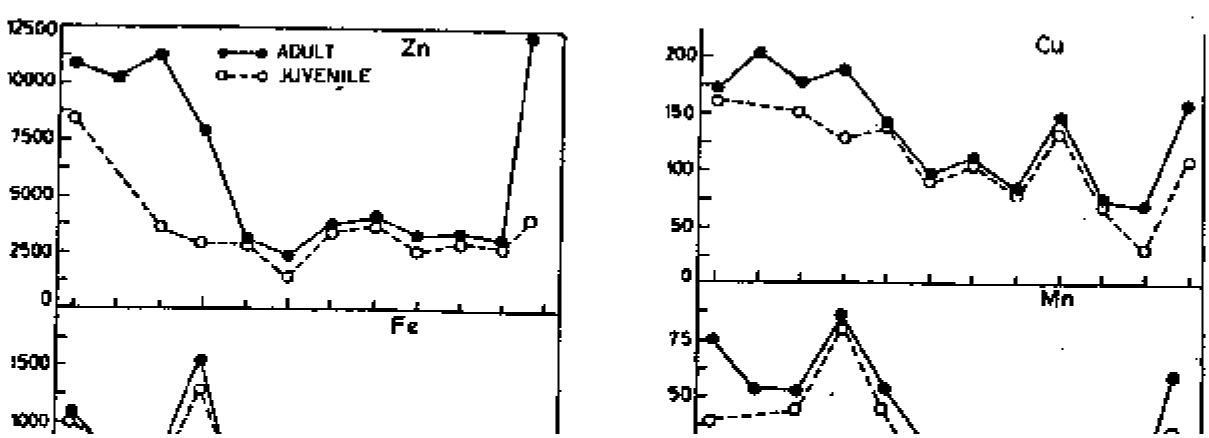
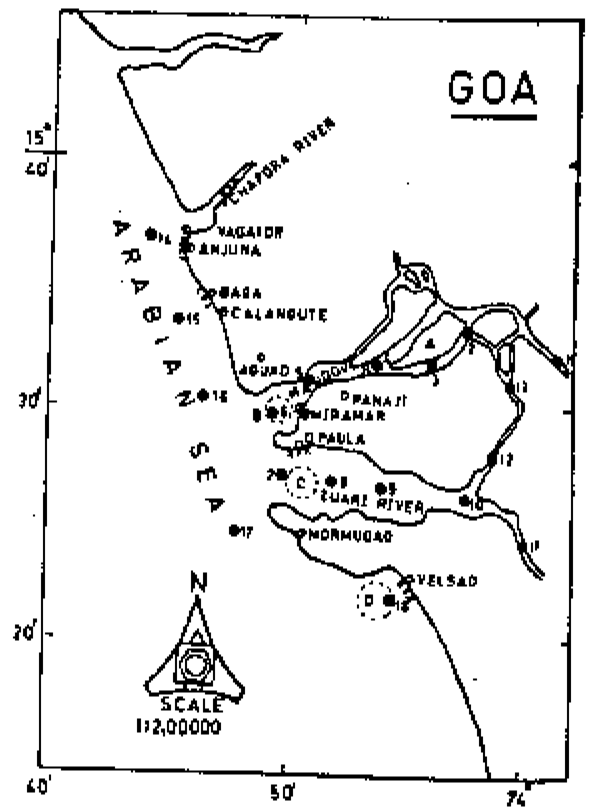


Table 47 : Levels of trace metals of Mandovi-Zuari estuaries along the coast of Goa

:ation No.	Depth (m)	Conc. of metals (µg/litre) Zn	Mn	Cu*	As†
1	0	28·1	85·6	5·8	—
	4	12·5	92·3	4·2	—
2	0	20·4	74·8	4·9	9
	3·5	18·7	80·1	3·3	9
3	0	16·9	50	3·6	1·5
	5	20	35	3·3	—
4	0	18·3	50·2	4	8·25
	5	12·1	46·7	3·1	10·5
5	0	14·1	22·5	2·5	3·75
	5·5	6·3	23·4	4·8	6
6	0	8	11·4	3·6	—
	7	6·2	10·5	4·5	—
7	0	12·1	10·3	4·8	16·11
	4	8·8	6·2	2·7	30·53
8	0	12·6	51·4	3·2	2·97
	5	5·2	22·8	3·5	18·65
9	0	10·3	21·5	—	66·57
	5	19·8	45·6	—	30·1
10	0	28·2	37·1	5·4	47·91
	3·5	28·1	28·3	6	43·25
11	0	35·5	40·3	2·6	—
	3	28·4	72·5	6·8	—
12	0	35·8	56·6	7·1	—
13	0	42·3	102·2	8·2	—
14	0	8·4	15·9	38·87	—
	10	6·3	20	69·77	—
15	0	4·6	12·5	—	—
	10	2·8	20·7	—	—
16	0	12	15	34·34	3
	9	3	21	42·06	5·25
17	0	7·3	21·5	3·41	—
	9	6·2	25	17·66	—
18	0	7·6	24·4	—	—
	10	5·1	21·5	—	—

'alues for *Cu for stations 14 to 18 are from reported
ies and for †arsenic for all stations from reported
ies†-1.



From : Arsenic, Copper, Zinc and Manganese in the Marine Flora and Fauna of Coastal Estuarine Waters around Goa

M. D. ZINGDE, S. Y. S. SINGBAL, C. F. MORAES & E. V. G. REDDY (1976)

Table 48 : Trace metal concentrations in different marine organisms

Location	Conc. of metals (ppm dry wt)			
	As	Cu	Zn	Mn
MARINE ALGAE				
Ulva fasciata				
Vagator	2·5	12·4	25·2	167
Anjuna	2·8	6·8	17·8	203
Baga	1	10·1	19·3	37
Caulerpa sertularioides				
Vagator	2·9	12·6	6·4	115
Anjuna	3·2	8·7	12·9	175
Baga	3·5	3·2	18·5	216
Sargassum tenerimum				
Vagator	10·4	20·1	35·7	302
Baga	8·7	27·5	60·2	270
Dona Paula	13·6	10·3	40·1	586
Padina tetrastromatica				
Vagator	12·6	8·7	20·2	456
Baga	4·8	12·5	31·5	233
Dona Paula	7	20·1	28·8	388
Dictyota dumosa				
Dona Paula	6·7	12·9	37·9	560
Hypnea musciformis				
Vagator	2·5	8·6	50·8	193
Baga	4	22·5	19·4	63
Dona Paula	3·9	15	22·1	361
FISHES				
Leiognathus splendens (Silver bellies)				
B	0·5	5·4	30·6	5·3
C	1·6	2·3	27·1	9·8
D	1·2	6·1	21	12·9
Otolithus ruber (Rosy Jew fish)				
B	3·3	4·9	30·1	20
C	1·8	12·6	11·5	12·5
D	1·3	5·2	15·7	9·7
Pellona ditchela (Shad)				
C	2·1	3·6	—	—
D	4	8·1	—	—
Pampus argenteus (Pampret)				
C	0·5	3·5	40·2	3·9
D	1·7	12	21·8	12·6
Lactarius lactarius (Butter fish)				
C	0·3	2·6	15·4	15·9
D	0·8	5·4	11·5	8·2
Sardinella fimbriata (Sardine)				
B	3	12·2	13·1	—
C	2·3	12·4	17·6	—
D	7·6	5·9	7·5	3·8

Location	Conc. of metals (ppm dry wt)			
	As	Cu	Zn	Mn
FISHES				
Carcharias sorrakowah (Dog fish)				
C	6·3	23·2	17·6	10·6
D	10·8	15·8	18	6·6
Mugil parsia (Grey mullet)				
A	8·3	28·6	47·8	17·9
B	12·6	32·5	63	26·3
Etroplus suratensis (Pearl spot)				
A	8·6	17	76·5	—
C	11·2	14·9	51·8	—
Rastrelliger kanagurta (Mackerel)				
B	3·2	15·8	23·4	4·2
CRUSTACEANS & MOLLUSCS				
Crassostrea cucullata (Small oysters)				
Vagator	5·6	433	715	3·2
Baga	4·2	728	1398	—
Miramar	2·3	251	446	—
Dona Paula	3·5	356	2618	—
Shiridao	3·5	480	2232	11·7
Velsao	6·3	325	2800	17·5
Crassostrea gryphoides (Edible oysters)				
Chapora	3·2	210	321	—
Verem	5·8	175	550	—
Penaeus monodon (Tiger prawn)				
A	9·3	48·3	70·0	21·3
C	11·2	21·5	21·5	14·9
Metapenaeus affinis (Prawn)				
D	13·6	28·9	58·3	—
Portunus pelagicus (Blue swimming crab)				
Chapora	24·8	45·3	78·5	—
C	11·3	29·0*	80·2	—
D	25·2	94·4	73·7	—
Mytilus viridis (Common mussel)				
Baga	9·6	12·9	15·3	—
Miramar	8·2	25·0	63·0	—
Velsao	8·9	8·6	21·2	—
Meretrix casta (Bivalves)				
Chapora	10·9	16·1	50·2	—

A, B, C, D are trawling areas (Fig. 1).

9.0 OIL POLLUTION

9.1 Introduction

With the increasing number and sizes of tankers travelling through the Indian Ocean area, fear of oil spills has also increased. Some paths used by these tankers are shown in fig. 24. In 1979, 355 million tonnes of oil was transported through the main route from the Arabian Sea to the Far East. Oil pollution risks include collisions or groundings of laden tankers and operational discharge from tankers in ballast condition.

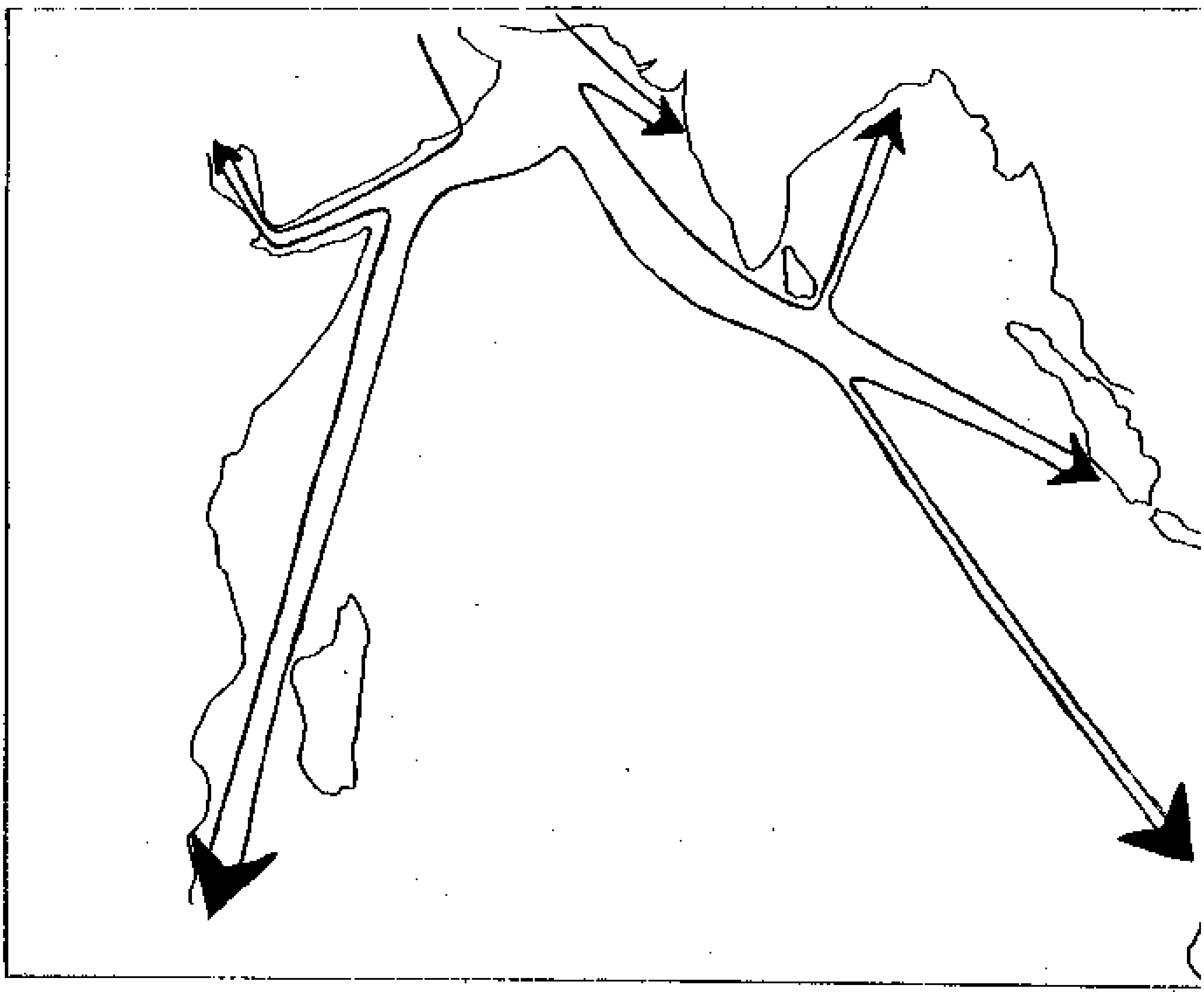
The hydrocarbons usually found in the open ocean are a mixture of saturated and aromatic compounds. The aromatic fractions are usually the more toxic and rarely arise from crude oil spills or refinery produce. Sampling from the top meter show a smaller amount than expected. It is thus thought that the aromatics are preferentially removed by evaporation, for those of C15 and lighter and dissolution for those of C10 and lighter. Heavier fractions are often adsorbed onto suspended materials and sink to the bottom being washed ashore by heavy wave action in monsoon months. Degradation and absorption are other means by which oil is removed.

9.2 East Africa

Despite the opening of the Suez Canal, the major tanker routes from the Gulf to Europe, which are adjacent to the East Coast of Africa, are still heavily used. Over 12 years, 21 individual spills of more than 160 tonnes have occured in the area. Examples of these are the Ennerdale which lost 40,000 gallons fuel oil off Mahé, Seychelles, the Silver Ocean which lost 18,500 tonnes off the southern tip of Madagascar, the 239,000 ton tanker Albahaa B which exploded and sank 300 miles of Tanzania in April 1980 and the Tayeb which broke up on the reefs in Mauritius in 1972 and released 200 tonnes of heavy oil. East Africa is beginning to accept heavy tankers and hence the probability of oil pollution occurring has increased. Often, contamination of the East African Coast by oil is due to slicks being brought in by coastal currents from spillages in the open ocean. This is especially true along the Kenya coast during the southwest monsoon when it is carried onshore by the Equatorial Counter Current.

Oil-pollution is noticed from Diani Beach in Kenya and northwards. Some contamination is noted at Mombasa, Kisumu and Nakuru, the former from tankers and refineries and the latter from a diesel station. Poor algal communities were seen in the port and creek areas of Mombasa, Kenya and it is possible that pollution by oil slicks has put some restraint on growth in Kilindini Harbour for example. Algae appear to have damaged some of the coral reefs by smothering the corals after invasion of the ecosystem probably triggered off by eutrophic conditions. The south coast of Mombasa suffers most from this in March and June and may be contaminated by oil from unloading and loading of ships from refineries seen in the Mombasa area. Oil is also found on the coasts from wastes from industrial sites but as yet is not a serious threat. In recent research programmes, the presence of tar balls on the coast of Kenya has been monitored. On Shelley Beach, south of Mombasa, tar concentrations of 29.5 g/m^2 were recorded with individual lumps weighing up to 3 kg being found.

Figure 24: Oil tanker routes through the Indian Ocean



From: The Times Atlas of the World

In Tanzania, oil pollution has been noted close to a refinery near the floating oil mooring in Dar es Salaam. Tanzania, too, is near the tanker route and some damage to coral reefs can be observed with many of the beaches showing some crude oil contamination. At Zanzibar, values of 1,620 g per 100 square yards have been recorded and at Mafia Island, 1,350 g per 100 square yards. Deposition is dependent on the prevailing winds and currents and is higher during the southwest monsoon when the oil is carried by the South Equatorial Current to the southern coast of East Africa.

9.3 The Islands

In Madagascar, a refinery at Tamatore handling 200,000 tonnes per annum, periodically causes local pollution problems. Due to the increasing tanker traffic in the Mozambique Channel, some contamination has been seen along the western and southern coasts of Madagascar.

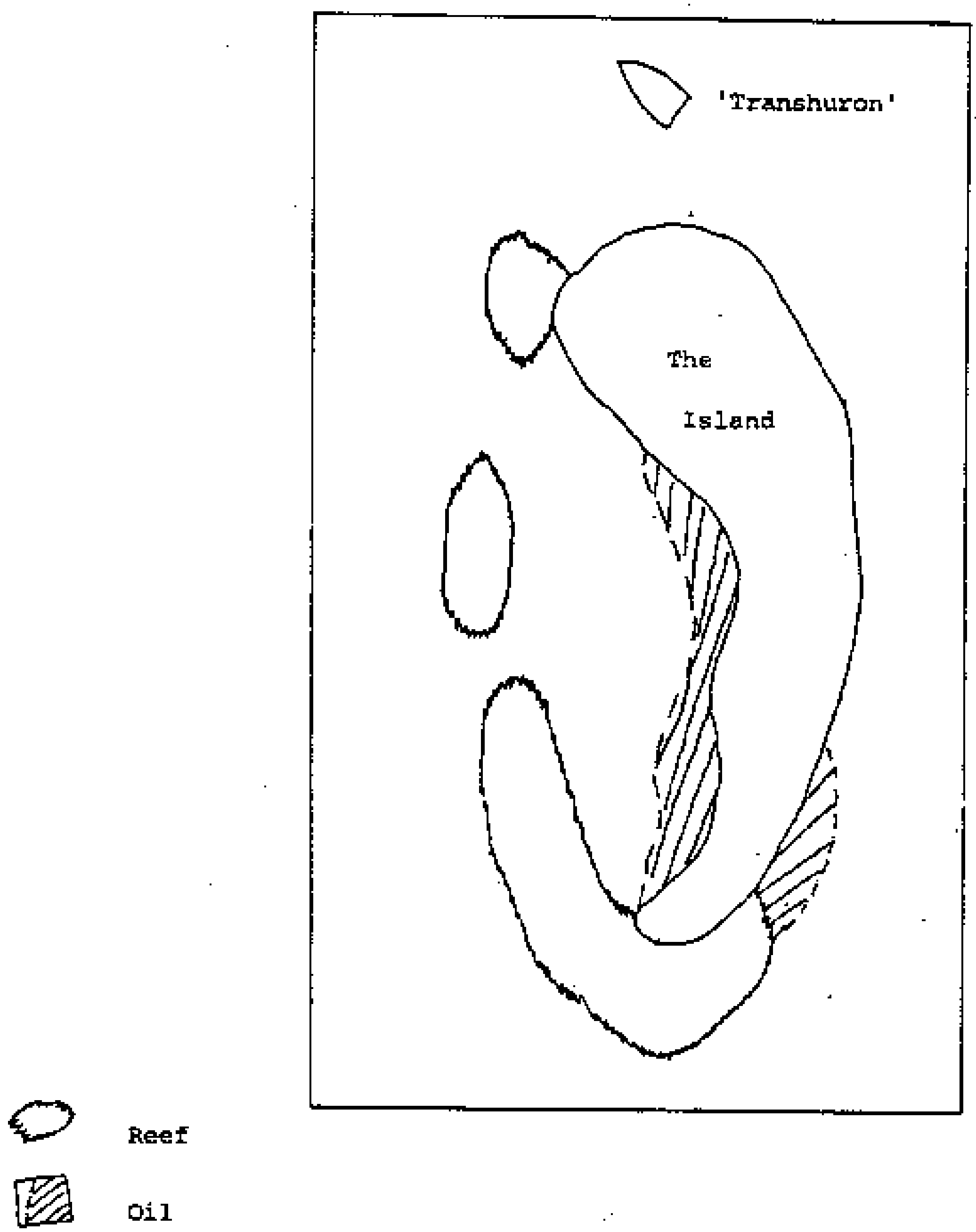
In Mauritius the degree of oil pollution has not yet become alarming but it is a threat since the breakup of two ships near Mauritius in 1972 and 1976. In 1978, a mass of tar balls appeared off the east coast of Mauritius carried in by the South Equatorial Current from a slick in the open ocean but no serious damage to flora or fauna was noticed. There is also some concern about the possible spills in the future near the site of a new oil refinery being set up on the west coast of Mauritius.

Some contamination of oil from the washing of oil tankers has been seen just off Colombo port off the west coast of Sri Lanka.

The Seychelles, although fairly distant from major tanker routes, experience heavy deposits of oil on the northern and western sides for example off Mahé Island. Aldabra, too, is subject to oil contamination and some fouling by tar balls has been noticed on the beaches of the islands. Although the Royal Fleet Auxiliary, Ennerdale, was grounded in the Seychelles area in 1970, offshore winds carried the 64 km slick seaward and no damage was noted to fauna or flora. The rupture of a submarine hose caused a spill in February 1979 but despite the oil blowing into the South East Island cove, wind and wave action dispersed it and again no damage to species was noted.

In Kilton, in the Laccadives, the tanker 'Transhuron' was grounded 700 km from the mainland island (see fig 25). On the southwest rocky shore, rock pools had floating oil in them. Dead fish, lobsters and crab were seen and fish and holothurian were found later on the beach. In the lagoon, plankton and seaweed were found dead. Due to the lack of oxygen and turbidity, both pelagic and benthic species were killed. The hermatypic corals were badly hit and fishing was temporarily banned. The east coast was contamination free but on the west coast tar-like materials were found 3-10 cm deep in the beach lagoon.

Figure 25: Sketch of site of oil spill from the tanker Transhuron and the affected area



9.4 The Asiatic Subcontinent

Many studies on the presence of oil have been carried out along the Indian coastline. Figure 26 and table 49 show the presence of oil slicks around the asiatic subcontinent. In June 1977, the M.T. Cosmos Pioneer broke up near Porbander on the Gujarat coast of northwest India. 10,000 tonnes of LDO (black oil) was released into the prevailing southwest monsoon. The 70-80 km/h winds caused the oil slick to change direction. The shape and pattern of the slick was dependent on the tide and current. 70% of the barnacle population was killed due to an oil coating and oil on the thallus of plants also caused damage to the flora. The oil became less viscous when warmed by the summer sun and ran over new areas contaminating more plants. The local fish were reported to have a diesel taint. 50% of the top and 25-30% of the sides of the rock were covered in oil with up to 4 cm-deep oil in rock pools. The lower and middle areas of the coast were not so badly affected due to being constantly washed by the waves.

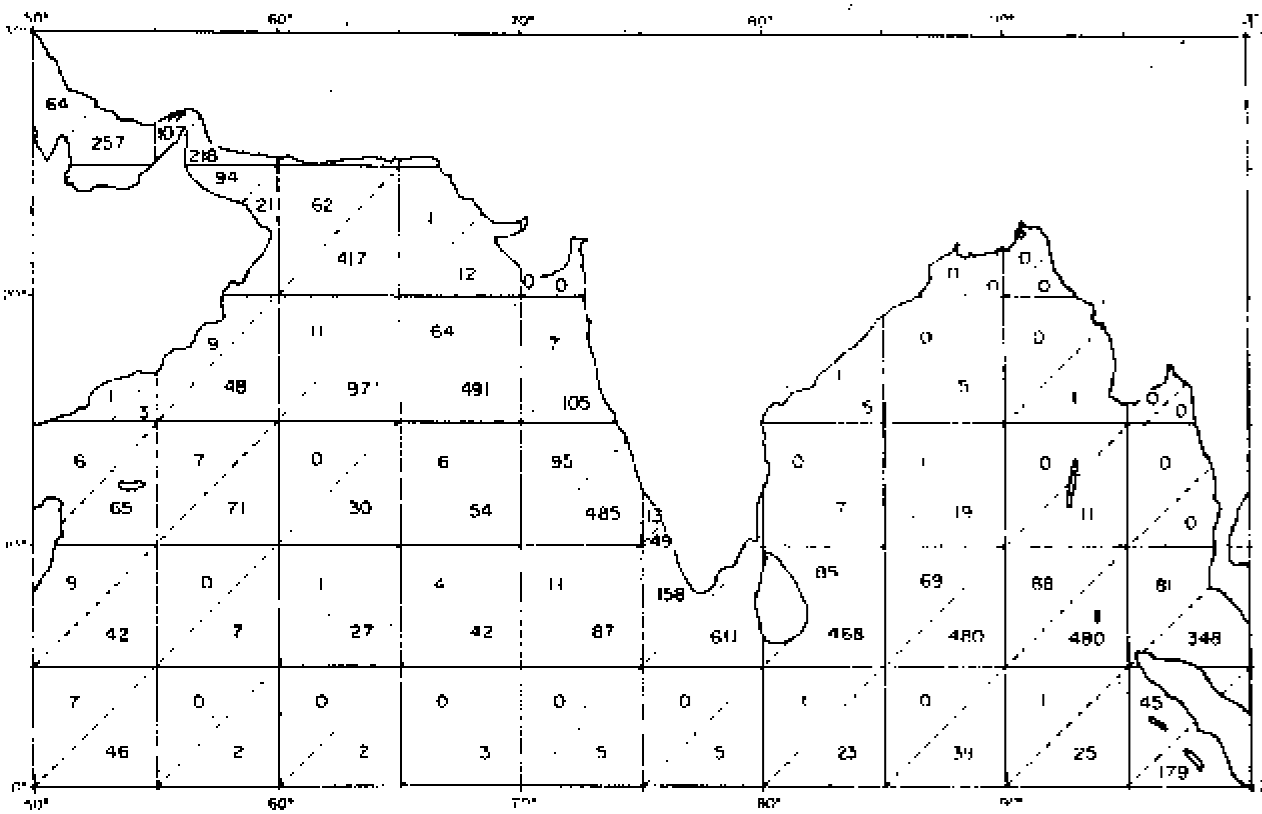
Tar-like materials, first seen in 1970 and increasing 3-5 times since 1971, are becoming a common site on beaches in India. Oil wastes and tar balls were found for 100 km along the Goa coast (see table 50). In March/April of 1970, a 3 year investigation of 24 beaches began, coinciding with the start of wind in the coastal direction. Tar balls 1-8 mm in diameter were found floating in the water. At low tide deposition is less and at low and mid-tide they are transitory as the tar balls tend to concentrate at high tide and supratide level. Sand and leaves found in the tar balls indicate that they have been on the coast and sometimes moved along the coast, for example from a mangrove region. Polychaete tubes and teritella shells show how far from the coast they can be, probably near coastal ship routes. Algae and goose barnacles growing on them suggest they have been around long enough to become a substratum (see for example table 51). In February 1972, contamination was seen to a 10 m depth. The increase in the Indian shipping fleet could account for the increasing concern over the problem: in 1947 there were 59 ships with a gross tonnage of 1.92 lakh tons and in 1975, 259 ships with a gross tonnage of 26.17 lakh tons.

The site of contamination is dependant on currents, wave action, configuration of the beach and the level of degradation. These materials probably arise from tanker washings and inter-tidal discharge when no accidents are reported and the quantity is too large to be accounted for by natural seepage. The east coast samples seem to be more weathered as indicated by the larger percentage of asphaltene that they contain.

Oils often affect organisms by coating the gills and hence limiting the oxygen exchange with the surface. Ingestion of volatile paraffin, olefin and aromatic hydrocarbons can cause functional alterations. Certain aromatic constituents of oil are carcinogenic. The majority of the toxic constituents are water soluble and volatile and are thus quickly lost unless the spill is continuous or extensive. On the Indian coast, of the 59 beaches studied only 2 were not contaminated with tar balls. On the west coast, deposition starts in May/June and on the east coast, in December/January with the start of the southwest and northeast monsoons respectively.

Off the coast of Goa, measurements were made of the concentration of petroleum hydrocarbons in water, plankton and sediment. Surface values in the south were found to be higher than those in the north ranging from 16.8 micrograms per litre to [illegible] micrograms per litre. [illegible]

Figure 26 : Reported sightings of oil slicks in the northern Indian Ocean



Observations on oil slicks and other floating pollutants every 5°-square in the Indian Ocean. Numbers at the lower right hand corners of the squares indicate the total occasions when oil slicks were sighted. Numbers at the top left hand corners indicate the occasions of the absence of oil slicks.

From: Present State of Oil Pollution in the Northern Indian Ocean, R. SEN GUPTA & T. W. KUREISHY (1981)

Table 49 : Concentrations of petroleum residues in the northern Indian Ocean

Arabian Sea

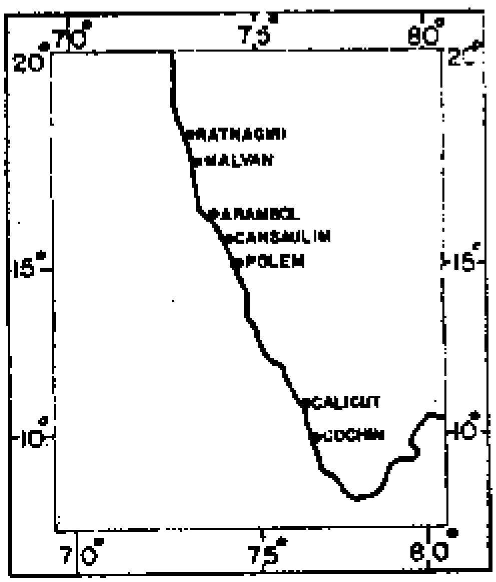
Depth (m)	Number of Observations	Mean (µg/kg)	Range (µg/kg)
0	39	35.5	0 - 395
10	34	30.6	3 - 217
20	15	29.4	2 - 112
Mean of all values 32.5			

Bay of Bengal

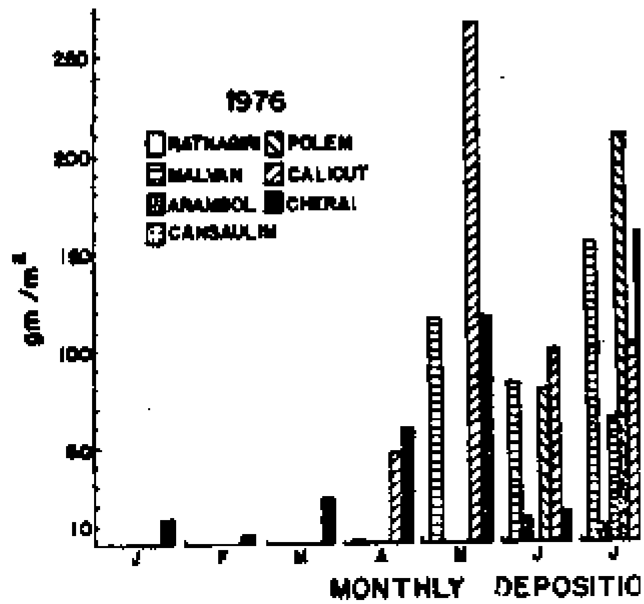
Depth (m)	Number of Observations	Mean (µg/kg)	Range (µg/kg)
0	46	29.1	4 - 229
10	43	25.1	2 - 147
20	43	17.6	1 - 75
Mean of all values 24.1			

From: Present State of Oil Pollution in the
North Indian Ocean
R. SEN GUPTA & T. W. KUREISHY (1981)

Table 50 : Deposition of some oil along the west coast of India



Map showing observation station positions along the west coast of India (IGOSS).



From: Deposition of Tar Balls (Oil Residue) on the Beaches Along the West Coast of India (1977)
V. K. DHARGALKAR, T. W. KUREISHY & M. V. BHANDANE

Table 51: Characteristics of some tar balls found along the Indian coast

Summary of the survey showing deposition at different tide levels

Sl. No.	Station	Type of beach	Deposition (g/m^2) at different tide levels				Remarks
			EHWS	HTL	MTL	LTL	
1	Porbander	Open sea	2.28	31.45	—	—	Wave action very high
2	Odedar	Open sea	230.50	90.00	15.25	—	Beach gradient very steep. Algal growth on the deposit.
3	Cosabara	Estuarine	750.01	2375.00	630.00	—	Plastic beads embedded in deposits
4	Veraval	Open sea	5.30	165.50	1.73	—	Goose barnacles (*Lepas* sp.) on coal tar lumps
5	Prabhas-puttam Somnath	Open Sea	6.25	250.90	3.24	0.72	Plastic beads and (*Lepas* sp.) found associated with deposition
6	Dumas Surat	Estuarine influence	1.05	15.25	—	—	Traces of oil-film in the intertidal region.

EHWS Extreme High Water of Springs MTL Mid Tide
HTL High Tide Level LTL Low Tide Level

Form: Oil Pollution Along Gujarat Coast and its Possible Source
S. N. DWIVEDI, B. N. DESAI, A. H. PARULEKAR & V. JOSANTO (1974)

The fringing mangroves of Goa are polluted by oil notably from ship, barge and trawler engines. Petrol, diesel and motor oil show significant adverse effects on growth and survival of seedlings. Avicennia species are more sensitive than the Rhizophora. Sonneratia species have been defoliated near Elephanta Island, Bombay as a result of frequent crude oil spillage. There is damage to both leaf and root, the latter probably by clogging of lenticels and air holes of prop roots. What starts as adverse growth is often ultimate death.

A survey of petroleum hydrocarbon concentrations in the shelf regions and adjacent waters of the west coast of India showed results seen in fig. 27. At the surface, values ranged from 0.12-2.44 mg/l. Off Bombay the results were amongst the highest as a result of the busy port and industrial area, and the proximity of the Arabian Sea tanker route and Bombay High, the site at which petroleum exploration is underway. Studies on probable oil patch movement from a hypothetical spill have been carried out at the Bombay High region see figs. 28 and 29 and table 52. These are an overall view and would be affected by any residual changes in current and wind but it is encouraging to find studies being made before any incident has occurred.

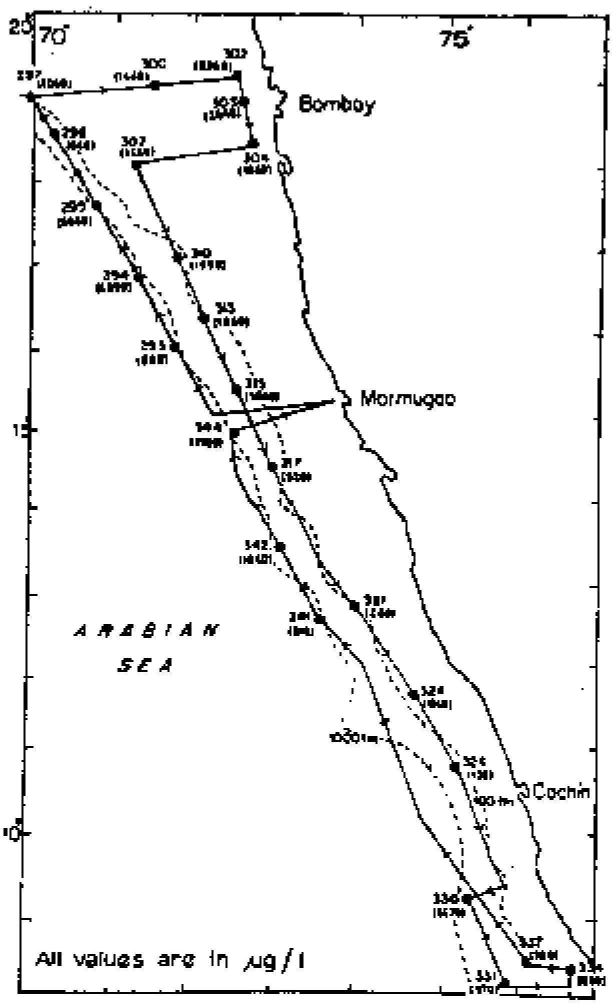
According to studies made in 1975-1976 on beaches in India, oil contamination has decreased by 75%, the reason given being the decreasing number of tankers going through the Arabian Sea since the opening of the Suez Canal. A lot of the oil pollution occurring along the beaches is a result of the southwest monsoon carrying spills to the Indian Coast from the Western Arabian Sea.

A petroleum complex with a refinery is situated on the East Coast of India at Manali, 25 km from Madras. After treatment of the wastes, most of the oil has been removed and as yet no damage to fauna or flora has been noted.

Polyurethane can be used for oil clean-up techniques and experiments in India have shown that a local brand can absorb up to 100% of it's own weight and be re-used once the oil has been squeezed out of it. Oil dispersents are more commonly used to attempt to disperse oil slicks but often they are found to be more toxic than the oil slick itself. Results of some laboratory expriments are shown table 53. Mortality usually occurred within 48 hours after which, survival indicated adaptation to the environment. With the mussel, excessive mucus secretion, failure to form new byssal threads and irritation of the epithelium was noticed. With the prawn, reversal was possible if the specimen was transferred back to clean water but it depended on the dispersant it had been in. Dispersants 2, 3 and 4 were more toxic than 1, although all of them were toxic to some extent the aromatic part being the most toxic. The dispersants were seen to be less toxic when mixed with oil and are most effective when used on a 1:1 ratio with the oil.

Although hydrocarbon degrading bacteria counts studied in the Eastern Indian Ocean indicate the presence of large numbers of them, no correlation was discovered between their presence and the presence of oil. Once the volatile fractions of the oil are lost it is in a dispersed state readily available for the bacteria to degrade. Degradation is a slow process and often tarry residue is seen on rocks, settling-birds and beaches before the bacteria have a chance to degrade the oil sufficiently. New "tar killer bacteria" are being investigated in Goa which are reputed to have an accelerated bio-degradation capability.

Figure 27 : Concentrations of petroleum hydrocarbons at 10 m depth along the w

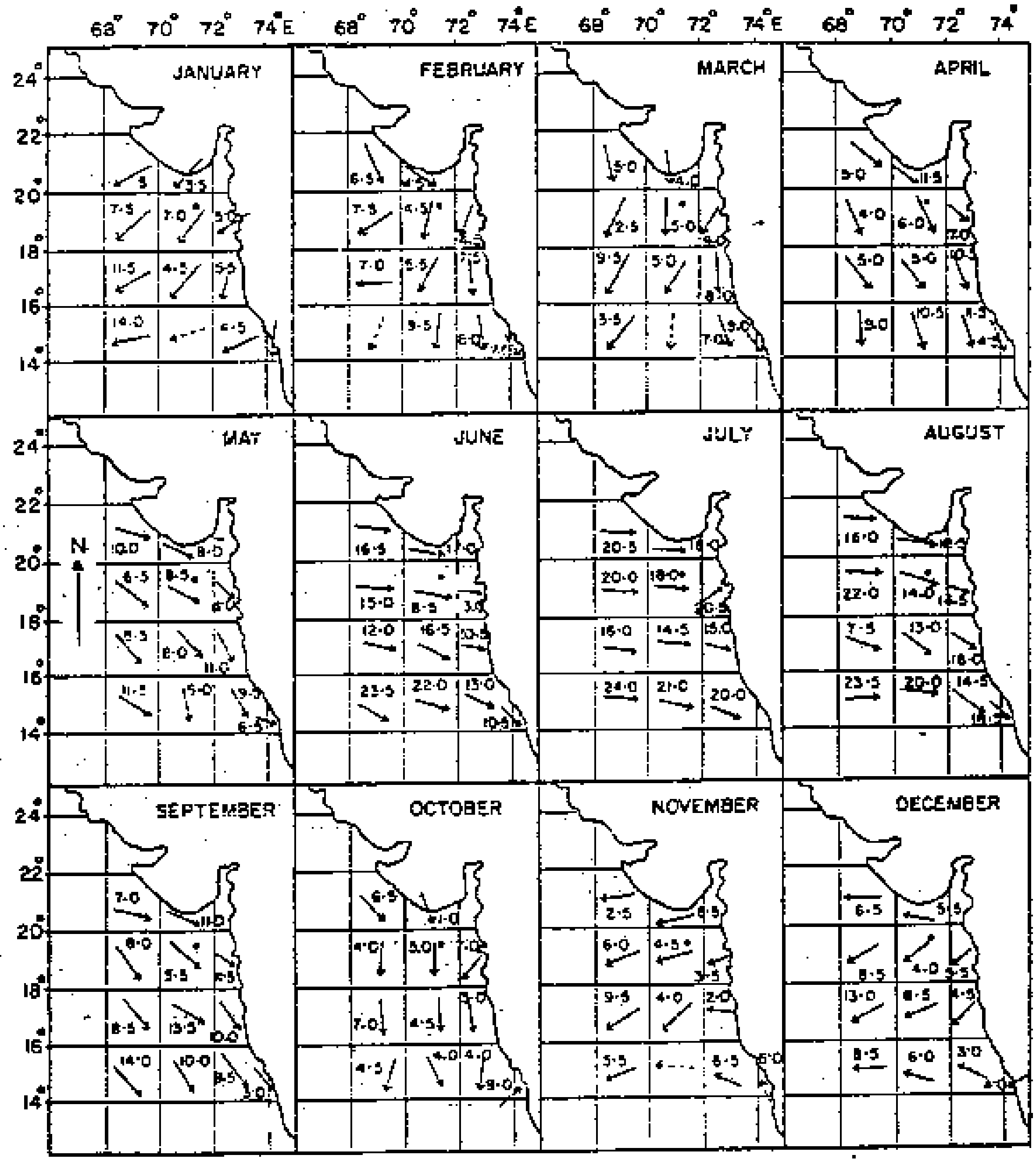


Network of Observation Stations [Numbers within brackets indicate concentrations of petroleum hydrocarbons in µg/litre at the surface]

Station Number
295
297
303
310
315
321
326
330
334
337
344

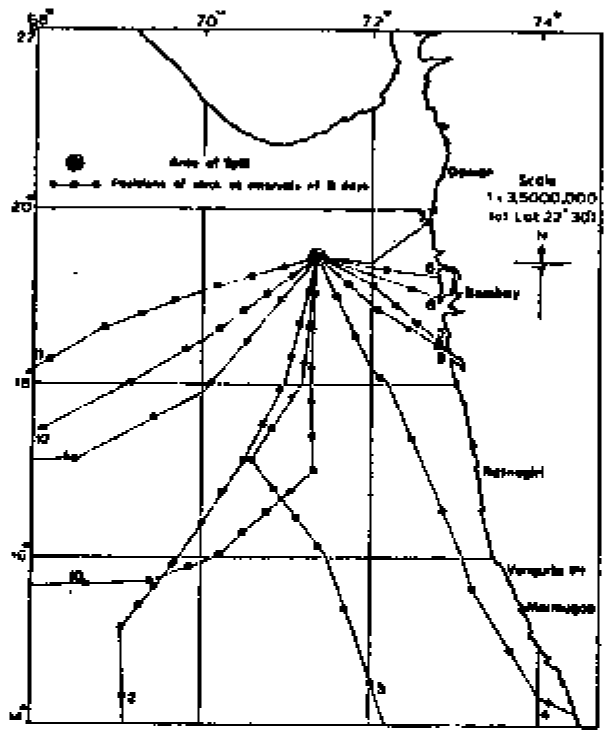
From: A Survey of Petroleu
in the Shelf Region
West Coast of India
R. SEN GUPTA, S. P.

Figure 28: Hypothetical movements of an oil patch off the west coast of India



— Slick drift directions during January-December [Speeds of slick drift in nautical miles/day are indicated along the arrows. Interpolated directions are shown by broken arrows]

Figure 29 : Probable movements of an oil patch



— Trajectories of oil spills occurring in different months of the year [1-12 represent the calendar months, January to December]

Table 52 : Time taken for oil patch to reach and affect the coastlin

Time of Spill	Coastline threatened as a result of spill	Time Interval Between Spill and Oil Reaching the Shore
Early March	No threat	-
Mid March	Far South of Bombay	105 days
Early April	Around Karwar	45 "
Mid April	Around Ratnagiri	35 "
Early May	70-80 km South of Bombay	22 "
Early June	Around Bombay	10 "
Early July	70-80 km North of Bombay	4½ "
Early August	Around Bombay	7 "
Early September	70-90 km South of Bombay	22 "
Mid September	No threat	-

From: Probable Movements of a Hypothetical Oil Patch
from the Bombay High Region
A. D. GOUVEIA & P. G. KURUP (1977)

Tables 53a,53b,54 : Effects of oil dispersants on crab and mussel

Characteristic	Disp. 1	Disp. 2	Disp. 3	Disp. 4
Appearance	Light yellow	Yellow and slightly turbid	Light yellow clear liquid	Light yellow clear liquid
Viscosity	Non-viscous	Non-viscous	Highly viscous	Viscous but less than disp. 3
Solubility	Insoluble in water; partly soluble in alcohol but completely soluble in acetone	Insoluble in water; partly soluble in alcohol but completely soluble in acetone	Soluble in water; alcohol and acetone	Soluble in water, alcohol and acetone
pH	6.5 - 7.5	7.95	5.3	5.3

LC 50 values in green mussels (*Mytilus viridis*) after 24, 48 and 96 hours exposure of different dispersants.

Dispersant	24 hr LC 50 ppm	48 hr LC 50 ppm	96 hr LC 50 ppm
1	> 10	> 10	> 10
2	0.16	0.09	0.09
3	0.085	0.079	0.079
4	0.09	0.08	0.08

Concentration of dispersants at which 0%, 50% and 100% mortality was observed in *Mytilus viridis* after 48 hours of exposure.

Dispersant	LC 0% ppm	LC 50% ppm	LC 100% ppm
1	> 10	> 10	> 10
2	0.025	0.09	0.16
3	0.04	0.079	0.1
4	0.04	0.08	0.1

From: Toxicity Tests of Oil Dispersants on Some Marine Animals
X. N. VERLENCAR, N. B. BHOSLE & A. H. PARULEKAR (1977)

In Pakistan, the Manora Channel and backwaters have been subject to oil contamination particularly in the lower harbour areas and eastern backwaters. Over 12,000 tonnes of oil was discharged into Karachi Port in 1980. High tide carries oil-contaminated waters up Chinna Creek into the eastern backwaters and hence increases the area affected by the oil. The basin is reported nearly black with oil and the degradation products thereof. The incoming coastal water mixes not only with the oil but also with the outfall waters of Lyari River and returns these polluted waters to the coastal areas.

10.0 POLLUTION FROM DOMESTIC AND MUNICIPAL SOURCES

10.1 Introduction

In the littoral states of the Indian Ocean, most of the effluent from municipal and domestic sources is released untreated into natural waters. There are few sewage treatment plants in the region and where they are present they are often overloaded and in bad working order. Stabilization (oxidation) ponds are an ideal way of treating sewage as the climatic conditions of the area are suitable for this form of treatment. Furthermore, they require little trained personnel or finance as it is a natural treatment method. The 'clean' water obtained at the end of the lagooning system can be used for controlled irrigation. However, although it is frequently planned th have these ponds, the plans are not always implemented. Most of the contamination from these sources is found in the vicinity of coastal towns. Many of the countries in the area depend on the tourist industry for their income and it is therfore important that the coastline and beaches remain clean. The presence of faecal bacteria is used as an indicator of sewage pollution.

Presence of faecal coliform (Escherichia coli) and faecal streptococci (Streptococcus faecaelis) in water and the sediment is a hazard to health as these organisms get ingested into the body of filter feeder organisms, bottom dwelling fish, prawns and bivalves and make them unfit for human consumption. They arise from human and non-human faecal matter and constitute an 'indicator bacteria' group. The streptococcus distribution of E. coli is more random but with slightly higher counts in water than in the sand.

10.2 East Africa

There are 150 sewage treatment plants in Kenya but as population and industrial growth increases these are becoming insufficient. Kenya has a large coastal tourist industry and although all the hotels have septic tanks or small treatment plants the increase in their capacity has not been commensurate with the expansion of the hotels. Septic tanks and soak pits are found on the mainland but most of the population uses pit latrines. The most serious domestic sewage problems are found at Nakuru, Mombasa and Nairobi. The Nairobi city sewage treatment plant is overloaded and partially treated effluent enters the Nairobi River which is a tributary of the Athi River. The 25 year-old sewage system in Mombasa discharges 1,200,000 gallons per day of sewage into the Indian Ocean, 80% being primary treated and 20% secondary treated. The wastes going into Mombasa Harbour are neutralized naturally to some extent.

In Tanzania, wastes from Dar es Salaam, Tanga, Zanzibar, Kilwa, Lindi, Pemba, Mafia, Bagamayo and Mtwara are all discharged directly into the sea and harbour without treatment. Kurasini Creek also dumps sewage at two adjacent points to Dar es Salaam Harbour and hence the area is beginning to show signs of pollution. The Msimbazi Valley is heavily polluted and is a hazard to the health of the residents of Dar es Salaam. Sewage and refuse treatment systems are practically non-existant and often get blocked where they do exist. Septic tanks are widely used but these often get flooded in the rainy season. In Somali, treatment is restricted to the use of septic tanks but is otherwise not apparent and solid waste is dumped anywhere.

The sewage system in Mozambique covers 10% of the population and the rest use septic tanks or pit latrines. Pit latrines are not very effective in the North as the water table is high and they become a source of pollution as in Beira. Both Maputo and Beira have 10 untreated oulets into the sea. Solid waste disposal is good in Maputo but the beaches are polluted by thousands of tourists and townspeople. Effluent from the central hospital is delivered to the sewers without chlorination. A sewage treatment plant is under planning in Lourenço Marques Bay (outlet E2 in figs. 30, 31a, 31b & 31c). The inner bay values are much higher than the outer bay with CN and PC having intermediate values due to sewage influx and clean water tidally entering the bay. C7 acts as a dilution pool between inner and outer bays. 24% of values inside the inner bay and 36% at station E2 are greater than 2 mg/l, the point at which eutrophication is considered to begin. The more sewage there is the more eutrophication will occur and in the long run, the bay's production will decrease due to anaerobic conditions of the bottom layers.

10.3 The Islands

Most of the population in Mauritius is concentrated in the industrial area at Port Louis and Plaine Welhems hence major sewer systems discharge about 500l/sec (1974) into a lagoon on the west coast of the island near the harbour. There is rapid dispersal due to high wave action but seaweeds proliferate and the decay of these dense mats causes foul odours. This excessive growth along with siltation has resulted in damage to benthic and coral ecosystems. Faecal coliform contamination is seen on the west coast but is at a minimal level as is the pollution of the rivers.

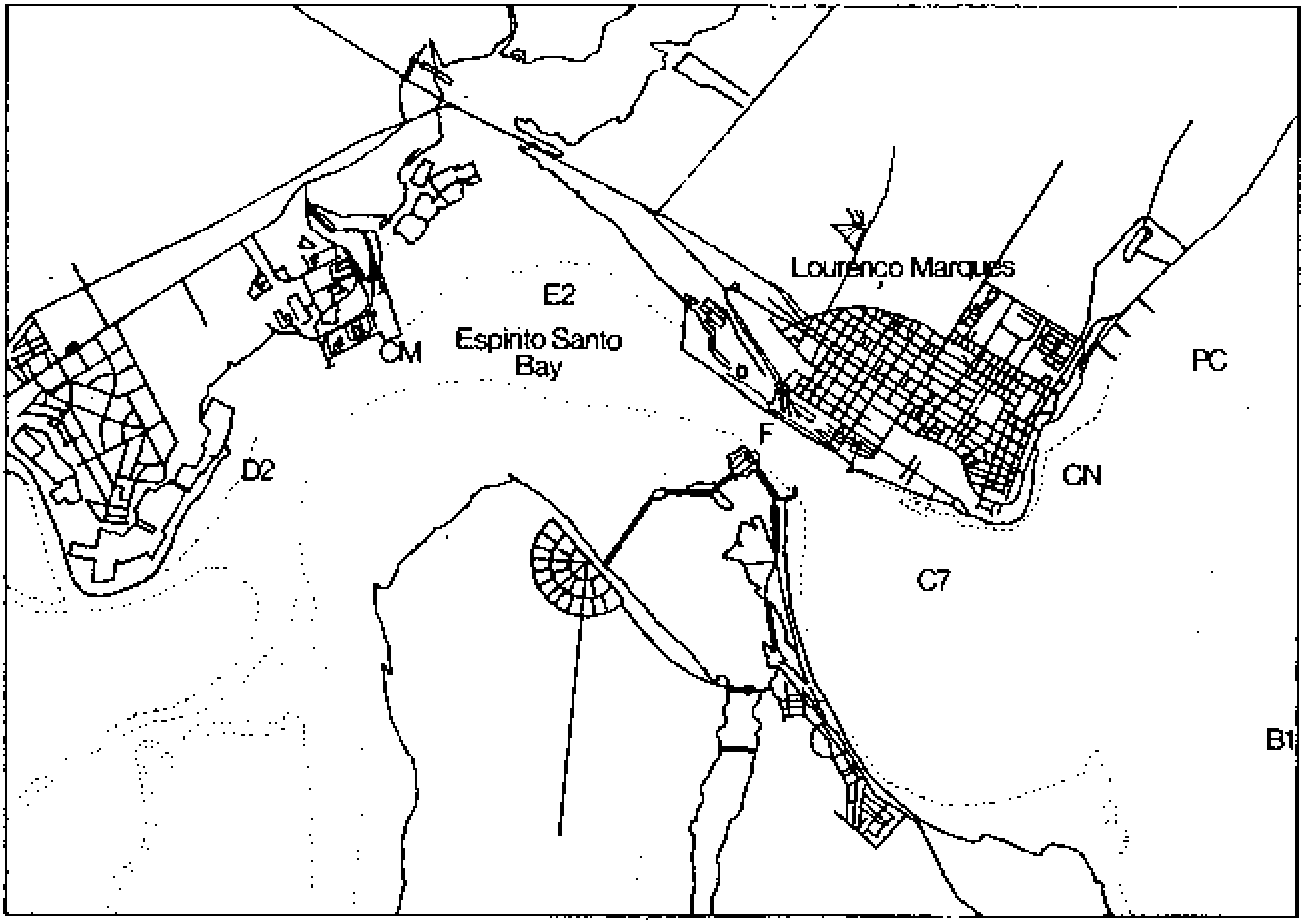
In Sri Lanka, raw sewage is dumped directly from Colombo into the Keleni River without treatment and flows directly into the sea.

In Madagascar, sewage treatment is practically non-existant and municipal wastes from Tananrive and Nosy Bé are merely dumped in the sea contribute to eutrophication in the region. Offshore latrines on stilts at sea or on the river are common and the beaches and coast are polluted thereby jeopardizing the tourist centre at Nosy Bé.

In the Seychelles, sewage, though mostly untreated, does not appear to have any adverse effects. There is some incidental pollution, for example through the effects of blasting to lay a new pipeline. Dumping of solid wastes at sea is controlled and initially was limited by a sea wall. But now, some dumping is done beyond the wall. Septic tanks and soakage pits are in use although they are now

Figure 30 :: Geography of Lourenco Marques Bay, Mozambique

Figure 31a : Total dissolved phosphorous present



Espirito Santo Bay, town and port layout and the sampling stations network.

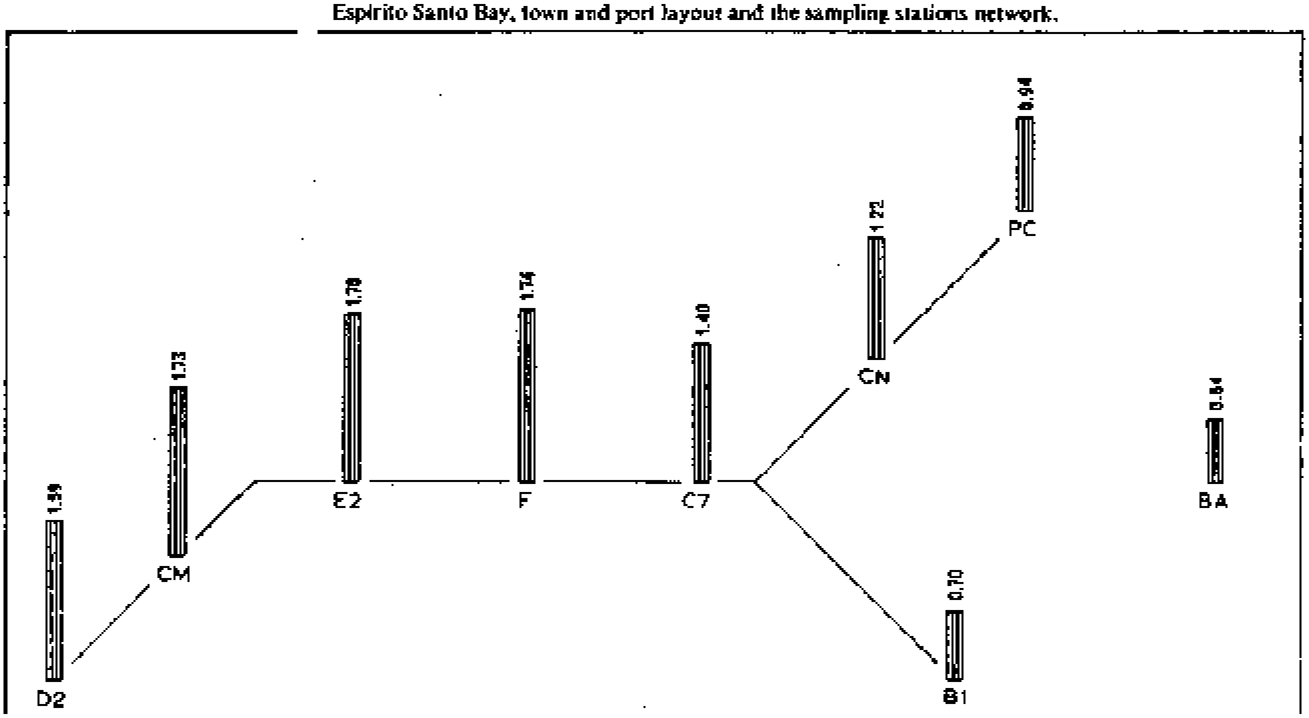
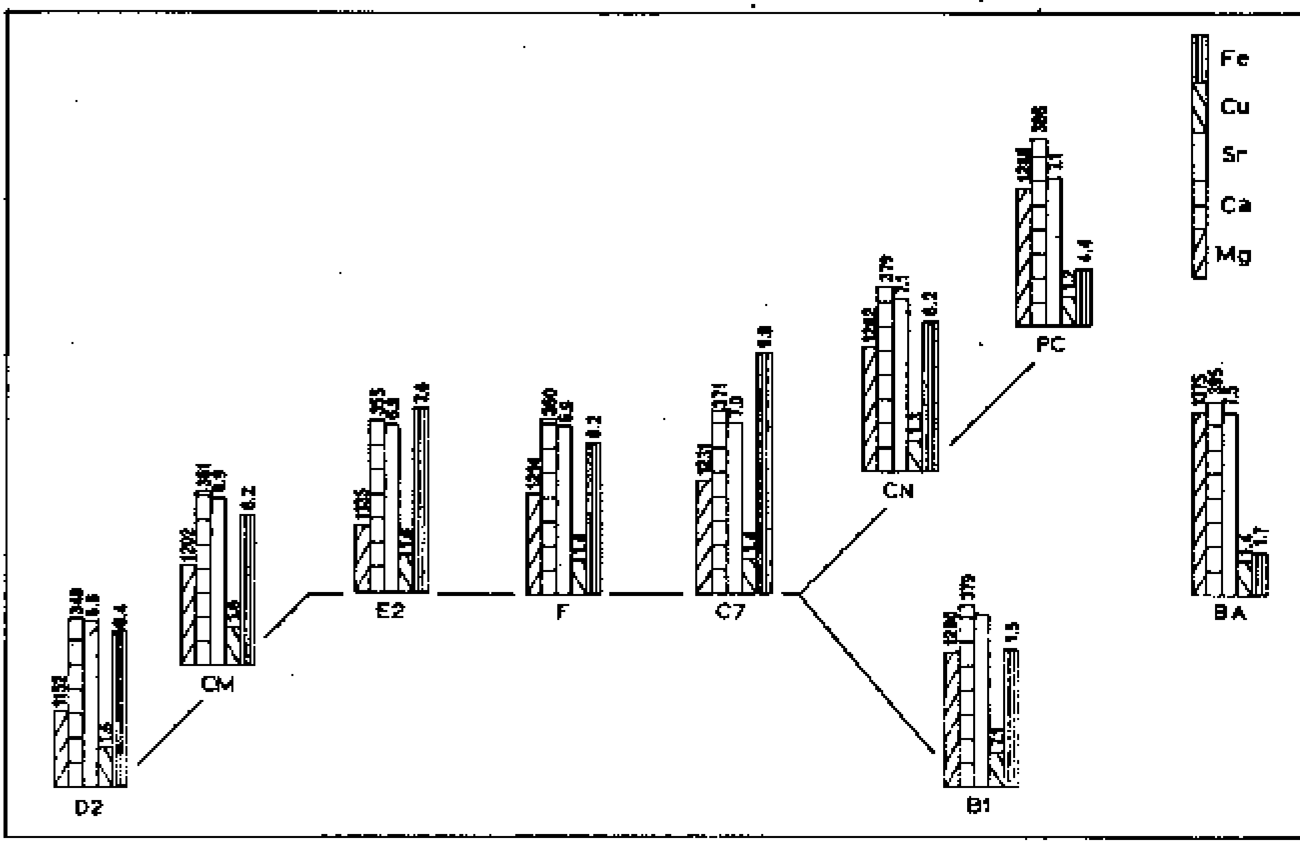
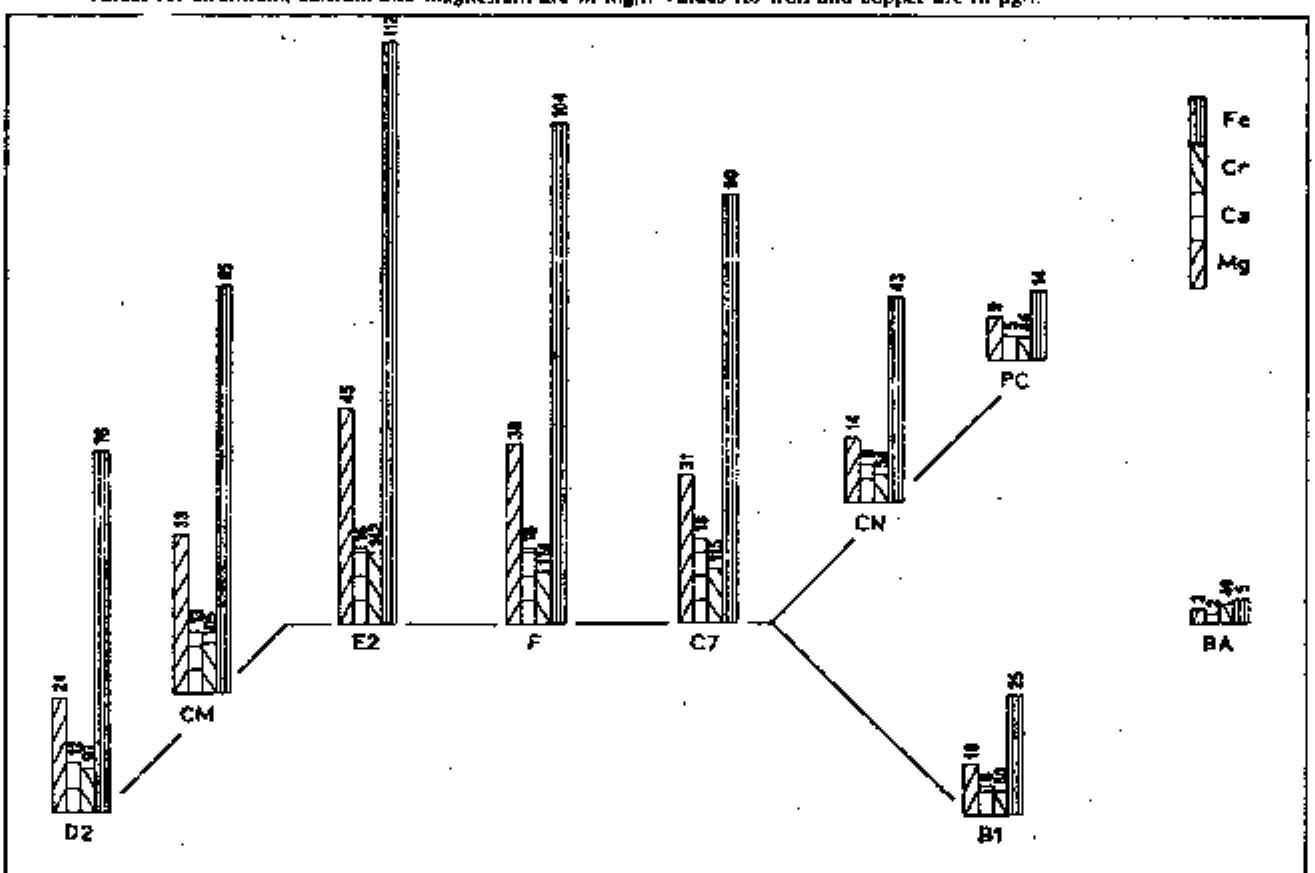


Figure 31b : Metal concentrations in Lourenco Marques Bay
Figure 31c : Suspended solid composition in the Bay



Average value recorded at each station, over the sampling period, for dissolved iron, copper, strontium, calcium and magnesium. Values for strontium, calcium and magnesium are in mg/l. Values for iron and copper are in µg/l.



10.4 The East Asiatic Subcontinent

Discs of Ulva fasciata delile were used to study the algal growth in the waters of Visakhapatnam Harbour and gave results seen in figs. 32 a and b. The Southern Lighter Channel has high concentrations of untreated sewage and is toxic to the growth and survival of Ulva fasciata. Although the Northern and Western arms are polluted, some increase in growth is noted due to the increased presence of nutrients and the dilution of pollution by tidal currents. High BOD and COD values as well as high phosphorous and nitrogen values are characteristic of the domestic sewage wastes and indicate a high incidence of organic pollution.

The fact that Visakhapatnam Harbour is polluted is emphasized by the presence of Capitella capitata found in large numbers (50,000/m2) in the north, west and northwest arms of the harbour. C. capitata satisfies most of the criteria for an indicator species. They are high in density, other species are excluded, they are scavengers and they tolerate low oxygen values. Visakhapatnam is subject to both domestic and industrial pollution in varying degrees. Maximum numbers of fauna are seen in the pollution free mangrove swamps from December to March when salinity and temperature values are fairly stable. Minimum numbers are found in the northwestern arm which is subject to heavy industrial pollution. Thermal blue-green algae eg Nostoc are found in the thermal effluent of the oil refinery and fertiliser plants. The Southern Lighter Channel is subject to heavy pollution but still has a fair amount of fauna.

10.5 The West Asiatic Subcontinent

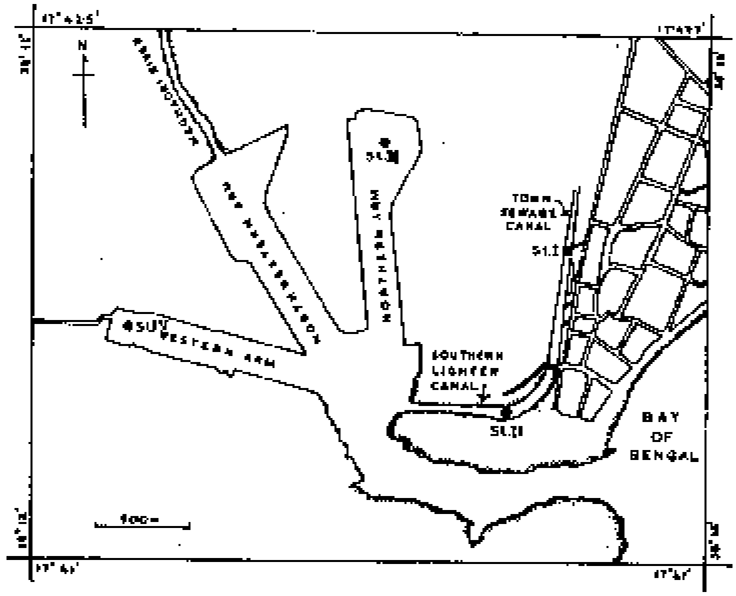
The Cochin Backwater area is also substantially polluted by sewage. The effects of the outflow are dependent on the area they discharge at and the season in which it occurs. In the peak of the southwest monsoon, salinity is < 1‰. A large tidal flow and the current effect reduce the oxygen deficiency and temperatures lie between 26.1 and 31.2°C at the surface and 24.6 and 31.1°C at the bottom. At low tide, oxygen values drop to < 0.05 ml/l due to the high level of organic matter decomposing in the area. The lowest oxygen values are found at the sewage canal outflow points. The highest H_2S values are 3.41 mg/l. There is some level of pollution at points 1,2 and 7 point 2 being the most depleted of fauna. Polychaete are fairly tolerant to sewage and are found commonly in the area. However, crustacea and molluscs are few in number or absent in the marginal and polluted regions.

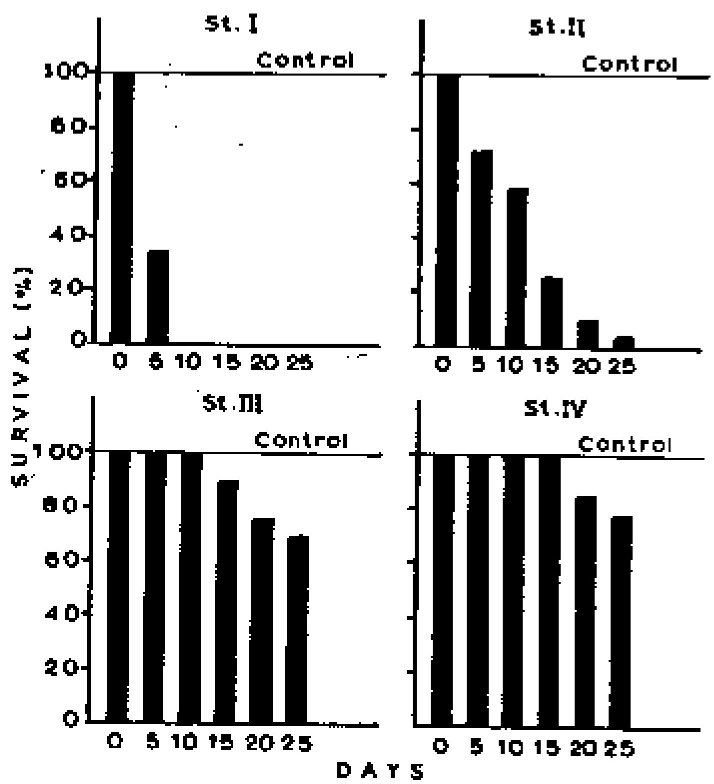
During September 1974 - August 1975, 6 "dirty" stations and 1 clean station were studied. High temperatures and rapid decomposition of organic waste during the monsoon accelerated the pollution effect. DOC values varied with the sewage input but BOD values varied with the stations and the tide. The oxygen consumption of bottom waters was 12-13 times higher in the polluted station than at the barmouth. BOD increased with the start of the premonsoon and decreased with the monsoon in polluted areas.

Decaying plant and animal matter contribute to pollution by increasing the suspended load in water and increasing H_2S levels and BOD. This applies particularly with the African weed Salvinia molesta which are washed ashore in monsoon months and then proceed to decay through the post monsoon period. During late post-monsoon and pre-monsoon months, the weed pollution disappears. The fern Salvinia auriculata is also noted for this blanketing effect. This forms an important source of primary nutrition but also creates

Figure 32a : Geography of Visakhapatnam Harbour with selected stations

Figure 32b : Survival of Ulva fasciata in Visakhapatnam Harbour





At the bottom of the polluted station, during low tide of the premonsoon, high sulphide concentrations were noted to a maximum value of 4.92 mg/l. Faunal composition was also noted and was the least affected at station 3 (see fig. 33). Stations 1 and 2 were the most polluted and had the least amount of fauna. Polycheate, a pollution tolerant group, were found in all stations and were dominant in the polluted zone as they had few competitors. Tidal conditions and monsoonal inflow prevent the area from becoming polluted to the stage where polycheata cannot survive (see table 54).

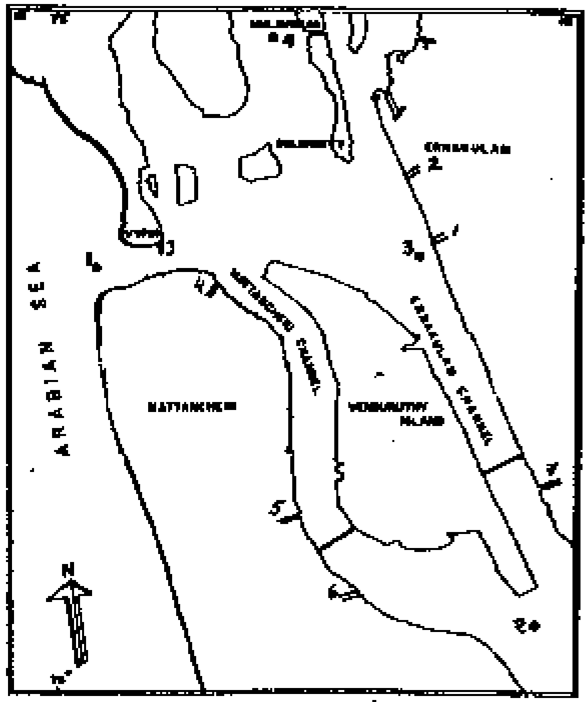
The Cochin Beach is among one of the most contaminated. Incidence of faecal coliform and faecal streptococci as well as faecal coliform and faecal streptococci ratios for this area may be seen in tables 55 and 56. With bacterial counts of more than 100,000 colonies per gram sand the health risk at Cochin beach is high. High BOD5 values recorded at Cochin correspond with the high bacterial counts as do the high H_2S values. Cherai Beach in particular, along with other beaches, has faecal contamination. At Cherai, this contamination is considered to be of non-human origin (see table 57). In general, the beaches appear to be contaminated to a greater degree in the monsoon and post monsoon months at which time the salinity is lower and the conditions more conducive to bacterial survival but occasional high values have also been noted in pre-monsoon months. Usually, during late post-monsoon and pre-monsoon months, faecal pollution is at a minimum or even absent. At monsoon times the cuurents stir up the mud substratum and the sediment load is high. This too is thought to correlate with the numbers of indicator bacteria. Ezhumala beach on the Kerala coast has received some tar and faecal pollution but it is negligeable and sporadic and the beach is considered safe and clean. On the same stretch of coast, species of Salmonella have been isolated in at least five beaches creating again, a health hazard, however, positive occurrence seems to be restricted to the sand and none appeared in the water. Many of the beaches along Kerala had faecal bacteria present as seen in table 58.

In Jaleshwara reef at Veraval, Enteromorpha prolifera variation tubulosa has formed a luxuriant growth due to sewage outflow. From August-October 1966, the algae increased in growth. They were found to be richer in protein, soluble and insoluble ash, sodium, calcium, potassium, magnesium, chloride and sulphate and poorer in carbohydrates than those in non-polluted areas (see table 59).

In Goa, higher concentrations of Foraminifera are found in the Zuari estuary (3600-13100 per sample) than in the Mandovi (700-6400) specimens per sample). In the lower reaches of both estuaries, numbers are lower due to organic pollution effects. Sewage from the town of Panjim enters the Mandovi estuary and results in high organic carbon content. This leads to a lower species diversity with a dominance by the Ammonia beccarii group.

In Bombay, about 2000 million m3 of sewage are discharged along the beaches resulting in considerable oxygen depletion in the nearshore waters.

Figure 33 : Sampling sites in the Cochin Backwaters



—Station location map

Table 54 : Distribution of some bottom fauna in the Cochin Backwaters

— DISTRIBUTION OF BOTTOM FAUNA AT SEVEN FIXED STATIONS

Station	Number of observations	Polychaeta			Crustacea			Mollusca		
		Minimum	Maximum	Mean	Minimum	Maximum	Mean	Minimum	Maximum	Mean
1	5	120	2240	620	0	300	60	0	60	12
2	5	20	1980	440	0	80	16	20	40	16
3	5	100	2200	980	1100	10560	8364	20	240	56
4	5	60	4500	1052	0	40	16	0	60	12
5	5	80	6520	2356	20	120	32	20	40	16
6	5	120	1720	644	60	100	32	0	0	0
7	5	940	2800	1238	20	240	88	20	120	56

From: Studies on Organic Carbon, Nitrogen and Phosphorus in Sediments of the Cochin Backwater, V. N. SANKARANARAYANAN & S. D. PANAMPUNNAYIL (1979)

Table 55 : Incidence of coliforms E. coli and S. faecalis in Cochin backwaters

(Results are expressed per ml for water samples (W) and per gram for mud samples (M))

Month	Coliforms (× 10^3)		*E. coli*		*S. faecalis*		Coliforms (× 10^3)		*E. coli*		*S. faecalis*		Coliforms (× 10^3)		*E. coli*		*S. faecalis*	
	W	M	W	M	W	M	W	M	W	M	W	M	W	M	W	M	W	M
			Station 1						Station 2						Station 3			
June '75	210	11	94	19	8	9	118	16	33	10	3	nil	120	9	21	1	2	nil
July '75	42	5	32	6	1	6	22	3	nil	nil	nil	2	17	3	9	4	1	2
Aug. '75	8	5	10	4	6	nil	32	12	2	nil	nil	3	11	16	2	7	1	2
Sept. '75	12	24	4	6	3	6	13	18	5	8	2	3	28	20	4	5	2	3
Oct. '75	20	28	37	nil	3	2	24	20	46	nil	4	3	26	31	7	nil	2	3
Nov. '75	124	68	22	10	22	19	62	12	12	1	12	11	140	69	14	9	16	17
Dec. '75	210	122	41	22	16	21	110	28	8	8	10	13	118	89	12	5	7	11
Jan. '76	96	48	12	16	13	26	42	20	8	3	3	11	78	42	11	9	8	17
Feb. '76	260	136	36	10	22	40	112	21	12	6	10	30	218	39	12	8	12	20
March '76	128	39	17	14	18	28	58	22	8	4	8	12	90	30	13	5	10	21
April '76	112	36	16	17	14	18	75	48	61	10	8	7	93	42	7	5	12	18
May '76	131	72	14	nil	20	20	118	28	5	nil	10	22	118	74	nil	nil	nil	nil
			Station 4						Station 5						Station 6			
June '75	172	10	20	2	2	nil	235	11	30	4	nil	nil	108	10	28	nil	nil	nil
July '75	13	9	4	3	1	2	7	8	nil	nil	1	nil	10	12	nil	3	nil	nil
Aug. '75	23	9	3	10	3	2	5	12	3	4	nil	4	8	11	nil	1	nil	3
Sept. '75	20	12	4	5	3	2	10	11	2	3	1	3	15	8	3	5	1	3
Oct. '75	21	11	33	nil	3	1	8	12	66	nil	1	4	12	10	34	nil	1	3
Nov. '75	73	22	8	4	15	17	51	22	8	2	6	13	14	14	1	1	6	8
Dec. '75	120	61	9	7	9	11	20	132	10	12	8	10	70	15	7	12	2	3
Jan. '76	71	35	8	11	51	15	92	30	6	9	5	17	24	21	2	8	2	8
Feb. '76	205	37	14	5	31	30	104	31	10	5	12	25	91	24	8	3	8	20
March '76	110	72	15	8	16	13	123	55	11	9	14	22	81	23	18	8	8	12
April '76	82	63	13	7	14	15	102	53	10	15	11	8	62	38	9	10	9	7
May '76	102	88	5	4	22	20	82	72	nil	nil	nil	nil	73	36	nil	nil	nil	nil

From: Pollution in Cochin Backwaters With Reference to Indicator Bacteria
P. S. GORE, O. RAVEENDRAN & R. V. UNNITHAN (1979)

Table 56 : Faecal coliform and faecal streptococci ratio of water and mud in Cochin backwaters from June 1975 to May 1976

Month	Station 1		Station 2		Station 3		Station 4		Station 5		Station 6	
	W	M	W	M	W	M	W	M	W	M	W	M
1975												
June	12.2^{a}	2.1^{a}	11^{a}	10^{a}	10.5^{a}	1^{b}	10^{a}	2^{a}	30^{a}	4^{a}	28^{a}	0
July	32^{a}	1^{b}	—	0	1^{b}	2^{b}	4^{a}	1.5^{b}	0	—	—	3^{a}
Aug.	1.66^{b}	4^{a}	2^{a}	0	1^{b}	3.5^{a}	1^{b}	5^{a}	2^{a}	1^{b}	—	0.33^{b}
Sept.	1.33^{b}	1^{b}	2.5^{a}	2.6^{a}	2^{a}	1.6^{b}	1.33^{b}	2.5^{a}	2^{a}	1^{b}	3^{a}	1.6^{b}
Oct.	12.3^{b}	0	11.5^{a}	0	3.5^{a}	0	11^{a}	0	66^{a}	0	34^{a}	0
Nov.	1^{b}	0.5^{b}	1^{b}	0.09^{b}	0.8^{b}	0.5^{b}	11^{a}	0	2^{a}	1^{b}	3^{a}	1.66^{b}
Dec.	2.56^{a}	1.04^{b}	0.8^{b}	0.06^{b}	1.7^{b}	0.45^{b}	1^{b}	0.63^{b}	1.2^{b}	1.7^{b}	3.5^{a}	4^{a}
1976												
Jan.	1^{b}	0.6^{b}	2.6^{a}	0.27^{b}	1.37^{b}	0.5^{b}	0.7^{b}	0.73^{b}	1.2^{b}	0.52^{b}	1^{b}	1^{b}
Feb.	1.6^{b}	0.25^{b}	1.2^{b}	0.2^{b}	1^{b}	0.4^{b}	1.3^{b}	0.16^{b}	0.83^{b}	0.2^{b}	1^{b}	0.15^{b}
Mar.	0.94^{b}	0.5^{b}	1.0^{b}	0.3^{b}	1.1^{b}	0.14^{b}	0.93^{b}	0.6^{b}	0.7^{b}	0.8^{b}	1.5^{b}	0.66^{b}
Apr.	1.14^{b}	0.8^{b}	1.37^{b}	1.4^{b}	0.57^{b}	0.27^{b}	0.9^{b}	0.47^{b}	0.9^{b}	1.8^{b}	1^{b}	1.4^{b}
May	0.7^{b}	0.1^{b}	0.6^{b}	0	—	—	0.4^{b}	0.2^{b}	—	—	—	—

a= human and b= non-human

From: Pollution in Cochin Backwaters with Reference to Indicator Bacteria
P. S. GORE, O. RAVEENDRAN & V. UNNITHAN (1979)

Table 57 : Occurence of different bacteria in Cherai Beach

— OCCURRENCE OF DIFFERENT BACTERIA IN CHERAI BEACH DURING APRIL-DECEMBER 1976

(Values are average of 3 observations)

	Sand counts/g				Water count/ml			
	Coliforms	*E. coli*	Faecal streptococci	FC/FS	Coliforms	*E. coli*	Faecal streptococci	FC/FS
Apr.	7	2	5	0·4*	3	1	2	0·5*
May	11	3	8	0·3*	7	nil	2	—
June	17	4	9	0·4*	15	2	3	0·6*
July	17	6	9	0·6*	6	2	1	1*
Aug.	19	8	4	2†	11	nil	1	—
Sept.	19	4	3	1·33†	11	nil	1	—
Oct.	18	6	3	2†	18	3	nil	3†
Nov.	13	2	1	1*	10	nil	1	—
Dec.	7	1	2	0·5*	16	nil	nil	—

*Nonhuman faecal pollution.
†Human faecal pollution.

Average Hydrographical Parameters

— AVERAGE HYDROGRAPHICAL PARAMETERS

Month	Temp. (°C)		Dissolved oxygen (ml/litre)	Salinity ‰	*p*H
	Water	Sand			
Apr.	30·3	36	5·16	32·43	7·4
May	30·6	37·8	6·61	33	7·3
June	30·2	36	5·88	31·8	>7
July	27·5	38·2	6	24·1	>7
Aug.	28·3	37·2	6·15	25·4	7·5
Sept	30·1	40	7·03	30·81	7·5
Oct.	29·5	32·3	6·6	31·09	7·4
Nov.	29·7	31·7	6·73	32·03	7·5
Dec.	30·5	37·6	6·34	28·6	7·4

Table 5B : Occurence of salmonella in some beaches of Kerala

Month	Beach	Faecal matter HT	Faecal matter MT	Faecal matter LT	*Salmonella*
July 1978	Vizhinjam	+++	++	++	•
	Kovalam	—	—	—	—
	Shankumugham	—	—	—	—
	Quilon	—	—	+	—
	Neendakara	+++	++	++	•
	Alleppey	++	+	++	—
August 1978	Calicut	+	—	++	—
	West Hill	+	+	+++	•
	Kappad	+	—	++	•
	Mopla	++	+	++	—
	Payyambalam (Cannanore)	—	—	+	—
September 1978	Vizhinjam	+++	++	+++	—
	Kovalam	—	—	—	—
	Shankumugham	—	—	—	—
	Quilon	—	+	—	—
	Neendakara	++	+	++	—
	Alleppey	++	+	+	—
October 1978	Calicut	+	—	++	—
	West Hill	—	—	+	—
	Kappad	—	—	+	—
	Mopla	++	—	+	•
	Payyambalam (Cannanore)	—	—	+	—

HT=High Tide; MT=Mid Tide; LT=Low Tide; + =Minimum present; ++=Medium; +++=Abundant; •=Present; —=Absent.

From: Isolation and Significance of Salmonella Species from some Beaches of Kerala (1980)
P. S. GORE, T. S. G. IYER, O. RAVEENDRAN & R. V. UNNITHAN

Table 59 : The effect of sewage on the growth of *Enteromorpha prolifera* var. *tubulosa* (cm)

Constituents	August		October	
	Normal Growth	Growth in Sewage	Normal Growth	Growth in Sewage
Length	3.75	5.95	21.55	26.35
Moisture	6.15	7.48	7.91	7.65
Crude Protein	12.88	18.44	15.52	19.81
Carbohydrates	57.12	35.64	52.52	37.58
Crude Fat	1.03	0.68	1.02	1.05
Soluble Ash	20.51	32.81	20.86	30.42
Insoluble Ash	2.31	4.95	1.92	3.49
Sodium	3.53	10.31	2.21	3.56
Potassium	3.36	3.85	2.65	3.21
Calcium	1.53	1.94	1.78	4.28
Magnesium	2.24	3.14	2.10	2.94
Chloride	2.08	3.26	-	-
Sulphate	7.60	8.83	7.63	10.37

From: The Effect of Sewage Pollution on Enteromorpha [illegible]

Sewage can be used to aid aquaculture as is done at some places on the Indian coastline for example Kakdwip in West Bengal and in the Lake Vidyadhari region where major carp fingerlings 7.5-15 cm long and 5-6 months old are grown using Calcutta sewage. Organic wastes have a high quantity of suspended solids which are highly oxidizeable in nature. In aquaculture waters, suspensions can be oxidized by bacteria. In general the addition of heat or domestic wastes have been shown to change oligotrophic waters to nutrient-rich conditions. However, the addition of sewage can also have adverse effects, one of the major ones being plankton number reductions. Rivers carrying insecticides may wash into estuaries, the principal area of aquaculture, where, for example, the culture of shrimp may be affected. Shellfish may keep their shells closed for awhile if they detect that the waters are toxic and often on opening again still find the conditions lethal. Larvae and eggs may be destroyed by the addition of excess sewage. Respiratory and metabolic disruption are the usual cause of death and sometimes disease and parasitism may begin to appear on surviving specimens.

Sewage systems in Karachi, Pakistan are still inadequate. The city's drinking water supply is heavily polluted by untreated sewage and industial wastes. In the summer of 1980, the consumption of these waters resulted in an outbreak of gastroenteritis which caused several deaths. The examination of the water revealed that virtually the whole of the city's supply of drinking water was contaminated by the bacteria E. coli. Effluent is carried from industrial and municipal sources via the Lyari River to the western backwaters of Menora Channel. Some values of waste flowing to the sea from the Lyari River are given in table 60. The various creeks, namely Korangi, Phitti and Gharo, all receive effluent, especially the former.

11.0 POLLUTION FROM AGRICULTURAL ACTIVITIES

11.1 Introduction

Many countries in the Indian Ocean area are predominantly agricultural. Some of the main agricultural products are seen in table 61. These countries use appreciable quantities of insecticides, fertilizers and pesticides such as DDT, aldrin and endrin (see tables 62 and 63). They constitute an important source of pollution from factories and from drainage and run-off from land via the rivers to the sea. Being fairly stable and non-biodegradable they persist in the sea and often lead to spots of eutrophication.

In developing countries, the use of organo-chlorine pesticides in agriculture is inevitable in order to sustain a food supply for the expanding population. Demands for DDT in the agricultural and anti-malarial programmes of the tropical countries is unlikely to decrease in the near future. Total DDT concentrations in the Indian Ocean seem to be higher than those in the other ocean areas excluding the North Pacific. Some values of DDT and HCH are seen in table 64.

11.2 East Africa

In Kenya the use of pesticides has increased 10 fold since 1966. The

Table 60 : Composition of the waters of the Lyair river entering the Arabian Sea (g)

Composition	Daily	Yearly
Chloride	152.46	53200.0
Sulphate	151.74	53209.0
Suspended Solids	34.20	11970.0
Total Dissolved Solids	376.20	131070.0
Organic Matter	47.34	16555.0
Ammonial Nitrogen	2.30	805.0
Albuminoid Nitrogen	0.05	18.9
Total Nitrogen	2.35	822.5
Alkalinity as Calcium Carbonate	115.74	40495.0
Phosphate	2.62	917.0
Calcium as Bicarbonate	162.00	56700.0
Iron Oxide	5.14	1799.0
Aluminium Oxide	1.36	476.0
Magnesium Oxide	60.00	21000.0
Arsenic Oxide	1.40	490.0

From: Survey of the Polluted Lyair River and its Effects on the Arabian Sea
A. A. BEG, N. MAHMOOD & A. H. K. G. YUSUFZAI (1975)

Table 61 : Main agricultural products in 1977 (in thousands of metric tonnes)

Countries	Rice	Maize	Wheat	Potatoes	Tobacco	Ground Nuts
Bangladesh	19,441	-	259	735	62.5	27.0
Burma	9,455	75	76	57	63.3	464.3
Comoros	15	-	-	-	-	-
India	79,094	5,947	29,010	7,171	418.8	6,068.5
Kenya	43	2,553	181	341	1.7	7.9
Madagascar	2,154	122	-	148	5.3	54.7
Mauritius	0	-	-	11	0.9	0.7
Mozambique	35	350	2	40	2.7	100.0
Pakistan	4,424	821	9,144	318	72.6	72.4
Somalia	6	80	1	-	0.1	9.8
Sri Lanka	1,677	18	-	29	6.5	7.4
Tanzania	194	968	71	88	19.1	74.0

From: United Nations Statistical Yearbook (1978)

Table 62 : Use of fertilizers 1976/77 (in thousands of metric tonnes)

Country	Nitrogenous fertilizer	Phosphates fertilizer	Nitrogenous (N)	Phosphates (H_3PO_4)	Potash (K_2O)
Bangladesh	130.4	20.6	165.6	61.5	14.5
Burma	55.5	—	42.9	6.7	1.5
India	1856.8	477.8	2457.0	635.0	319.0
Kenya	-	-	22.4	27.3	4.2
Madagascar	-	-	6.0	0.7	2.5
Mauritius	6.9	-	11.5	3.0	14.3
Mozambique	4.7	2.0	6.7	2.9	1.6
Pakistan	306.7	13.5	500.4	123.3	3.2
Sri Lanka	-	-	47.0	7.9	31.5
Tanzania	5.5	8.7	14.5	10.9	4.3

From: United Nations Statistical Yearbook (1977)

Table 63 : Estimated annual and future use of DDT in agriculture (tons per annum)

Area	Cotton Producing Countries	Non-Cotton Producing Countries	Other Countries
Africa (present)	2,186	605	729
Asia (present)	5,566	410	1,523
Africa (future)	13,100	1,170	1,410
Asia (future)	33,500	905	3,350

Table 64 : Total DDT and HCH concentrations found in some parts of the northern Indian Ocean

Area	Station	Date	Total DDT	Total HCH
Sea Surface (ng/l)				
Bay of Bengal	8 59'N 88 03'E	10 '76	0.06	1.9
	8 02 86 01	10 '76	0.08	1.1
	7 20 92 21	10 '76	0.09	0.66
Arabian Sea	24 36 66 53	12 '79	0.16	1.3
	11 01 63 58	11 '79	0.12	1.4
	5 25'S 64 01'E	11 '76	0.06	0.17
Air (ng/m^3)				
Bay of Bengal	8 36'N 87 12'E	10 '76	0.17	0.37
	8 17 90 27	10 '76	0.19	0.95
	7 08 84 05	10 '76	0.15	0.20
	6 16 95 12	10 '76	0.27	0.36
	6 03 90 31	12 '76	0.16	0.16
	5 55 81 20	12 '76	0.22	0.14
Arabian Sea	23 04 65 15	11 '76	0.40	3.3
	20 53 64 19	11 '76	0.24	2.1
	19 29 64 13	11 '76	0.20	2.5
	11 43 63 56	11 '76	0.15	0.81
	6 08 64 05	11 '76	0.09	0.92
	1 36 64 00	11 '76	0.10	0.24
	3 05'S 64 03'E	11 '76	0.13	0.18
	4 12'S 66 12'E	11 '76	0.16	0.28
Eastern Arabian Sea	21 10'N 68 25'E	12 '76	10.90	2.0
	18 50 70 26	12 '76	1.3	9.1
	14 55 73 03	12 '76	1.1	10.1

Tanzania's economy is largely dependent on agriculture of which coffee, sisal and cotton are predominant. In Tanzania and Somalia, pesticides are used increasingly for cotton fields but again effects are not very noticeable and if so only in the inland waters. Some metabolic residues of copper fungicides used for the prevention of coffee leaf rust may be apparent.

In Mozambique, the Incomati, Maputo and Umbeluzi rivers carry large quantities of phosphorous into the Lourenço Marques Bay causing spots of localized eutrophication. Off Mogadishu, in Somalia, a large scale fish kill was observed in 1972 caused by a red tide. But the problem is usually very localized.

11.3 The Islands

In Madagascar, about 20,000 tonnes per annum of about 50 compounds of pesticides particularly DDT, HCH, phosphoric and sulphuric compounds are used for agricultural purposes as on the sugar-cane farms. DDT and endrin are used regularly for spraying houses against insects.

In Mauritius, some pollution problems are apparent from pesticides used in sugar plantations. In 1977, 1160 tonnes of pesticides were being used, increasing the concern about pollution due to them draining into the sea via the rivers.

In the Seychelles, agriculture is at a minimum and hence pollution from fertilisers is absent. However disease control is fairly estensive and pesticides and insecticides are used freely. Their effect is minimal so far with very small amounts being found, for example, in mussels.

11.4 The Asiatic Subcontinent

Already large amounts of HCH are being consumed in India. Some studies of DDT content in zooplankton have been made off Bombay. Variations in concentrations of phosphates, nitrates and oxygen from waters off Bombay are seen in table 65. Similarly, distribution of total phosphorous, total nitrogen and organic carbon in Cochin Backwaters are seen in fig. 34.

In August 1970, a survey in West Bengal showed that the organo-phophorous pesticides DDVP phosphamidon and parathion, killed many fish from Punarbhava River and West Dinajpur. The gill tissue, alimentary tract, liver and brain of the exposed carp and catfish were found to be severely damaged. These are a commercially important fish and thus a direct hazard to man too. Heavy rains result in heavier run-off from land and hence larger quantities of chemicals reach the sea. Intermittent fish mortality is associated with the fertiliser factory at Velsao in Goa, India. The effluent is nitrogenous with arsenic compounds (see table 66). The former is toxic due to the presence of ammonia and the latter is considered to be a cumulative poison. Some eutrophication is already apparent which could lead to low oxygen content and asphyxiation.

A fertilizer plant at Menali discharges effluent around the Ennore Backwaters which has important migratory fish, oyster, mussel and prawn grounds. 250-500 ppb oil, chromium, ammonia, hydrogen sulphide, phosphates and sulphuric acid are amongst the wastes discharged. After treatment most of the oil been removed and only ammonia and phosphate are still present. The treated effluent is harmless to fish but has a nutritive effect. Bottom fauna is

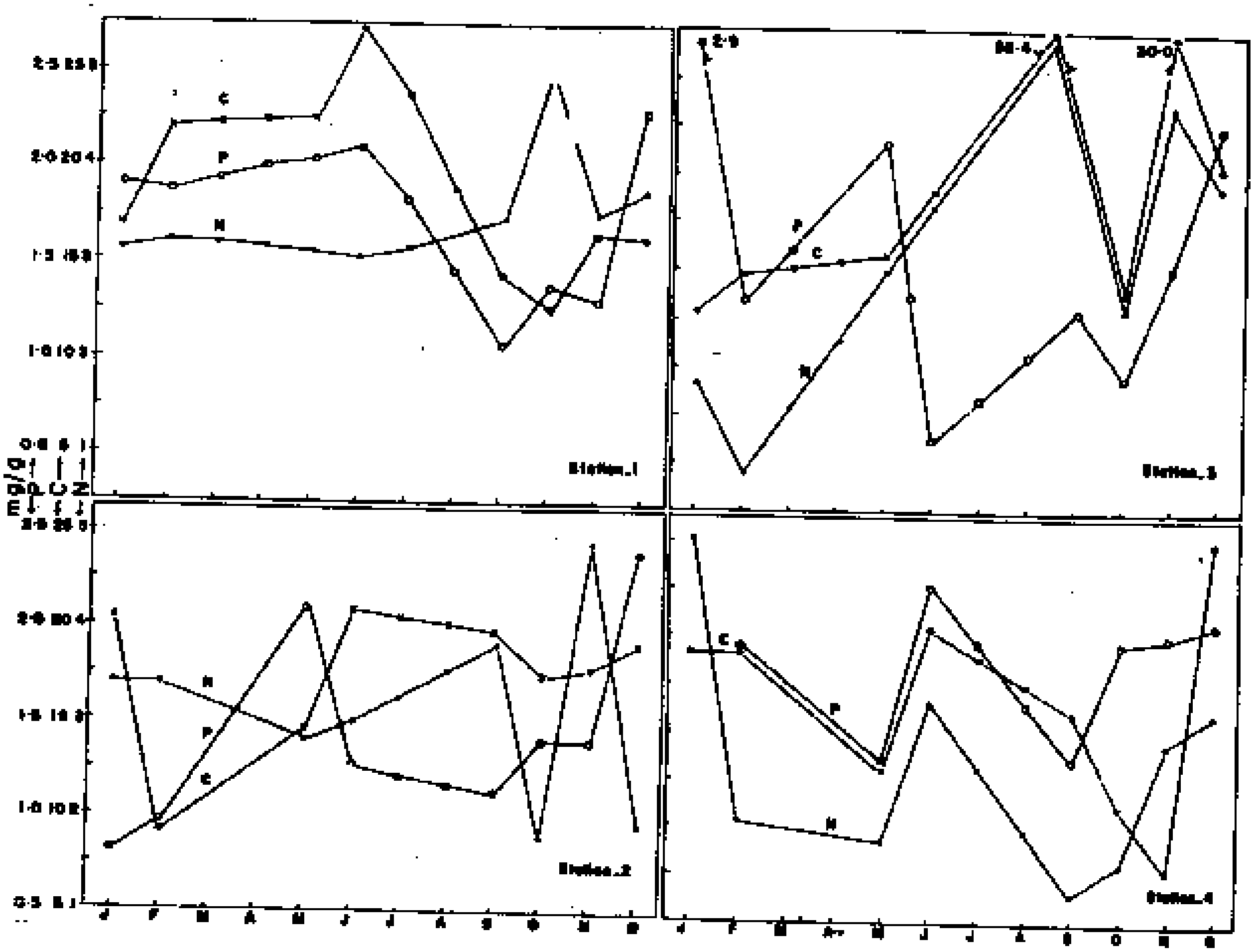
Table 65 : Variations in some chemical constituents in waters off Bombay

Date	Depth (m)	s* ‰	O_2 ml/l	O_2 saturation%	PO_4^{3-}-P µg-at/l	NO_3^--N µg-at/l	NO_2^--N µg-at/l	pH
29-1-74	1	35.52	4.52	95	0.40	2.06	0.54	—
	5	35.52	4.91	103	0.88	2.21	0.59	—
	10	35.53	4.62	97	0.80	1.24	0.46	—
	20	35.52	5.42	115	1.30	2.28	0.32	—
5-2-74	1	35.34	4.49	95	0.51	2.17	0.44	—
	5	35.33	4.42	93	0.70	2.13	0.44	—
	10	35.28	4.47	95	0.70	2.54	0.	—
	18	35.30	4.46	94	0.57	1.75	0.66	—
1-3-74	1	35.45	5.02	109	0.38	1.72	0.46	—
	5	35.43	5.00	106	0.32	1.34	0.48	—
	10	35.43	4.71	100	0.63	2.44	0.64	—
	15	35.43	4.70	100	0.82	2.38	0.57	—
	20	35.45	4.74	101	0.57	1.97	0.31	—
16-3-74	1	35.31	4.98	109	2.43	2.02	0.31	8.52
	5	35.31	4.86	106	2.43	1.66	0.22	8.58
	10	35.39	4.52	98	2.56	3.17	0.59	8.55
	15	35.38	4.73	102	2.73	3.38	0.68	8.53
	20	35.38	4.92	107	2.43	4.06	0.79	8.50
3-5-74	1	35.43	3.78	83	0.94	1.24	0.47	8.17
	5	35.50	3.64	80	1.17	1.46	0.29	8.16
	10	35.40	3.64	80	1.17	1.71	0.25	8.19
	13	35.41	3.80	83	1.28	1.97	0.38	8.19

* By courtesy of Naval Physical & Oceanographic Laboratory, Cochin

From: Pollution Studies off Bombay
R. SEN GUPTA & V. N. SANKARANARAYANAN (1974)

Figure 34 : Distribution of total phosphorous, total nitrogen and organic carbon in Cochin backwaters



From: Studies on Sediments of Cochin Backwater
V. N. SANKARANARAYANAN & S. U. PANAMPUNNAYIL (1979)

Table 66 : Nutrient content of some effluent

Nutrients	Minimum	Maximum	Normal
NH_4-N	2.90	174.00	5.00
Nitrites	2.50	42.79	1.00
Phosphates	0.05	26.84	1.00
Nitrates	2.40	271.00	2.00
Arsenic	3.00	583.20	1.00 - 43.00

From: Chemical Characteristics of the Ibshore Waters in Velsao Bay, Goa.
S. Y. S. SINGBAL, S. P. FONDEKAR & C. V. G. REDDY (1976)

Periodic phytoplankton blooms are reported in the waters of Visakhapatnam Harbour. These are dominated by the centric diatom, Skeletonema costatum. The bloom usually lasts for 12-15 days with a peak abundance within 5-10 days. Asterionella, Chaetoceros and Coscinodiscus are amongst the other species observed at densities which often exceed 10,000 cells/ml. On the 14th October, 1976 as many as 60,470 cells/ml were seen, with 99.6% being S. costatum. These blooms are thought to be a result of high concentrations of nitrite, nitrate and ammonia. Generally, concentrations of nitrogen and phosphorous decreased as the phytoplankton standing crop increased whereas the nutrient levels were high when phytoplankton numbers were low.

The bulk of the nutrient source entering the harbour comes from the nearby fertiliser factory and domestic wastes. High values of dissolved oxygen are noted during periods of phytoplankton blooms with super-saturation at the surface indicative of increased photosynthetic activity. Inadequate flushing of the harbour waters promotes optimum conditions for bloom growth. Peak blooms occur in calm weather with increased sunshine and reduced fresh water inflow. Following low sunshine and heavy rainfall, bloom cell numbers appear to decrease. Phytoplankton blooms have also been noted in the area from high phosphate values of 13.62 and 12.45 ppm, high pH values, high chlorophyll and defieciency in oxygen leading to eutrophication.

Pakistan imports 500 tonnes DDT per year as well as several hundred tonnes of chlorinated pesticides such as aldrin and dieldrin which are widely used throughout the country. In 1976, in Kohat in northern Pakistan, a faulty batch of malathion containing higher quantities of iso-malathion than normal was the cause of the intoxication of over 2000 sprayers 7 of whom died. This batch was 600 times more toxic than the normal malathion and potentially very harmful to freshwater and marine populations.

12.0 RADIOACTIVE POLLUTION

As nuclear research increases so will the amounts of radionucleoids being released into the ocean. With their long residence times they will remain contaminants for many years. Nuclear research is not very evident in the countries of the East African Coast.

Some radioactive substances are discharged from the Karachi Nuclear Power Plant located on the west coast of Karachi Harbour near Paradise Point, Hawks Bay but so far these remain within the permissible level and no contamination has been noted in the fauna and flora of the region.

In India, radioactive pollution has become a major concern recently with the number of nuclear power stations being built constantly increasing. Values for the radionuclides around the coast of India are seen in table 67. The plants at Tarapur and Trombay are of primary concern (see fig. 35). Some values of various radionuclides found in the seas are listed in tables 68, 69 and 70. Trombay Research Station is situated near Bombay while Tarapur is found 100 km further north. This area is very rich in fauna. The research station at Trombay has four reactors, thorium and uranium plants, an irradiated fuel processing plant, metallurgy and engineering labs, isotope production facilities and other research labs. 0.14 million litres of radioactive effluent are discharged every day. The 420 MWe generator needs 2950 million litres a day for cooling. The outgoing temperature is 7-10 warmer than the incoming. In the immediate vicinity of the outflow the increased temperature leads to an oxygen deficiency due to the increased oxidation rate of organic matter. The solubility of the oxygen is also reduced. The increased temperature has a mild effect causing peaks of zooplankton in December and March and dominance by siphonophores, copepod and decapod larvae. The pipe length is such that the water has time to cool off a little before it reaches the sea.

The bottom sediments show a high pick up of Cesium 137, Cerium 144 and Rubidium 106. Fish tissue is found contaminated with Cesium and Strontium but at a lower level. Non benthic crab Scyella serrata picks up cesium, cerium and rubidium and non benthic catfish arius species pick only cesium. Examples of values in both sediment and faunal tissue are seen in tables 71 and 72. Oysters are found to accumulate zinc 65, iron 59, cesium 137, cerium 144, 141, rubidium 295, silver 110, cobalt 60, manganese 54, plutonium 32, niobium 110 and tin 112, 113 the latter two being from zirconium 2 and 4 alloy used in structural metal and selenium 74, 75.

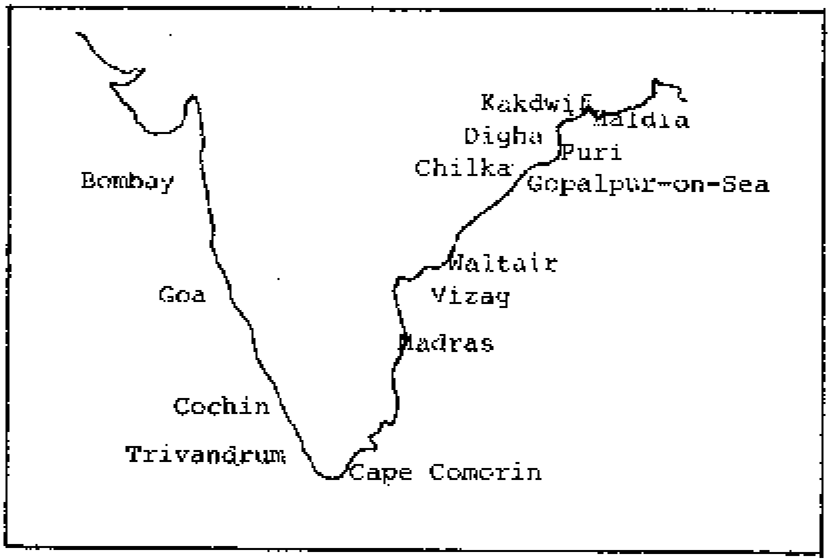
14.0 SILTATION AND EROSION

The effects of siltation are apparent in most of the countries of the Indian Ocean. Siltation begins by erosion of topsoils in inland area. This usually follows periods of heavy rainfall when the rivers often overflow and water runs overland carrying soil with it to the sea. The effects are greater when rains follow a long dry spell during which the soil has already been loosened. Intensive grazing by livestock and a poor choice in crops can also lead to erosion. Erosion of the coastal areas by heavy wave action often leads to the destruction of tourist beaches and leaves them covered only with pebbles. Coastal reefs can act as a barrier against erosion of the beaches by waves.

The retreat of the coastline is a problem arising from erosion and siltation is an important way of counteracting this. However, siltation results in an increased amount of nutrients entering the sea which leads to excessive algal growth, damage to coral reefs, particularly by smothering them, and adverse affects on the coastal nursery grounds.

Some of the major rivers draining into the Indian Ocean are the Athi/Galana, Tana, Ganges, Bramaputra, Irrawaddy, Indus, Kelani, Ruvumu, Juba, Rufiji, Zambesi and Lipopo. Where these discharge, large zones of turbid waters are usually seen. The Indian Ocean receives about 3,400 million tonnes of

Table 67 : Radium content in some coastal areas of India

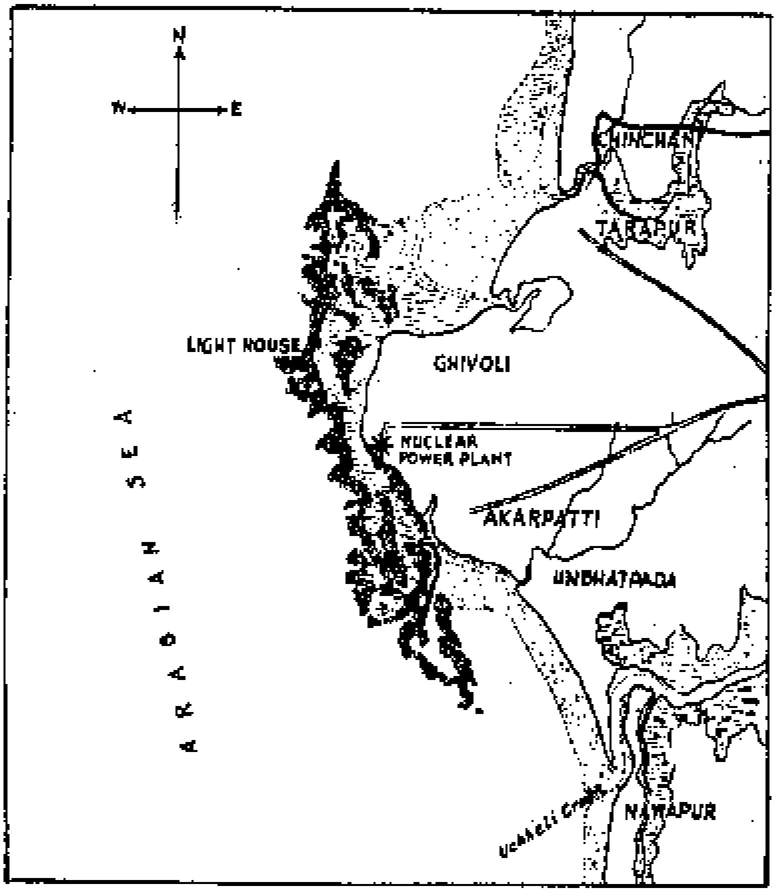


Serial No.	Station	Location	Radium content X 10^{-11} g/ml	Remarks
1	Goa	Arabian Sea	0.82	
2	Bombay	"	1.6	
3	Cochin	"	2.5	Monazite sand Beach
4	Trivandrum	"	3.2	
5	Cape Comorin	Indian Ocean	2.0	
6	Madras	Bay of Bengal	1.5	
7	Waltair	"	2.0	
8	Gopalpur-on-Sea	"	0.66	
9	Puri	"	0.94	
10	Chilka	"	1.7	
11	Digha	"	1.1	
12	Haldia	"	3.0	Ganges estuary
13	Kakdwip	"	4.6	"

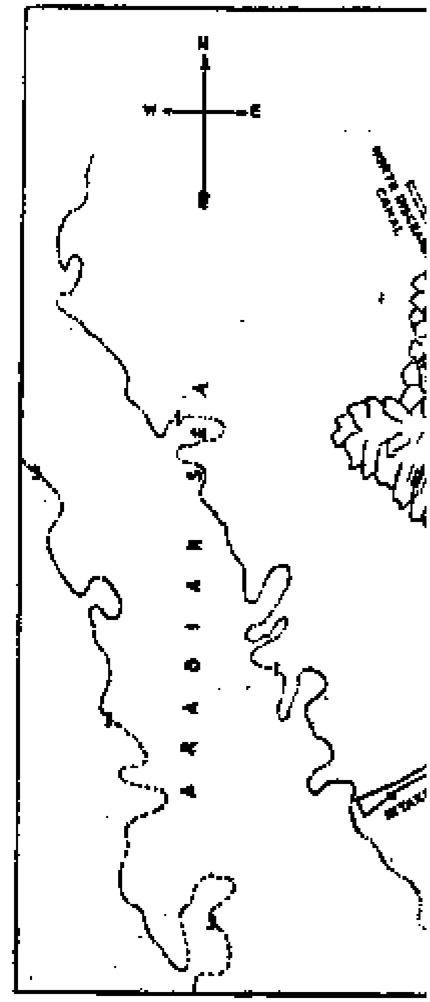
From: Radium Content in Sea Water along the Indian Coast

S. D. CHATTERJEE & P. BANERJI (1976)

Figure 35 : Geography of power station at Tarapur



Site map showing the Power Station and the near by sea environment.



Intake and discharge Canal S

From: Intertidal Ecology of the Sea Shore near Tarapur Atomic Power Stati
M. C. BALANI (1975)

Table 68 : Presence of radioactive substances in selected organisms

Organism	Mn^{54}	I^{131}	Sr^{90}	P^{32}	Fe^{59}	Co^{60}
Fish		+		+		
Phaeophycae		+				
Brown Algae			+			
Plankton					+	
Marine Crustacea	+					+
Sea Hare		+				+

From: Intertidal Ecology of the Sea Shore near
Tarapur Atomic Power Station.
M. C. BALANI (1975)

Table 69 : Values of radioactive substances found in some species of tuna

Species	pCi wet wt. Cs^{137}	pCi dry wt. Cs^{137}	Wt. of fish kg.	nCi wet wt. K^{40}
Albacore Tuna	9.6 - 1.4	33.1 - 5	17	2.89-0.08
Albacore Tuna	8.2 - 1.2	33.2 - 5	17	
Bigeye Tuna	9.9 - 1.0	33.6 - 3.4	14	2.7-0.1
Bigeye Tuna	8.9 - 1.1	34.8 - 7.0	14	2.8-0.6
Yellowfin Tuna	5.0 - 1.2	18.5 - 4.6	11	3.8-0.3

Table 70 : Major element concentrations in selected species of fish (micrograms atom/g wet weight)

Species	Potassium	Magnesium	Calcium	Strontium
Ghol	116.50	7.32	74.00	0.011
Lobster	133.20	14.82	90.00	0.040
Pomfret	115.00	6.34	23.00	-
Catfish	114.00	0.29	3.50	0.012
Bombay Duck	95.50	13.94	85.00	0.018
Flat Fish	99.50	13.77	209.00	-
Koth Fish	99.50	37.00	225.00	-
Sea Water	10.33	53.60	9.60	0.042

From: Radioactive and Stable Element Distribution in Marine Biospheres off Tarapur Coast.
T. P. SARMA, S. M. SHAH, V. N. SASTRY,
T. M. KRISHNAMOORTHY, C. K. UNNI, S. S. GOGATE,
G. R. DOSHI & S. R. RAO (1973)

Table 71 : Values of some radionuclides in coastal marine organisms

ACCUMULATION OF RADIONUCLIDES IN COASTAL ORGANISMS FROM AREAS CLOSE TO DISCHARGE LOCATION

Organism	Part analysed	^{106}Ru	^{137}Cs	^{144}Ce	^{239}Pu	Remarks
		(pCi/g wet)				
Crab *Scylla serrata*	Flesh	1.44	0.2	1.22	ND	Sample size small
	Shell	ND	25.68	ND	ND	Sample size small
Scylla serrata	Flesh	5.35	3.7	4.54	0.0016	
	Bone	-	15.52	-	0.0025	
Scylla serrata	Flesh	24.7	15.5	7.8	-	
	Shell + bone	86.3	54.7	ND	0.0033	
Prawns			8.18		ND	Sample size small
Oysters	Flesh	13.68	6.11	6.9	0.0139	Contamination from sediment suspected
	Shell	25.3	ND	ND	0.0017	
Mackerel	Flesh	ND	0.023	ND	0.0005	
	Bone	-	-	-	0.0028	
Arius sp.	Flesh	ND	29.6	ND	0.0004	
	Bone	ND	62.6	ND	0.0080	
	Gut	230.6	16.2	33.7	0.0023	
Arius sp.	Bone	ND	40.1	ND	0.024	

Form: Determination of Plutonium in the Marine Environment
K. C. PILLAI (1975)

Table 72 : Values of some radionuclides in bottom sediments

ACCUMULATION OF ^{106}Ru, ^{137}Cs AND ^{144}Ce IN BOTTOM SEDIMENTS AT DISCHARGE LOCATION

Location	^{106}Ru	^{137}Cs	^{144}Ce
	(pCi/g (dry))		
1	116.8	129.0	276.5
2	58.1	89.3	221.9
3	177.5	296.5	538.8
4	59.1	116.1	255.4
5	-	1551.0	313.1
6	3.7	135.7	-
7	-	125.4	97.5
8	-	180.3	391.8
9	31.6	105.2	196.5
10	62.4	142.0	339.6
11	89.0	125.3	234.6

Sedimentary accumulations are higher off the Asiatic subcontinent than those found off the East African coast. The submarine cones of the Indus and Ganges rivers have, respectively, sediment volumes of 2.12 x 10/14 m^3 and 7.28 x 10/14 m^3 whereas the basin off Africa has a sedimentary volume of about 4.81 x 10/14 m^3.

The building of dams across naturally flowing rivers decreases the rate of flow, reduces nutrient concentrations in estuaries and coastal waters and decreases the number of plankton blooms and fish landings.

14.0 CONCLUSION

Pollution problems in the Indian Ocean have not yet reached the magnitude of those found in regions such as the Mediterranean and the Baltic which are bordered by industrialized countries. The East African Coast, in particular, is still relatively free from pollution. However, the coastal areas of the Asiatic subcontinent are beginning to show signs of deterioration. This is especially true in the vicinity of coastal industrial sites and towns such as Karachi, Calcutta and Bombay.

At present there is a lack of information on pollution problems in the region. Many of the institutes in the area concentrate their efforts on general research into marine science and development of fisheries.

There are few adequate or satisfactory methods for treatment and disposal of effluent. Often, wastes are dumped directly into rivers and seas causing damage to coastal marine ecosystems and resulting in hazards to human health.

Research on the effects of pollution other than from industrial sources is still scarce. The countries of the area are primarily agricultural and it is therefore important to develop research on the problems of these forms of pollutants. Oil contamination from accidental and operational sources is a growing threat to the coastal areas most of which are on key shipping lanes. The dumping of untreated sewage directly into the sea has resulted in many bathing beaches being contaminated.

Much of the information available in the area comes from research carried out by institutes in India particularly on the effects of industrial pollution in the country. Data is not available from the other large countries of the Indian subcontinent. However, data that has been collected often remains unused.

The treatment of industrial and domestic wastes needs to be promoted throughout the countries of the region. There is therefore a need to develop monitoring programmes to assess sources, levels and effects of pollutants and also a need to implement programmes on pollution abatement and control.

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