

Present Status of Marine Pollution in India

S.Z. QASIM and R. SEN GUPTA

India has a coastline of about 6000 km in which many rivers flowing from land discharge about 1645 km³ of fresh water annually. Of this quantity of fresh water, nearly 75% is added to the Bay of Bengal. About 1.4 million tonnes of fish is harvested per year from the seas around India and due to increasing fishing effort the fish yield is increasing at the rate of about 10% every year, thus doubling every 10 years. Nearly 155 million people of India or about 25% of the total human population of 620 millions, live in coastal areas. The rate of sewage production in metropolitan cities is about 120 litres per person per day and about 60 litres per person in non-metropolitan areas of the country. The total addition of sewage waste to coastal water would be of the order of 35 km³.

The industrial waste going into the coastal waters has been estimated to be about 10% of the total sewage outfall. This would mean that another 3.5 km³ of waste per year comes from the industries located along the coast. Calculating at the rate of 1.7 kg per person per day, the coastal population would generate about 96 million tonnes of solid waste per year. A small portion of waste of inland origin, say about 5%, will find its way into the sea.

Industries discharge about 0.41 km³ of wastes in the delta region of the river Ganga, which has an annual runoff of 370 km³. Using almost a similar rate of waste disposal for all the Indian rivers, the total industrial wastes of inland origin going into the sea would be 0.1 km³.

The production of pesticide in India during the period 1970-76 was about 250,000 tonnes. Similarly, about 110,000 tonnes of synthetic detergents are being used annually in the country. Assuming that about 25% of these will finally reach the sea, the total addition of pesticides and detergents to the sea would be 62,500 and 27,500 tonnes respectively.

In 1978, of the total world's crude oil and its products, 1681 million tonnes were transported by the sea route. Of this, 975 million tonnes, or approximately 58% of the total, were shipped along the oil tanker routes across the Indian Ocean.

Such enormous quantities of pollutants, when added to the seas around India will undoubtedly have some effect on the water quality of marine environment. The Exclusive Economic Zone of 200 nautical miles from the shores declared by India, has an area of 2.016 m km² which is about 61.5% of the total landmass of 3.276 m km² (Table 1).

Table 1. Population and Related Data for India and Some Estimates of Total Quantities of Pollutants Entering the Sea Around India

| | |
|--|---|
| Population | 620 million |
| Coastal population (approx. 25% of total) | 155 million |
| Land area | 3.276 × 10 ⁶ km ² |
| River runoff (annual) | 1645 km ³ |
| Domestic sewage added to the sea by coastal population (@ 60 litres per capita per day) | 35 km ³ |
| Industrial waste added to the sea by coastal industries (10% of domestic sewage) | 3.5 km ³ |
| Solid waste added by coastal population (@ 1.7 kg per capita per day) | 93 × 10 ⁶ tonnes |
| Pesticides manufactured 1970-1976 | 250,000 tonnes |
| Synthetic detergents manufactured per year | 110,000 tonnes |
| Oil transported in 1978 across the Arabian Sea | 975 × 10 ⁶ tonnes |
| To Western hemisphere | 652 × 10 ⁶ tonnes |
| To Far East and Japan | 323 × 10 ⁶ tonnes |

Studies on marine pollution is a relatively new field of oceanographic research in India. It was started in 1970 when severe contamination of beaches with tar balls was first noticed and reported (NAIR *et al.*, 1972).

This paper discusses and reviews the efforts being made by the National Institute of Oceanography, as the part of its project entitled "Protection of Marine Environment". The investigations include the estimation of petroleum hydrocarbons and several heavy metals in sea water, plankton and fishes, and the measurements on organochlorine pesticides in plankton.

Experimental Technique

SAMPLING

Collections of water samples, plankton and fish in offshore areas were made during the different cruises of research vessel "Gaveshani". Water samples for the analysis of dissolved petroleum hydrocarbons at the sea surface were collected using a stainless steel bucket while the ship was slowing down at stations. Samples of water from 10, 20 and 30 m depths were obtained using a glass bottle encased in a brass frame and provided with a sinker (SEN GUPTA *et al.*, 1978a). An aliquot of 400 ml was taken immediately after the collection from each sample and shaken with 10 ml double-distilled hexane, and stored in a deep freeze.

A neuston net (mesh size 300μ), having a stainless steel frame, was towed at the surface for 15 minutes while the ship was running at a slow speed. The samples thus collected were frozen for further examination of *floating petroleum residues*. *Tar deposition on beaches* were sampled according to the procedure outlined by UNESCO (1976).

Water samples for the analysis of *heavy metals* were collected using a series of "aged" 10 litre Van Dorn water samplers. The first sample was always collected at a depth of 10 m which was taken as the surface layer to avoid any suspected contamination from the metallic hull of the ship. However, for the analysis of mercury, samples were collected from the sea surface using a plastic bucket. The samples were filtered through $0.45\ \mu\text{m}$ membrane filter (millipore HA), and pH was adjusted to between 3 and 4 with 1 N HCl, and the filters were preserved under refrigeration.

Samples for the *analysis of mercury* were immediately transferred, after collection, to acid-washed 2.5 l glass bottles and their pH was adjusted to 1.8 with 9 N H_2SO_4 .

Zooplankton samples for the analyses of heavy metals and organochlorine compounds were collected by towing Neuston net at the surface. The samples from the plankton bucket were immediately collected, without washing the net, and frozen. Zooplankton samples thus collected from the surface were examined and only those which were found to be free from floating petroleum residues and paint chips were used for the analyses of heavy metals.

Fish samples from different areas were collected using hook and line during different cruises. Samples of flying fish and myctophids were obtained from the zooplankton net. A portion of the skinfree muscle, liver and gonads from each fish was collected using stainless steel knives and forceps, dried in a hot-air oven, homogenized and stored under refrigeration.

The stations occupied in the Arabian Sea and Bay of Bengal are presented in Figure 1.

ANALYTICAL TECHNIQUES

A method for the analysis of *dissolved petroleum hydrocarbons* was developed after modifying the procedure outlined by LEVY (1971, 1972; see also UNESCO, 1976). The method used involved the application of UV spectrophotometry preceded by chromatographic clean-up using treated and deactivated silica gel, to remove most of the hydrocarbons of biogenic origin (SEN GUPTA *et al.*, 1978a and 1980). The instrument used was a double-beam Beckman ACTA C-III spectrophotometer. Replicate analysis of the samples gave a coefficient of variation $\pm 0.6\%$.

Samples collected using Neuston net were thawed and after drying in air, were divided into several equal aliquots. These were examined under a microscope and the *particulate petroleum residue* was separated, pooled and

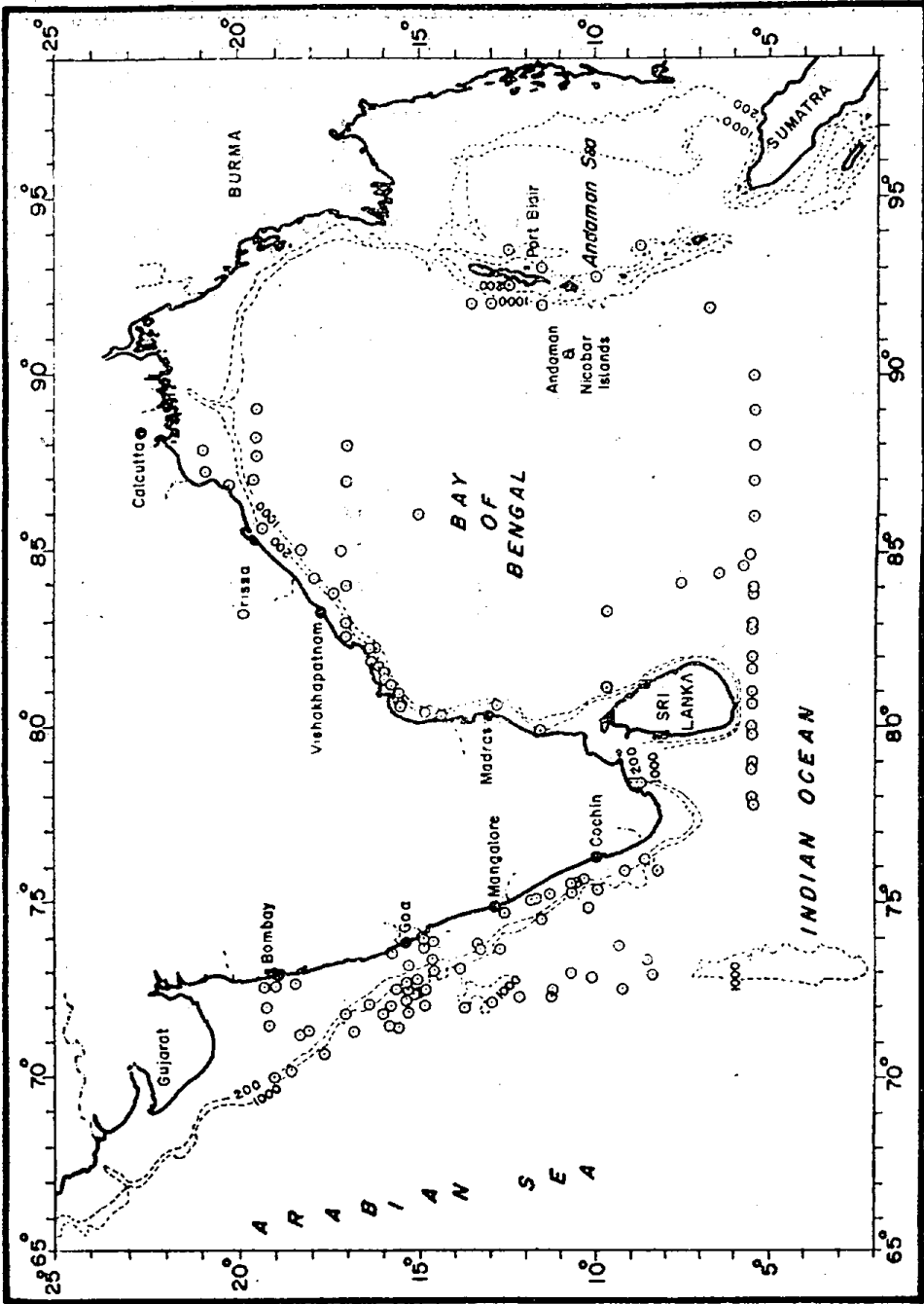


Fig. 1. Map showing the location of stations in the Arabian Sea and Bay of Bengal. Each open circle denotes station position where observations on pollution were made. Dotted lines indicate 200 and 1000 fms isobaths.

weighed. The concentrations per square metre were computed using the ship's speed and the mouth area of the net.

Tar deposits on beaches after collection were separated by floatation, air dried and weighed. The results were expressed as deposit in g/m².

The analytical method used for the estimation of *dissolved fractions of heavy metals, except mercury*, was the standard addition technique followed by chelation with ammonium pyrrolidine dithiocarbamate and extraction with methyl isobutyl ketone (BREWER *et al.*, 1969). The ketone extracts were aspirated into air-acetylene flame of an Hilger Watts Atomspek model H 1550. The result of the analysis were expressed as coefficients of variation.

From the filters, *particulate fractions of the metals* were analysed using a digestion step followed by atomic absorption spectrophotometry.

Cold vapour atomic absorption spectrophotometry was used for the analysis of *dissolved mercury* (GARDNER and RILEY, 1973). The coefficients of variation, in replicate runs of the samples, varied between 2 and 4%.

Metal concentrations in zooplankton and fishes were estimated after acid digestion using the above methods for the dissolved fractions of metals. At least three replicates were measured from each sample. The coefficient of variation was found to range from 5 to 10%.

Chlorinated hydrocarbons in zooplankton were analysed by gas chromatography following the methods described by BERNHARD (1976) and FAO (1975). Redistilled hexane extracts of all the samples were injected into a gas chromatograph equipped with 6 ft × 6 mm glass column and a 3% DC QF-1 Chromosorb W (HP) 80/100 and an electron capture detector having a tritium source. Standards used for this analysis were obtained from the Environmental Protection Agency (EPA), USA, and the components were identified by comparing the peaks of the sample with the standards. The concentration in each sample was calculated by taking the sum of the areas under the curve (measured by a planimeter).

Distribution of Petroleum Hydrocarbons

Of the total crude oil and its products transported along the Arabian Sea in 1978, 323 million tonnes were carried along the oil tanker routes.

The intensive shipping of oil from the Gulf countries is one of the important reasons of oil pollution in the seas around India. The other source is the refinery waste which contains 50-60 mg l⁻¹ of oil matter. The annual consumption of petroleum and its products in India is approximately 30 million tonnes.

Results obtained from the studies of dissolved petroleum hydrocarbons in the Indian seas are presented in Figure 2. The range and some of the average values with their standard deviations, have been given in Table 1.

It can be seen from Table 2 that the difference in the oil values at the surface from the coastal areas and the tanker route in the Arabian Sea is

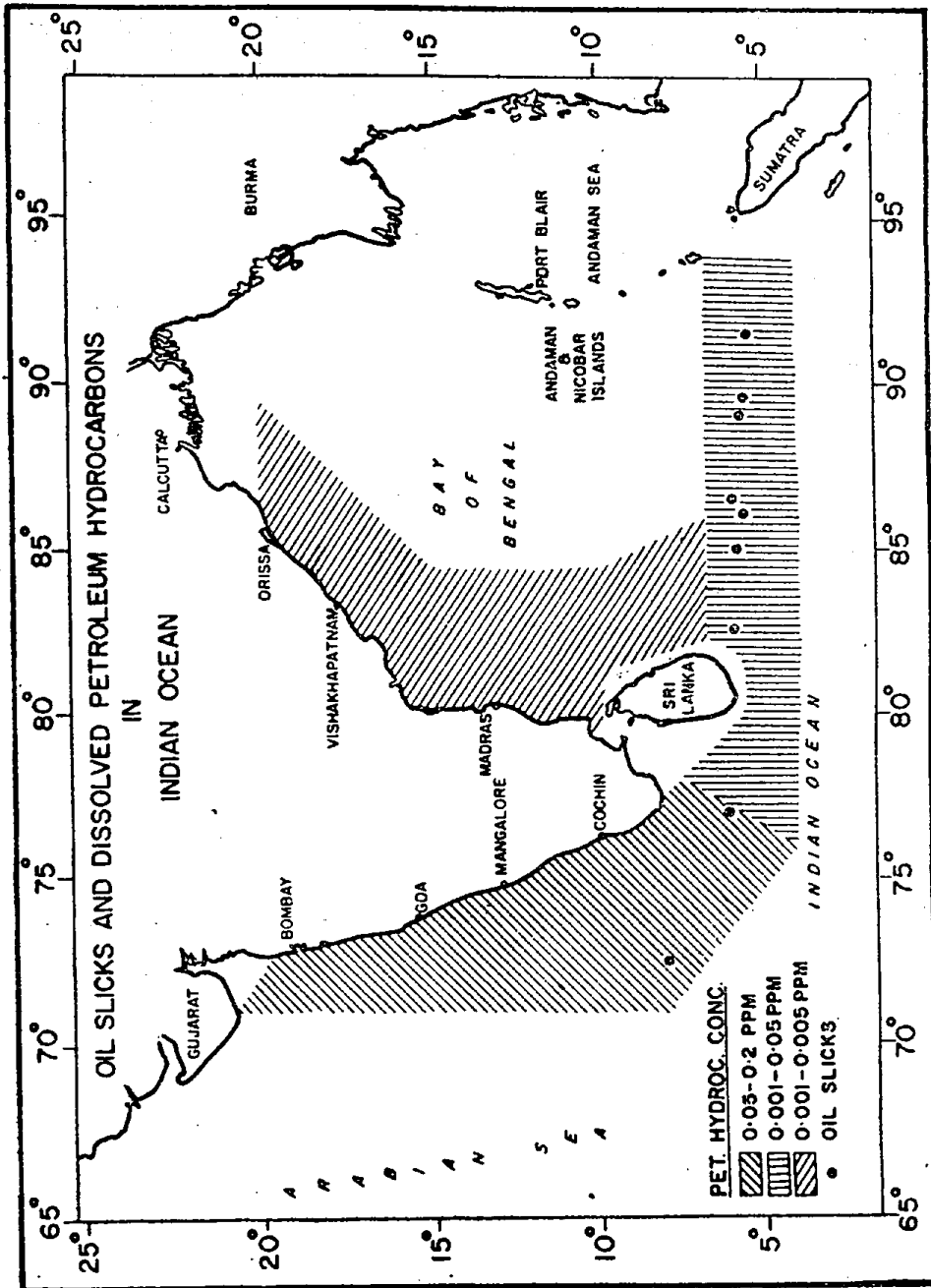


Fig. 2. Shaded areas indicate 3 different ranges of surface concentration of petroleum hydrocarbons in the seas around India. Closed circle give the approximate position in the sea where the presence of floating oil slicks was recorded.

not very significant. However, this difference is quite large in the Bay of Bengal. This is probably due to greater harbour activities and intensive nearshore fishing in the Arabian Sea which leads to a greater oil pollution in coastal waters of the Arabian Sea as compared to Bay of Bengal.

Table 2. Dissolved and Floating Hydrocarbons from the Arabian Sea and Bay of Bengal and on Tar Deposition on Beaches

| <i>Dissolved Petroleum Hydrocarbons ($\mu\text{g/l}$)</i> | | |
|--|--|---|
| | <i>Arabian Sea</i> | <i>Bay of Bengal</i> |
| Coastal area Surface | 8.6—31.0 (March 1978) | 0—2.3 (June 1978) |
| Tanker route Surface | 17.1 \pm 4.1 (March 1978) | Surface 21.7 \pm 1.0 (June 1978) |
| " | 21.5—42.8 (December 1978) | 10 m 23.2—26.9 (") |
| 10 m | 0.9—22.9 (March 1978) | 20 m 13.1—28.2 (") |
| 10 m | 16.8—42.5 (December 1978) | Surface 75.2 \pm 10.0 (February 1979) |
| | | 10 m 22—94 (") |
| | | 20 m 24—73 (") |
| <i>Floating Petroleum Residues (mg/m^2)</i> | | |
| | <i>Arabian Sea</i> | <i>Bay of Bengal</i> |
| Tanker route | 0.02—0.32 (March 1978) | 0.42—3.45 (June 1978) |
| | 0.09—6.0 (May 1979) | |
| <i>Tar deposition on beaches from Kutch to Kerala</i> | | |
| | <i>Average (g/m^2)</i> | <i>Total (tonnes)</i> |
| 1975 | 28 | 1000 |
| 1976 | 20 | 750 |

Source: SEN GUPTA *et al.* (1980) and FONDEKAR *et al.* (1980); DHARGALKAR *et al.* (1977) (tar on beaches).

Concentrations of petroleum hydrocarbons from the surface to 20 m depth were found to be almost uniform in different cruises (Table 2). However, there appears to be some seasonal variation in the values obtained during March and December 1978 from the Arabian Sea and in June 1978 and February 1979 from the Bay of Bengal (Table 2). This variation may be due to a difference in the intensity of tanker traffic across the Arabian Sea and Bay of Bengal. Petroleum hydrocarbons in the surface waters range from 0 to 1000 $\mu\text{g/l}^{-1}$. Considering the magnitude of transportation of oil across the Arabian Sea and the Bay of Bengal, both the seas appear to be relatively clean. Further floating petroleum residue present in the sea was directly related to the oil discharged from the ships, suggesting that the oil tanker route across the Bay of Bengal is relatively more polluted than a similar route in the Arabian Sea (Table 2).

Surface currents along the west coast of India are bimodal in nature. During the period October-April, the longshore currents do not have a

shoreward component, while from May to September a strong shoreward component develops (VARADACHARI and SHARMA, 1967). These shoreward currents stir up the sediment and bring the tar residue to the beaches. Observations on several beaches selected at random (Figure 3) during 1975-76 gave the average tar deposition of 28 and 20 $\text{g}\cdot\text{m}^{-2}$ respectively.

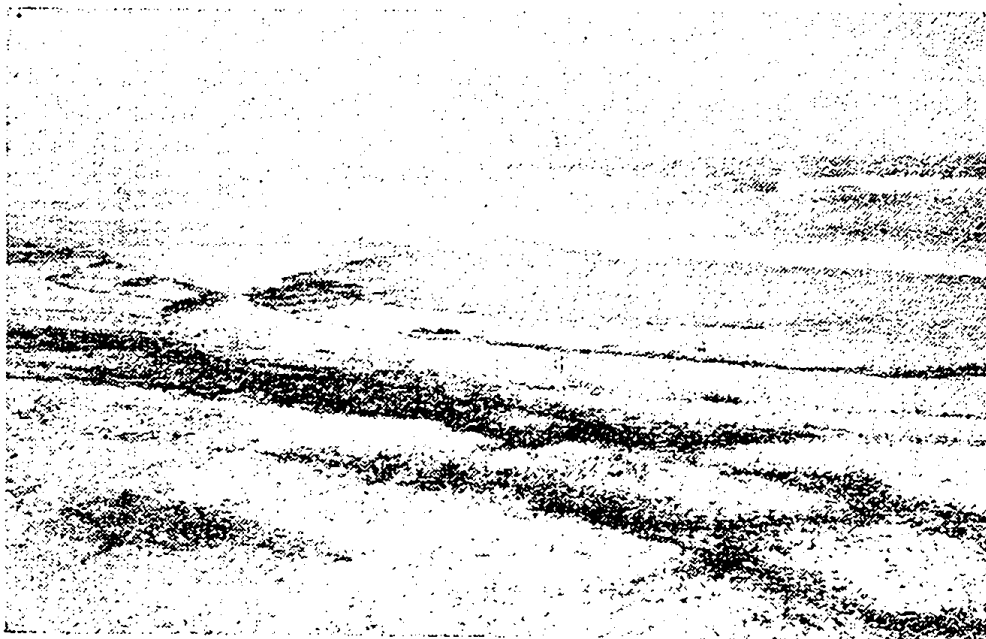


Fig. 3. Tar deposition on a beach on the west coast of India during the monsoon months.

Using these values and the approximate length of the west coast of India, the total tar deposition was calculated to be about 1000 and 750 tonnes respectively for the two years (DHARGALKAR *et al.*, 1977). One of the main reasons for the reduction in tar deposition during the two years may be because of the reopening of Suez Canal for shipping after 9 years and thus decreasing the tanker traffic across the Arabian Sea. The reversal of currents after the SW monsoon leads to the return of the remaining tar residue from the beaches to the sea.

FONDEKAR *et al.* (1980) made some observations on the concentration of hydrocarbons in plankton and sediments of the coastal areas. In plankton the concentration was found to range from 19.5 $\mu\text{g/g}$ to 83.3 $\mu\text{g/g}$ dry wt, while in the sediments it ranged from 4.8 to 8.5 $\mu\text{g/g}$ dry wt.

Besides the field data mentioned above, laboratory experiments were also conducted on several physical and chemical methods to be used for fighting oil pollution in the event of an accidental oil spill (BHANDARE and SEN GUPTA, 1976; FONDEKAR *et al.*, 1977; VERLENCAR *et al.*, 1977; SOLIMABI

and TOPGI, 1978). Several brands of indigenously manufactured polyurethane foam and chemical dispersants were tested for their efficiency and suitability in the removal of spilled oil. Static bioassay tests were also carried out on molluscs and prawns to evaluate the toxicity of dispersants both individually and in combination with crude oil. A model study, using historical data on wind, wave and currents along the west coast of India, was also made to forecast the movements of a hypothetical oil spill in the Bombay High region in each month of the year (GOUVEIA and KURUP, 1977). Recently, 18 chemical dispersants of foreign origin were tested for their toxicity, efficiency and suitability to control oil spill. This work was carried out at the request of Oil and Natural Gas Commission (NIO, 1979).

Metals in Sea Water

Many of the heavy metals occurring naturally in sea water are at concentrations of parts per billion. There is a fairly wide range in the concentration of each metal, which is probably due to the biogeochemical cycle occurring in the sea. Transition group metals, have a tendency to attach themselves to donor atoms and undergo bioaccumulation (GOLDBERG, 1965). Hence, these become very important from the point of view of their possible adverse effect on marine biota.

Information on the heavy metals in marine environment of India has been very limited prior to the work carried out by the National Institute of Oceanography, Goa. With the rapid industrialization and urbanization in the country, the risk of wastes containing heavy metals going into the sea has been on the increase. Studies carried out so far include the estimation of dissolved and particulate fractions of copper, iron, manganese, zinc, cobalt and nickel (SEN GUPTA *et al.*, 1978b; SANZGIRI and MORAES, 1979; BRAGANCA and SANZGIRI, 1980) and the quantitative estimation of several heavy metals in zooplankton (KUREISHY and GEORGE, 1977; GEORGE and KUREISHY, 1979) and in fish (ZINGDE *et al.*, 1976) and seaweeds (AGADI *et al.*, 1978). Dissolved mercury in sea water has been estimated by SINGBAL *et al.* (1978) and by SANZGIRI *et al.* (1979) and the concentrations of mercury in some fishes have been reported by TEJAM and HALDAR (1975) and KUREISHY *et al.* (1980a, b).

Most of the heavy metals occur in natural sea water and many of these have been found to be necessary to promote the growth of marine organisms. However, over-accumulation of these may become hazardous to marine life. During the past 15-20 years, the concentrations of several heavy metals in certain areas of the world oceans have increased by about one hundred fold. The rate of man-induced mobilization of heavy metals exceeds the geological rates by factors ranging between 2 and 200. This is

particularly true with mercury which is considered to be the most toxic of all heavy metals. The over-accumulation of mercury in the organisms is not only harmful to the organisms but to predators and man.

Most of the trace metals occur in sea water as hydrated ions or as weakly bound complexes. Since, the metals were extracted by chelation with APDC using MIBK as a solvent, the dissolved metal content is expected to give a measure of both hydrated metal ions and their weakly bound complexes.

Before the interpretation of the heavy metal data from the Arabian Sea and Bay of Bengal, a description of some of the hydrographical and hydrochemical features of these two seas seems very desirable. The Arabian Sea is known to be an area of negative water balance, in which evaporation exceeds precipitation and runoff. This sea includes several water masses, e.g. the Arabian Sea-, the Persian Gulf-, the Red Sea-, and the North Indian Ocean deep and bottom-water. Except for the North Indian Ocean deep and bottom water, which flows between 1000 m and bottom, the depths of flow of the other water masses are regulated by the processes of mixing and turbulence. At depths ranging between 100 m and about 1000 m, the oxygen in the water ranges from 0.2 to 0.5 ml l⁻¹ and very often two oxygen minima have been identified in the Arabian Sea. Intense denitrification takes place at depths where oxygen minimum occurs (SEN GUPTA *et al.*, 1976a, b).

The Bay of Bengal, on the other hand, has a positive water balance where precipitation and runoff exceed evaporation. The total fresh water runoff it receives from the river every year is about 2000 km³. The surface water of the Bay of Bengal upto a depth of about 25 m gets diluted by about 5.5% (SEN GUPTA *et al.*, 1978c). The general distribution of the water masses here is almost similar to that of the Arabian Sea. It has a thick layer of low dissolved oxygen at depth ranging from 0.1 to 0.5 ml l⁻¹ and between 75 m and 1000 m. This zone is also a layer of intense denitrification with about 40% of the available nitrate being reduced to gaseous nitrogen (SEN GUPTA *et al.*, 1977).

These layers of low oxygen regulate the redox conditions of all the metals depending on their solubilities. The water column, therefore, can be divided on the basis of its varying oxygen concentrations. Ranges in values, together with the average values of all the metals in both dissolved and particulate forms for the Arabian Sea and the Bay of Bengal are presented in Table 3. No particular trend in depth wise variation could be noted in dissolved metals as their concentrations were probably dependent on the redox conditions of the water masses at the time of sampling.

Dissolved copper, in general, was higher in the Arabian Sea than in the Bay of Bengal. At shallow stations of the Arabian Sea, high copper values occurred at deeper layers than at the surface. This probably indicates a greater accumulation of copper in the sediments. Some organisms have

also been reported to accumulate copper (SEN GUPTA, 1972; NAIR *et al.*, 1977; D'SILVA and KUREISHY, 1978; D'SILVA and QASIM, 1979). Deeper stations had low values of dissolved copper at mid-depths while the particulate fraction of copper at these depths was quite high. Still deeper stations showed an increase in dissolved fractions of copper. Solubility of copper complexes has been reported to be dependent on the redox condition in water (LATIMER, 1952). Low concentration of oxygen at mid-depths, therefore, indicates that conditions were probably not favourable for the dissolution of copper in the upper layers.

In the Bay of Bengal, the average concentration of copper in the water column was lower than that in the Arabian Sea. However, in the depth-range 10-100 m, the concentration was found to be fairly high. This was probably because of the thermal discontinuity layer existing at the lower limit of this depth-range.

Particulate fractions of copper showed a similar trend. It was greater in the Arabian Sea than in the Bay of Bengal which may probably be due to differences in the particle size and the rate of sedimentation in the two seas. Perhaps, the occurrence of larger particle size in the Bay of Bengal leads to their quick settlement with adsorbed copper.

Dissolved iron in both Arabian Sea and Bay of Bengal was somewhat higher than those from the other oceans reported by SPENCER and BREWER (1969) and TOPPING (1969). High concentration of iron is normally associated with a large amount of soluble organic matter present in the sea. Both Arabian Sea and Bay of Bengal receive appreciable quantities of fresh water runoff; the latter receiving about four times more fresh water than the former. This may lead to a larger concentration of dissolved iron in the Bay of Bengal. The observed concentration of iron, possibly gives a measure of soluble Fe^{3+} ion complexes and perhaps colloidal ferric hydroxide. Ferric iron present as $\text{Fe}(\text{OH})^{2+}$ cannot exceed $1 \mu\text{g l}^{-1}$ at the normal redox condition of sea water (STUMM and MORGAN, 1970). Hence, most of the iron measured here was probably in the form of soluble complex and colloidal Fe^{3+} compound.

At the nearshore stations and river mouths of the Bay of Bengal, both dissolved and particulate iron at the surface were almost three times greater than those at the offshore stations. This indicates that presumably iron is largely contributed by the river runoff.

The average values given in Table 3 indicate that particulate fractions of iron tend to decrease with depth while reverse is the case with dissolved fractions of iron. Probably due to high pH both colloidal and Fe^{3+} fractions occur in larger proportion in deeper waters.

The APDC-MIBK combination method of analysis, did not extract dissolved manganese fully at pH 3 to 4. The extraction was, therefore, done with SDDC-MIBK raising the range of pH to 5-6, which gave the maximum recovery of manganese.

Table 3. Dissolved and Particulate Matter in Sea Water of the Arabian Sea and Bay of Bengal. Dissolved (D) is Expressed in $\mu\text{g l}^{-1}$ and Particulate (P) in $\mu\text{g/g Dry Wt}$. (R) Gives Range in Values and (A) Indicates Average Values

| Region | Depth range | Cu | | | | Fe | | | | Mn | | | | Zn | | | | Co | | | | Ni | | | |
|---------------|----------------|----------|------|---------|-----|------------|------|------------|-------|----------|------|---------|------|----------|------|------------|-------|-------|-----|-------|-----|----------|-----|--------|-----|
| | | D | | P | | D | | P | | D | | P | | D | | P | | D | | P | | D | | P | |
| | | R | A | R | A | R | A | R | A | R | A | R | A | R | A | R | A | R | A | R | A | R | A | | |
| Arabian Sea | Surface (10 m) | 2.5-19.9 | 11.2 | 33-420 | 226 | 6-66.9 | 38 | 260-70500 | 35380 | 7.7-16.6 | 12 | 14-3333 | 1670 | 2.9-42.4 | 22.5 | 92-204750 | 10240 | 0-5 | 2.5 | 0-86 | 43 | 0-16.3 | 8 | 38-203 | 120 |
| | 10-100 | 1.7-19.9 | 10.8 | 18-1417 | 717 | 8-66.9 | 37 | 260-70500 | 35380 | 3.8-37 | 20.4 | 14-3333 | 1670 | 1.8-42.4 | 22 | 92-204750 | 10240 | 0-5 | 2.5 | 0-86 | 43 | 0-16.3 | 8 | 0-203 | 101 |
| | 100-500 | 2.1-16.9 | 9.5 | 11-700 | 355 | 7.2-85 | 46 | 350-25750 | 13050 | 3.8-80 | 42 | 12- 778 | 390 | 1.2-37.9 | 19.5 | 147- 88389 | 44270 | 0-6.7 | 3.3 | 0-144 | 72 | 0-16.1 | 8 | 0- 87 | 43 |
| | 500-1000 | 1.9-15.7 | 8 | 11-533 | 272 | 10.8-49.5 | 30 | 350- 4830 | 2360 | 1.8-80 | 40.5 | 22- 500 | 260 | 3-31.2 | 17 | 155-154700 | 77430 | 0-6.6 | 3.3 | 0-144 | 72 | 0-1.61 | 8 | 0-138 | 69 |
| | 1000 & below | 1.9-15.7 | 8.8 | 67-411 | 239 | 15.7-96 | 56 | 692- 4600 | 2650 | 1.8-40.2 | 20.9 | 24- 106 | 65 | 2-11.2 | 6.5 | 583- 1280 | 930 | 0-2 | 1 | 0-100 | 50 | 2-5.6 | 3.8 | 16-138 | 69 |
| Bay of Bengal | Surface (10 m) | 2.7- 6.8 | 4.7 | 10-211 | 110 | 6.5-131.5 | 69 | 4506-27965 | 3650 | 2-2.5 | 13.5 | 10-401 | 200 | 2.6-15.3 | 9 | 644-2853 | 1750 | 0 | 0 | 0-144 | 72 | 0-12.2 | 6.1 | 0-115 | 57 |
| | 10-100 | 2.7-37.2 | 20 | 10-252 | 131 | 6.2-131.5 | 69 | 4506-42408 | 23460 | 1.6-40.8 | 21 | 115-572 | 340 | 2.6-15.3 | 9 | 621-2853 | 1740 | 0-5.2 | 2.6 | 0-163 | 81 | 0-12.2 | 6.1 | 0-115 | 57 |
| | 100-500 | 2.2-11.2 | 6.7 | 18-398 | 208 | 6.2- 47.2 | 26.7 | 4539-42408 | 23470 | 1.6-40.8 | 21 | 175-572 | 370 | 2.4-14.3 | 8.3 | 621-2816 | 1720 | 0-5.2 | 2.6 | 0-251 | 125 | 1.7-7.7 | 4.7 | 0-146 | 73 |
| | 500-1000 | 3 -11.2 | 7.1 | 18-71 | 44 | 8 - 71.5 | 39.7 | 2586- 7683 | 5130 | 2.2-37 | 19.6 | 113-323 | 220 | 2.4-20 | 11.2 | 511-2816 | 1660 | 0 | 0 | 0-251 | 125 | 1.7-6.8 | 4.2 | 0-74 | 37 |
| | 1000 & below | 3 - 9.5 | 6.2 | 0-71 | 35 | 10.5- 71.5 | 41 | 2586- 7683 | 5130 | 2.5-37 | 19.7 | 113-323 | 220 | 4.8-20 | 12.4 | 511-1311 | 910 | 0-7.9 | 3.9 | 0-160 | 80 | 4.4-11.2 | 7.6 | 0-44 | 22 |

From SEN GUPTA *et al.*, 1978; SANZGIRI and MORAES, 1979; BRAGANCA and SANZGIRI, 1980.

Table 3 gives the average concentrations of manganese in the depth range 100-1000 m. In the Bay of Bengal, manganese was lower than in the Arabian Sea. Above and below this depth range, the concentrations were almost identical in both the seas. The lack of manganese at the river mouths possibly suggests that their source is not riverine input (BRAGANCA and SANZGIRI, 1980).

Oxidation of Mn^{2+} to Mn^{4+} takes place at pH greater than 8.5 (STUMM and MORGAN, 1970). Both in the Arabian Sea and Bay of Bengal, pH has been observed to lie between 7.3 and 8.3 (SEN GUPTA *et al.*, 1976b; 1977). This shows that soluble manganese probably occurs in Mn^{2+} form.

Particulate manganese followed a variation similar to that of iron. Low concentrations of manganese in both dissolved and particulate forms probably indicate that with a gradual increase in dissolved oxygen and changing redox conditions, it gets precipitated.

Dissolved zinc was found to be high at 10 m depth in the Arabian Sea (Table 3). Most of the estimations of zinc were carried out in coastal waters (Figure 1) and some of the high values recorded were probably because of the pre-treated sewage coming from big cities (SEN GUPTA, 1972). Dissolved zinc decreased with depth in the Arabian Sea while in the Bay of Bengal the minimum was found at intermediate depths (Table 3).

Particulate fractions of zinc were maximum at intermediate depths of the Arabian Sea. In the Bay of Bengal, its concentration decreased progressively with depth. The upper few hundred metres in both the seas showed similar values. Particulate zinc seems to settle to the bottom.

Dissolved cobalt and nickel were found to be very low and often beyond detection limits. Particulate forms of these two metals decreased with depth. An examination of the two metals in the sediments from deeper waters of the Indian Ocean would be of much interest to the study related to the possible formation of polymetallic nodules.

Dissolved mercury in the open ocean at the surface has been found in the range of 10 to 100 ngl^{-1} (KLEIN and GOLDBERG, 1971; LEATHERLAND *et al.*, 1971; ROBERTSON *et al.*, 1972). FITZGERALD and LYONS (1973) found the mercury concentration in sea water to range from 3 to 364 ngl^{-1} . From the Indian Ocean, CHESTER *et al.* (1973) reported the mercury concentration at the surface to range from 0.5 to 127 ngl^{-1} .

Table 4 gives the dissolved and leachable values of mercury. At the surface of the Indian Ocean, mercury decreased with distance from the shore (SINGBAL *et al.*, 1978; SANZGIRI *et al.*, 1979). The range at the surface in the Northern Indian Ocean was 0-130 ngl^{-1} (Table 4). This compares well with the range (0.5-225) for the Atlantic given by CHESTER *et al.* (1973) and GARDNER and RILEY (1973). For the Pacific, FITZGERALD and LYONS (1973) give the range 12-153 and for the Southern Indian Ocean CHESTER *et al.* (1973) gives the range as 9-74 ngl^{-1} .

The mercury concentration in the Indian Ocean decreased with depth. This was more pronounced in the oxygen-deficient layer (SINGBAL *et al.*,

Table 4. Dissolved Mercury Concentration in Sea Water of the Arabian Sea and Bay of Bengal; (R) gives the Range and (A) Average Values

| Region | Depth Range | Dissolved Hg (ng/l) | |
|---------------|--------------|---------------------|-----|
| | | R | A |
| Arabian Sea | Surface | 26-130 | 78 |
| | 10 to 100 | 0-204 | 102 |
| | 100 to 500 | 0-60 | 30 |
| | 500 to 1000 | 0-50 | 25 |
| | 1000 & below | 0-25 | 12 |
| Bay of Bengal | Surface | 0-91 | 45 |
| | 10 to 100 | 0-222 | 111 |

From SINGBAL *et al.* (1978) and SANZGIRI *et al.* (1980).

1978). An attempt to draw a relationship between the mercury concentration and water masses in the Indian Ocean was made by SANZGIRI *et al.* (1979) and these authors concluded that the Red Sea and North Indian Ocean Intermediate Water Masses appear to contain very little or no mercury.

Metals in Zooplankton

Results of the analysis of trace metals in zooplankton are given in Table 5. Average concentrations of all the metals were found to be lower in the Bay of Bengal than in the Arabian Sea. In the nearshore stations, the metal concentrations were lower than in the offshore waters. Assimilation of metals in the biota probably occurs in dissolved form. The low bioaccumulation in zooplankton could be explained in terms of occurrence of trace metals, largely in particulate form. Higher values in the Arabian Sea may probably be due to a greater availability of metals in dissolved form. Another factor which may influence the lower occurrence of metals in coastal regions of the Bay of Bengal (Table 5) is the rapid settlement of particulate and suspended material at the river mouth during which much of the metals get adsorbed to silt and sand and are thus removed from the water column. The low values from the Bay of Bengal compare well with those reported from the other seas (SZABO, 1968; MARTIN, 1970), whereas the values from the Arabian Sea appears to be somewhat higher.

In the Arabian Sea, concentration factor was highest for zinc (31370) followed by iron (6487), cobalt (2989), copper (2060) and nickel (607) (SEN GUPTA *et al.*, 1978b). In the Bay of Bengal, the concentration factor was highest for iron (15638) followed by cobalt (228) (GEORGE and KUREISHY, 1979).

Table 5. Metal Concentration in Zooplankton (ppm Dry Weight), ND: Non Detectable

| Area | Position | | Copper | Iron | Manganese | Zinc | Cobalt | Nickel | Lead |
|-------------|-----------|-----------|--------|------|-----------|-------|--------|--------|------|
| | Lat. ° N | Long. ° E | | | | | | | |
| Arabian Sea | 19°22' | 72°34' | 32 | 555 | 48 | 1214 | 15 | 17 | — |
| | 15°32' | 72°36' | 72 | 1011 | 40 | 1383 | ND | ND | — |
| | 13°19' | 73°36' | 111 | 762 | 22 | 942 | 23 | 17 | — |
| | 09°20' | 75°55' | 232 | 1484 | 83 | 1723 | 10 | ND | — |
| | 08°29' | 76°49.5' | 10 | 1923 | 42 | 9274 | ND | ND | — |
| | 10°09' | 74°54' | 79 | 2984 | 129 | 22494 | 34 | ND | — |
| | 10°56' | 74°36' | 16 | 3278 | 78 | 6587 | ND | ND | — |
| | 12°42' | 73°39' | 29 | 3917 | 44 | 2204 | 73 | ND | — |
| | 20°48' | 87°45' | 25 | 2803 | 143 | 1378 | 5 | 61 | 173 |
| | 19°31.4' | 87°00' | 153 | 4873 | 110 | 1700 | 16 | 17 | — |
| 19°30' | 87°38' | 12 | 3161 | 172 | 938 | 8 | 14 | 208 | |
| 19°30' | 88°12' | 10 | 127 | 7 | 109 | 2 | 1 | 11 | |
| 19°30' | 89°00' | 31 | 1255 | 62 | 680 | 8 | 10 | 5 | |
| 16°59.24' | 82°30' | — | 4121 | 249 | 1390 | 26 | 26 | — | |
| 17°00' | 84°00' | 24 | 961 | 27 | 490 | 11 | 21 | 119 | |
| 17°15' | 84°58' | 97 | 684 | 17 | 592 | 31 | 6 | 63 | |
| 17°00' | 87°00' | 228 | 2443 | 66 | 1530 | 32 | 81 | — | |
| 17°00' | 88°00' | — | 6930 | 133 | — | 17 | 50 | — | |
| 15°00' | 86°00' | 81 | 2424 | 45 | 1237 | 5 | 11 | 54 | |
| 15°30' | 81°00' | — | 1363 | 19 | — | ND | 29 | 58 | |
| 15°29.42' | 80°33' | 52 | 1411 | 37 | 816 | 16 | 17 | 170 | |
| 15°30.30' | 80°45' | 4 | 134 | 7 | 105 | 6 | 5 | 8 | |
| 15°44.30' | 81°08' | 3 | 145 | 6 | 46 | 2 | 2 | 7 | |
| 16°00' | 81°21.30' | 20 | 82 | 5 | 107 | 3 | 2 | 5 | |
| 16°00' | 81°30.30' | — | 1162 | 34 | 514 | 9 | 12 | — | |
| 16°15.12' | 82°06.12' | — | 4011 | 95 | 1701 | ND | 30 | 135 | |

From KUREISHY and GEORGE (1977) and from GEORGE and KUREISHY (1979).

BOWEN (1966) showed that the affinity for cations in the living organisms is in the order of tetravalent and trivalent elements > divalent transition metals > divalent group IIA metals > univalent group I metals. When the concentration factors were arranged in their descending order, the above relationship was found to be valid for most of the metals.

Mercury in Fish

The results of the analysis of total mercury in fishes are given in Tables 6 and 7. Hammer-headed shark and the white spot shark showed the highest concentration of mercury while in the seer fish and in dolphin, the concentrations were low and ranged between 0.09–0.16 ppm dry weight. No mercury was detectable in the liver and gonads of almost all the species examined.

In contrast to the Arabian Sea, where mercury concentrations could be detected only in muscles, in the Bay of Bengal (Table 7) it could be found in the livers of the white-spot shark, skipjack tuna and dolphin. Excepting one barracuda, the mercury concentration in the liver was very low in all the species examined. The lone high value of 0.8 ppm in the barracuda could be suspect.

It is difficult to compare the values obtained on wet weight (Table 6) basis with those on dry weight (Table 7). If we assume that about 75% of the body weight of the specimens analysed was water, then the sharks and one tuna from the Bay of Bengal had somewhat higher concentration of mercury as compared to the Arabian Sea species. However, the total mercury concentration in the fishes of the Indian Ocean was found to be far below the minimum of 0.5 ppm dry weight prescribed by the USA and several European countries.

Chlorinated Hydrocarbons

So far only DDT and its metabolites in plankton have been analysed and some measurements have been made in sea water. These have been found to be far below the detection limits. From this it can be concluded that the concentration of chlorinated pesticides is very low in the coastal waters of India.

Table 8 gives the values of DDT in plankton. There was a direct relationship between DDT concentration and lipid content in plankton. The presence of BHC and PCB was also detected in the samples. From Table 8, it is clear that the total DDT in plankton of the northern part of the west coast of India is somewhat higher than from the other regions. The values, however, are not anyway higher than those reported from the other regions of the world oceans.

Table 6. Total Mercury in Different Tissues of Fishes from the Arabian Sea (ppm Wet Weight). ND, Non Detectable; Asterisks Indicate Range in Length and Weight of Composite Samples

| Common and species name | No. sampled | Length cm | Weight kg | Ovary | Liver | Muscle | Testes | Whole fishes |
|-------------------------------|-------------|-----------|-----------|-------|-------|--------|--------|--------------|
| Seer fish | 1 | 90 | 4.5 | ND | ND | 0.090 | — | — |
| <i>Acanthocybium solandri</i> | 1 | 81 | 3.0 | — | ND | 0.101 | ND | — |
| | 1 | 105 | 8.0 | ND | 0.200 | 0.151 | — | — |
| Skipjack tuna | 1 | 81 | 2.6 | ND | ND | 0.110 | — | — |
| <i>Katsuwonus pelamis</i> | 1 | 56 | 3.2 | — | ND | 0.160 | ND | — |
| Bluefin tuna | 1 | 55.5 | 2 | ND | ND | 0.120 | — | — |
| <i>Kishinoella tonggol</i> | | | | | | | | |
| Dolphin | 1 | 62.5 | 1.4 | ND | ND | 0.140 | — | — |
| <i>Coryphaena hippurus</i> | 4* | 54.5-58 | 0.8-1.0 | ND | ND | 0.072 | — | — |
| | 1 | 128 | 8.5 | ND | ND | 0.120 | — | — |
| Flying fish | 1 | 18.5 | 0.54 | ND | ND | 0.074 | — | — |
| <i>Cypselurus comatus</i> | 3* | 3-3.5 | 1-1.5 g | — | — | — | — | 0.001 |
| | 2* | — | — | — | — | — | — | ND |
| Myctophid | 1 | 3.0 | 2.5 g | — | — | — | — | 0.06 |
| White spot shark | | | | | | | | |
| <i>Eulamia ellioti</i> | 1 | 101 | 48 | — | 0.010 | 0.190 | ND | — |
| Hammer-headed shark | 1 | 74 | 52 | ND | 0.120 | 0.210 | — | — |
| <i>Sphyrna blochii</i> | | | | | | | | |

From KURIESHY *et al.* (1980a)

Table 7. Total Mercury Concentrations in ppm Dry Wt. in Fishes from the Andaman Sea and Adjacent Waters (Bay of Bengal). ND, Non-Detectable

| Common and species name | No. sampled | Length cm | Weight kg | Tissue analysed | | |
|--|-------------|-----------|-----------|-----------------|-------|-------|
| | | | | Muscles | Liver | Gills |
| White-spot shark (<i>Eulamia ellioti</i>) | 1 | 60 | 19 | 0.5 | ND | ND |
| | 1 | 180 | 60 | 0.65 | ND | ND |
| Skipjack tuna (<i>Katsuwonus pelamis</i>) | 1 | 30 | 1.2 | 0.26 | ND | ND |
| | 1 | 55 | 1.95 | 1.11 | ND | 0.06 |
| | 1 | 51 | 1.8 | 0.28 | 0.1 | 0.08 |
| Dolphin (<i>Coryphaena hippurus</i>) | 1 | 120 | 8.3 | 0.16 | 0.21 | — |
| | 1 | 115 | 8.8 | 0.20 | 0.1 | 0.07 |
| Barracuda (<i>Sphyraena jello</i>) | 1 | 86 | 2.8 | 0.31 | 0.04 | 0.17 |
| | 1 | 110 | 6.7 | 0.36 | 0.8 | 0.07 |
| Perch (<i>Lates calcarifer</i>) | 1 | — | — | 0.13 | — | — |
| | 1 | — | — | 0.5 | — | — |
| Small fishes Flying fishes, sardines, mackerel, squid and hay beaks | — | — | — | ND—0.2 | — | — |
| Zooplankton (whole biomass) | — | — | — | ND | — | — |

From KUREISHY *et al.* (1980b).

Table 8. DDT and Its Metabolites (a—b) in Plankton (ppm Wet Weight). P—Present; ND—Not Detectable

| Position | | o-p-DDT | p-p'-DDT | o-p-DDE | p-p'-DDE | Others | Extractable | Total |
|----------|----------|---------|----------|---------|----------|---------------|-------------|---------------|
| Lat. °N | Long. °E | (a) | (b) | (c) | (d) | (PCB and BHC) | lipid (%) | DDT (a+b+c+d) |
| 16°02' | 71°49' | 2 | 0.9 | ND | 0.31 | P | 6 | 3.21 |
| 19°02' | 69°57' | 1.28 | ND | 0.15 | ND | P | 3.7 | 1.43 |
| 19°10' | 71°00' | 0.94 | ND | P | 0.33 | P | 2.3 | 1.27 |
| 18°35'5" | 72°42' | ND | ND | ND | 0.05 | ND | 1.6 | 0.05 |
| 17°34' | 71°32' | ND | ND | ND | ND | ND | 2 | ND |

From KUREISHY *et al.* (1978).

The work on the present status of marine pollution in India summarised above clearly indicates that the levels of pollution in the Indian seas have not reached alarming limits to cause anxiety. The general conclusion, therefore, seems inevitable that, as compared to the other marine areas of the world, the seas around India are fairly clean and that the health of the Indian Ocean, barring a few isolated areas, is fairly good.

References

- Agadi, V.V., Bhosle, N.B. and Untawale, A.G. 1978. Metal concentrations in some seaweeds of Goa (India). *Botanica Marina*, **21** (4), 247-250.
- Bernhard, M. 1976. *Manual of methods in aquatic environment research—Part 3. Sampling and analysis of biological material* (Guidelines for the FAO, GPCM/UNEP joint coordinated project on Pollution in the Mediterranean).
- Bhandare, M.V. and Sen Gupta, R. 1976. The efficiency of Indian polyurethane foams in absorbing spilled oil. *Mahasagar—Bull. Natl. Inst. Oceanogr.*, **9** (1 & 2), 67-69.
- Braganca, A. and Sanzgiri, S. 1980. Concentrations of a few trace metals in some coastal and offshore regions of the Bay of Bengal. *Indian J. mar. Sci.* (in press).
- Brewer, P.G., Spencer, D.W. and Smith, C.L. 1969. Determination of trace metals in sea water by atomic absorption spectrophotometry. *Spec. tech. publ. 443 American Society for Testing and Materials*, 70-77.
- Bowen, H.J.M. 1966. *Trace Elements in Biochemistry*, Academic Press, New York, 241 pp.
- Chester, R., Gardner, D., Riley J.P. and Stoner, J. 1973. Mercury in some surface waters of the World Ocean. *Mar. Pollut. Bull.*, **4**, 28-29.
- D'Silva, C. and Kureishy, T.W. 1978. Experimental studies on the accumulation of copper and zinc in the green mussel. *Mar. Pollut. Bull.*, **9**, 187-190.
- D'Silva, C. and Qasim, S.Z. 1979. Bioaccumulation and elimination of copper in the rock oyster *Crassostrea cucullata*. *Mar. Biol.*, **52**, 343-346.
- Dhargalkar, V.K., Kureishy, T.W. and Bhandare, M.V. 1977. Deposition of tar balls (oil residues) on beaches along the west coast of India. *Mahasagar—Bull. Natl. Inst. Oceanogr.*, **10**, 103-108.
- FAO. 1975. *Manual of methods in aquatic environment research—Part 1. Methods for detection, measurement and monitoring of water pollution*, *Fish. Tech. Pap.* (137), 238 p.
- Fitzgerald, W.F. and Lyons, W.B. 1973. Organic Hg compounds in coastal waters. *Nature Lond.*, **242**, 452-453.
- Fondekar, S.P., Sen Gupta, R. and Bhandare, M.V. 1977. The efficiency of indigenously manufactured polyurethane foams and dispersants in the removal of spilled oil. *Mahasagar—Bull. Natl. Inst. Oceanogr.*, **10**, 151-156.
- Fondekar, S.P., Topgi, R.S. and Noronha, R.J. 1980. Dissolved, absorbed, and adsorbed petroleum hydrocarbons from the central west coast of India. *Indian J. Mar. Sci.* (in press).
- Gardner, D., and Riley, J.P. 1973. Mercury in the Atlantic around Iceland. *J. Cons. Int. Explor. Mer.*, **35**, 202-204.
- George, M.D. and Kureishy, T.W. 1979. Trace metals in zooplankton from Bay of Bengal. *Indian J. Mar. Sci.*, **8**, 190-192.
- Goldberg, E.D. 1965. Minor elements in sea water. In J.P. Riley and G. Skirrow, (Ed.), *Chemical Oceanography*, Academic Press, London, **1**, 163-196.
- Gouveia, A.D. and Kurup, P.G. 1977. Probable movement of a hypothetical oil patch from the Bombay high region. *Indian J. Mar. Sci.*, **6**, 118-121.
- Klein, D.H. and Goldberg, E.D. 1971. Mercury in the marine environment. *Environ. Sci. Tech.*, **4**, 765-768.

- Kureishy, T.W. and George, M.D. 1977. Trace metals in zooplankton from the west coast of India. *NIO Tech. Rep.*, 02/77; 60-62.
- Kureishy, T.W., George, M.D. and Sen Gupta, R. 1980a. Total mercury concentrations in some marine fishes from the Indian Ocean. *Mar. Pollut. Bull.*, (in press).
- Kureishy, T.W., Sanzgiri, S. and George, M.D. 1980b. Concentrations of mercury in fishes from in and around Andaman Seas. *Indian J. Mar. Sci.*, (in press).
- Latimer, W.M. 1952. *Oxidation Potentials*. Prentice Hall, New York, 329 pp.
- Leatherland, T.M., Burton, J.D., McCartney, M.J. and Culkin, F. 1971. Mercury in the north-eastern Atlantic ocean water. *Nature Lond.*, 232, 112.
- Levy, E.M. 1971. The presence of petroleum residues off the east coast of Nova Scotia, in the Gulf of St. Lawrence and the St. Lawrence river. *Water Res.*, 5, 723-733.
- Levy, E.M. 1972. The identification of petroleum products in the marine environment by absorption spectrophotometry. *Water Res.*, 6, 57-69.
- Martin, J.H. 1970. The possible transport of trace metals via moulted copepod exoskeletons. *Limnol. Oceanogr.*, 15, 756-61.
- Nair, S.A., Ansari, Z.A., Harkantra, S.N. and Parulekar, A.H. 1977. Uptake of copper by the mussel *Mytilus viridis*. *Indian J. Mar. Sci.*, 6, 90-91.
- NIO. 1979. Evaluation of chemical dispersant concentrates for their suitability to Indian conditions. *Tech. Rep. No. 03/79*: 48 pp.
- Nair, S.A., Devassy, V.P., Dwivedi, S.N. and Selvakumar, R.A. 1972. Preliminary observations on tar-like material on some beaches. *Curr. Sci.*, 41, 766-767.
- Robertson, D.E., Rancitelli, L.A., Lanford, J.C. and Perkins, R.W. 1972. In *Baseline Studies of Pollutants in the Marine Environment*, Brookhaven National Laboratory, U.S.A., 231 pp.
- Sanzgiri, S. and Moraes, C. 1979. Trace metals in the Laccadive Sea. *Indian J. Mar. Sci.*, 8 (in press).
- Sanzgiri, S., Sen Gupta, R. and Singbal, S.Y.S. 1979. Total mercury concentrations in waters of the Laccadive Sea. *Indian J. Mar. Sci.*, 8 (in press).
- Sen Gupta, R., 1972. On some trace metals in the Baltic. *Ambio*, 3, 226-230.
- Sen Gupta, R., Sankaranarayanan, V.N., De Souza, S.N. and Fondekar, S.P. 1976a. Chemical oceanography of the Arabian Sea—Part III: Studies on nutrient fractions and stoichiometric relationships in the northern and the eastern basins. *Indian J. Mar. Sci.*, 5, 18-34.
- Sen Gupta, R., Rajagopal, M.D. and Qasim, S.Z. 1976b. Relationship between dissolved oxygen and nutrients in north-western Indian Ocean. *Indian J. Mar. Sci.*, 5, 201-212.
- Sen Gupta, R., De Souza S.N. and Joseph, T. 1977. Nitrogen and phosphorus in western Bay of Bengal. *Indian J. Mar. Sci.*, 6, 107-110.
- Sen Gupta, R., Fondekar, S.P. and Topgi, R.S. 1978a. A survey of petroleum hydrocarbon concentrations in the shelf regions and adjacent waters of the west coast of India. *Indian J. Mar. Sci.*, 7, 12-14.
- Sen Gupta, R., Singbal, S.Y.S. and Sanzgiri, S. 1978b. Atomic absorption analysis of a few trace metals in Arabian Sea waters. *Indian J. Mar. Sci.*, 7, 295-299.
- Sen Gupta, R., Naik, S. and Singbal S.Y.S. 1978c. A study of fluoride, calcium and magnesium in the northern Indian Ocean. *Mar. Chem.*, 6, 125-141.
- Sen Gupta, R., Qasim, S.Z., Fondekar, S.P. and Topgi, R.S. 1980. Petroleum hydrocarbon concentrations in some parts of the northern Indian Ocean. *Mar. Pollut. Bull.*, (in press).
- Singbal, S.Y.S., Sanzgiri, S. and Sen Gupta, R. 1978. Total mercury concentrations in the Arabian Sea waters. *Indian J. Mar. Sci.*, 7, 124-126.
- Solimabi and Topgi, R.S. 1978. Chemical characteristics of some indigenously manufactured oil dispersants. *Indian J. Mar. Sci.*, 7, 203-205.
- Spencer, D.W. and Brewer, P.G. 1969. Distribution of Cu, Zn, Ni, in sea water of the Gulf of Maine and the Sargasso Sea. *Geochim. Cosmochim. Acta.*, 33, 325-339.

- Stumm, W. and Morgan, J.J. 1970. *Aquatic Chemistry*. Interscience, New York, 583 pp.
- Szabo, B.J. 1968. Trace element content of plankton populations from the Bahamas. *Carib. J. Sci.*, 8; 185-186.
- Tejam, B.M. and Haldar, B.C. 1975. A preliminary survey of Hg in fish from Bombay and Thane environment. *Ind. J. Environ. Hlth.*, 17, 9-16.
- Topping, G., 1969. Concentration of Mn, Co, Cu & Fe in the northern Indian Ocean and Arabian Sea. *J. Mar. Res.*, 27, 318-326.
- UNESCO, 1976. Guide to Operational Procedures for the IGOSS Pilot Project on Marine Pollution (Petroleum) Monitoring. *Manual and guides*, 7, 50 pp. mimeo.
- Varadachari, V.V.R. and Sharma G.S. 1967. Circulation of the surface waters in the North Indian Ocean. *J. Indian Geophys. Un.*, 4, 61-73.
- Verlencar, X.N., Bhosle, N.B. and Parulekar, A.H. 1977. Toxicity tests of oil dispersants on some marine organisms. *Mahasagar—Bull. Natl. Inst. Oceanogr.*, 10, 109-115.
- Zingde, M.D., Singbal, S.Y.S., Moraes C.F. and Reddy, C.V.G. 1976. Arsenic, copper, zinc and manganese in the marine flora and fauna of coastal and estuarine waters around Goa. *Indian J. Mar. Sci.*, 5, 212-217.