

- Portmann, J. E. & Connor, P. M. (1968). The toxicity of several oil-spill removers to some species of fish and shellfish. *Mar. Biol.*, **1**, 322-329.
- Spooner, M. F. (1977). Oil spill in Hong Kong. *Mar. Pollut. Bull.*, **8**, 62-65.
- Stirling, H. P. (1977). Effects of a spill of marine diesel oil on the rocky shore fauna of Lamma Island, Hong Kong. *Envir. Pollut.*, **12**, 93-117.
- Wilson, K. W. (1974). Toxicity tests for ranking oils and oil dispersants. In: *Ecological Aspects of Toxicity Testing of Oils and Dispersants* (L. R. Beynon & E. B. Cowell, Eds), pp. 11-22. Applied Science Publishers, London.
- Wilson, K. W., Cowell, E. B. & Beynon, L. R. (1974). The toxicity testing of oils and dispersants: a European view. In: *Ecological Aspects of Toxicity Testing of Oils and Dispersants* (L. R. Beynon & E. B. Cowell, Eds), pp. 129-141. Applied Science Publishers, London.
- Wormald, A. P. (1976). Effects of a spill of marine diesel oil on the meiofauna of a sandy beach at Picnic Bay, Hong Kong. *Environ. Pollut.*, **11**, 116-130.
- Wu, R. S. S. (1981). Differences in the toxicities of an oil dispersant and a surface active agent to some marine animals, and their implications in the choice of species in toxicity testing. *Mar. envir. Res.* (in press).

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Mercury in Thana Creek, Bombay Harbour

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Mercury content of the water column estimated along Thana Creek/Bombay Harbour gave a standing stock of about 77 kg in excess of the expected background. Mercury concentration in sediment from 23 locations which varied from 0.17 to 8.21 ppm (dry weight) with marked increase from the harbour to the creek region suggests substantial mercury input in the head region. Chemical extraction by hydrogen peroxide indicated that more than 70% of mercury was leachable and probably organically bound. The mercury enriched layer in the sediment cores was about 10-25 cm in the creek region and 0-8 cm in the harbour area. The data has been used to calculate an excess of 14 tonnes of mercury over the natural background. Analysis of a few zooplankton and benthic samples from the creek region gave indication of bioaccumulation of mercury.

Phenomenal increases in the industrial growth in and around Bombay (lat. 18° 55' N, long. 72° 49' E) has resulted in the use of Thana Creek for the release of industrial waste water amounting to about 56 m l d⁻¹ (million litres per day) from the eastern as well as the western shores. In many cases the waste is released without prior treatment. In addition, large quantities of domestic waste water from the densely populated localities along the western shores are released in the creek as well as the harbour regions. Earlier studies have clearly shown the signs of deteriorating water quality, especially of the creek (Zingde *et al.*, 1979). It has been found that the levels of some heavy metals are higher in the creek water as compared to the coastal region of Bombay (NIO, 1978). This paper examines the extent of pollution in Thana Creek and Bombay Harbour with special reference to mercury.

Materials and Methods

Water samples (500-2000 ml) for mercury analysis were obtained from some stations (Table 1) during May 1978. The sample was drawn in a precleaned glass bottle and preserved by adding acidified potassium permanganate. In the laboratory, mercury was preconcentrated and analysed by flameless atomic absorption (Harsanyi *et al.*, 1973). Replicate analyses (8) of a sample containing an average of 303 ng l⁻¹ gave standard deviation of ± 20 ng l⁻¹. Sewage waste water samples collected from Colaba and Ghatkopar treatment plants were analysed by a similar procedure after treatment with potassium persulphate. Samples were also collected for dissolved oxygen (DO) and salinity determination (Grasshoff, 1976).

Sediment samples obtained by Van Veen grab were collected from all the locations marked in Fig. 1. Seven sediment cores up to 35 cm long were obtained by a gravity corer (50 mm dia.), at positions shown in Fig. 1. The cores after return to the laboratory were sampled at 2 cm intervals. The subsample was transferred to an acid cleaned polyethylene container and kept frozen until the time of analysis. Mercury was leached by refluxing with nitric acid (Windom & Cutshall, 1976) and then determined by flameless atomic absorption. Replicate analyses (10) of a sample containing an average of 8.21 ppm (dry wt) gave standard deviation of ± 0.9 ppm. Dry weight was determined separately. A wet oxidation method described elsewhere (FAO, 1975) was used for determining oxidizable matter.

Zooplankton samples were collected using a Heron Tranter Net (mesh size 0.3 mm; mouth area 0.25 m²) and benthos samples were obtained by Van Veen grab. The sediment was sieved through a 0.45 mesh sieve and the

TABLE 1
Mercury and some other parameters for water and surface sediments

Station	Tide	Water				Sediment			
		Salinity (%)		Dissolved oxygen (mg l ⁻¹)		Mercury (ng l ⁻¹) Surface *	Moisture content (%)	Oxidizable matter (%)	Mercury ppm (dry wt)
		Surface	Bottom	Surface	Bottom				
1	Eb	35.78	36.06	1.8	3.6	—	68.1	4.2	8.21
2	Eb	35.49	35.31	2.8	3.1	320	70.6	—	7.90
3	Eb	—	—	—	—	—	74.8	2.2	6.23
4	Eb	36.12	36.14	4.0	4.0	303	66.8	2.8	4.36
5	Eb	—	—	—	—	—	68.6	1.3	4.71
6	Eb	37.09	36.89	4.8	5.0	—	66.2	2.6	5.20
7	Eb	36.05	36.81	5.3	5.3	316	65.5	0.8	4.27
8	Eb	—	—	—	—	—	67.2	3.9	1.95
9	Eb	36.94	37.86	4.2	4.9	289	70.3	—	2.53
10	Eb	—	—	—	—	—	69.8	1.7	4.94
11	Eb	36.12	36.84	6.5	5.6	266	75.1	2.6	1.70
12	Eb	36.04	36.91	6.3	6.1	—	76.5	1.9	1.80
13	Fl	37.16	37.09	6.1	6.4	—	70.2	1.3	0.32
14	Fl	37.65	38.11	6.3	6.5	132	77.4	—	0.27
15	Fl	37.31	37.42	5.5	5.5	—	77.9	1.1	0.61
16	Fl	37.47	38.14	6.4	5.8	241	73.5	—	0.39
17	Fl	36.92	37.64	6.0	5.9	—	68.3	2.5	0.23
18	Fl	37.21	36.46	6.3	5.8	242	69.0	0.9	0.27
19	Fl	36.16	36.46	6.5	6.3	—	64.4	1.2	0.17
20	Eb	36.32	36.25	6.0	6.2	—	60.8	2.6	0.24
21	Eb	36.40	36.24	6.4	6.3	287	65.0	—	0.27
22	Eb	36.09	35.80	6.7	6.3	—	60.9	—	0.24
23	Eb	36.10	36.32	6.7	6.7	79	60.1	0.9	0.17

organisms retained were taken for analysis. Mercury was analysed by the procedure similar to the one used for sediments (Windom & Cutshall, 1976).

Results and Discussion

Salinity data (Table 1) with a negligible vertical gradient indicate the well mixed nature of the water column. Some decrease at Stations 1 and 2 may result due to the flow of less saline water from the Ulhas River. Appreciable stratification has been observed during June–August, the period of high monsoonal fresh water flow into the creek and harbour regions (Zingde *et al.*, 1979). General decrease in DO from the harbour to the creek is immediately evident from Table 1. Low DO at Stations 1 and 2 clearly indicate the influence of organic load released in the region.

Mercury in water

A total of 10 surface samples analysed for mercury gave values varying in the range 79–320 ng l⁻¹. These values are for dissolved plus acid leachable mercury, as the samples were not filtered. Contribution from particulate matter therefore may be included in our values. The metal may be

partly organically bound but treatment with potassium permanganate oxidizes most of such compounds (Omang, 1971). Although the average concentration in sea water is taken to be 30 ng l⁻¹ (Goldberg, 1963), reported values from areas uncontaminated by external waste discharge vary in a rather broad range from nondetectable to 364 ng l⁻¹ (Fitzgerald & Lyons, 1975). Recently concentrations in the range 13–407 ng l⁻¹ are reported for total mercury in the Arabian Sea waters (Singbal *et al.*, 1978). The flux from domestic and industrial activity has been considered to be approximately equal to the natural flux from weathering, vulcanism and degassing of soils (Klein & Goldberg, 1970).

Some samples collected outside the harbour mouth gave an average mercury concentration of 75 ng l⁻¹. An estimate of the amount of mercury in the water column of Thana Creek/Bombay Harbour is obtained for low tide by approximating the density of water to 1 g cm⁻³ and assuming continuity of the distribution between sampling stations and depths (Table 2). The standing stock in the bay totals 194.5 kg. If we assume 75 ng l⁻¹ as the background level in the coastal water of Bombay then excess mercury in the bay region is about 77 kg. The quantity of input of mercury through industrial waste water is not known. The annual

TABLE 2
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

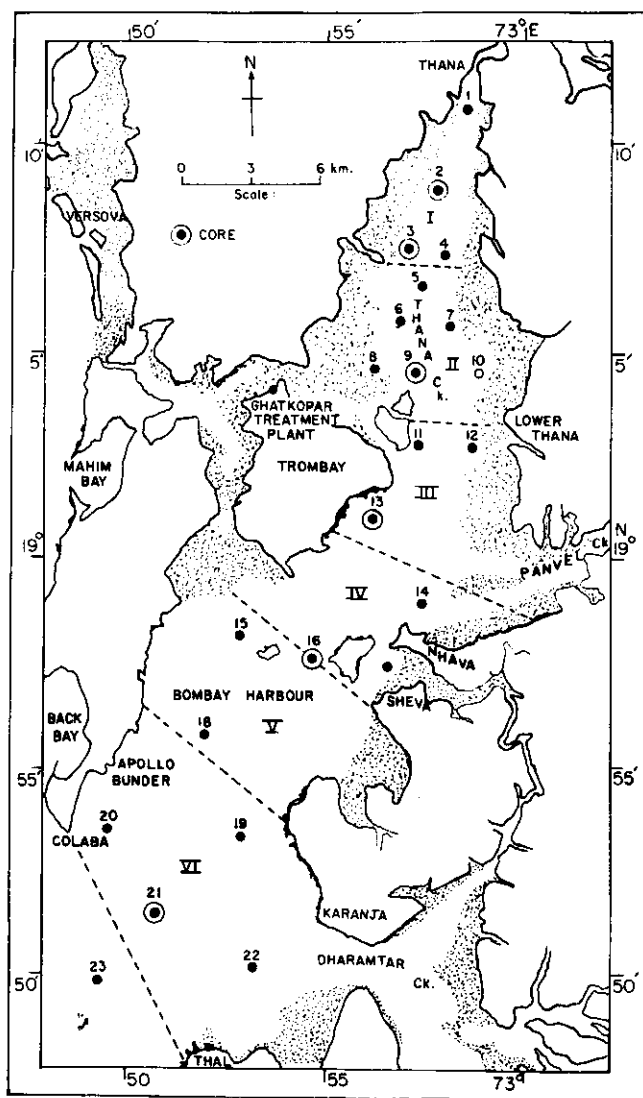


Fig. 1 Map showing locations of sampling stations.

consumption of mercury in Bombay is estimated at 100 tonnes out of which 90% is used by industries which produce mainly caustic soda and caustic potash. It has been considered that a loss of 30–40 g of mercury per ton of chlorine is unavoidable in the absence of special measures for the removal of metal from the waste water prior to discharge (Keches & Miettinen, 1972). Thana Creek/Bombay Harbour receives at least 250 ml d⁻¹ of domestic waste water from some treatment plants and pumping stations on the western bank. Effluents from the major treatment plants located at Colaba and Ghatkopar gave mercury concentration ranging from 100 to 1200 ng l⁻¹ with an average of 650 ng l⁻¹. Mercury released through sewage is therefore about 160 g per day.

Mercury in sediment

In Thana Creek/Bombay Harbour, total dry weight mercury concentration in bottom grab samples varied from 0.17 to 8.21 ppm (av. 2.47 ppm). The concentration is much higher than those reported for areas free from mercury contamination. In some parts of St Lawrence estuary and Gulf of St Lawrence where the sediments have been reported to be contaminated by mercury, the background levels were about 0.25 ppm (Loring & Bewers, 1978).

Concentrations of as low as 0.01 ppm have been reported for areas uncontaminated by mercury discharges (Knauer, 1976).

The surface distribution (Table 1) shows that the mercury generally decreased downstream from Station 1 to Station 9. This pattern suggests that there have been major mercury inputs in the upper reaches of the creek. The accumulation of mercury in sediments of Thana Creek and in other localities such as Minamata Bay, Japan, Saint Clair River, Michigan, and Mellingham Bay, Washington (Crecelius *et al.*, 1975) indicate that sediments serve as sink for part of the industrially discharged mercury. However, there is some evidence to indicate that the sediments may not be a permanent sink of mercury (Crecelius *et al.*, 1975). The high suspended load in Thana Creek/Bombay Harbour (Fig. 2) may be responsible for efficient removal of added mercury to the sediment. The data for the suspended load was collected during the earlier survey (1976–77). High load during June–September was associated with the land drainage. General decrease at Station 2 may be due to the weaker currents. Due to the great affinity of mercury compounds to –SH groups and the common occurrence of trace quantities of proteinous materials in natural waters it may be considered that the mercury in water is usually bound to organic matter in the suspended material, plankton, etc. Bothner & Carpenter (1972) showed that when mercury concentration was increased by a factor of only 2, 50% of added mercury was absorbed onto the suspended matter within 10 h.

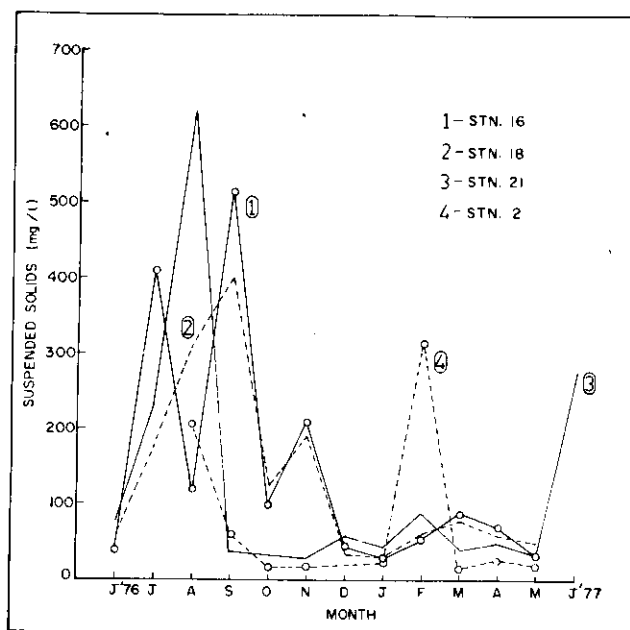


Fig. 2 Monthly variation of suspended solids at some stations.

Some workers (Crecelius *et al.*, 1975; Lindberg *et al.*, 1975) have reported a correlation between organic matter and mercury in the sediment. However, the mercury/oxidizable matter correlation for surface sediments of Thana Creek is not regular (Table 1). This may result because mercury and organic matter are introduced through different sources at different locations because of which the areas influenced by industrial mercury may have relatively low organic matter and areas receiving domestic

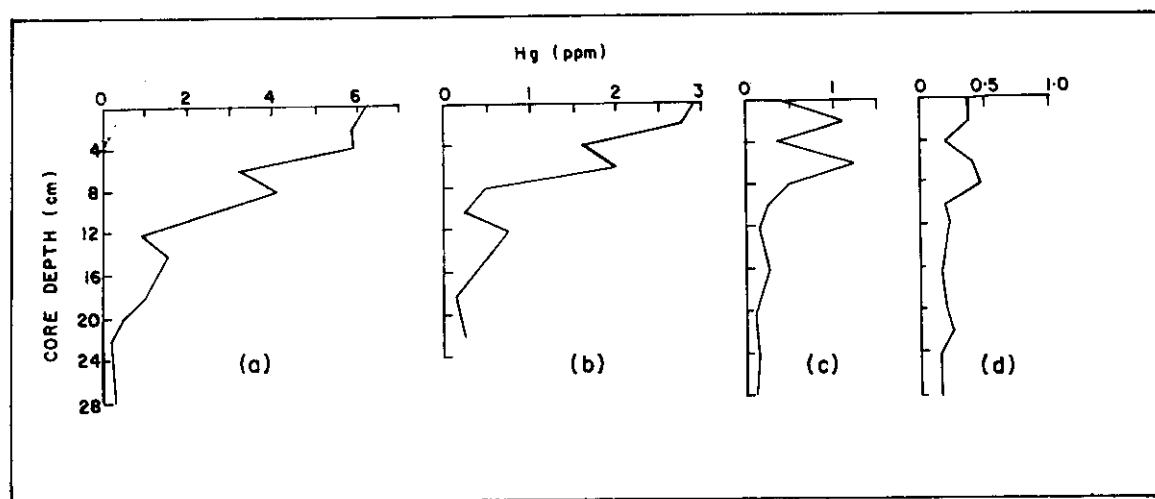


Fig. 3 Mercury in sediment cores: (a) Station 3, (b) Station 9, (c) Station 13, (d) Station 16.

TABLE 3
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

waste water have higher organic matter. Oxidizing sediment collected from Station 4 was subjected to chemical extraction by hydrogen peroxide. More than 70% of mercury was extracted and is presumably bound to the organic matter. Table 1 also reveals lower levels of mercury in the surface sediments of the harbour region. Two reasons are possible for this observation. There are no major industrial discharges and also the region is subject to frequent dredging. Higher values at Stations 15, 18 and 20 as compared to Stations 17, 19 and 22 are perhaps due to the greater human activity along the west coast of the harbour region.

The sub-surface sediments are similar to surface sediments and are composed of bluish-grey to black muds and sandy muds sometimes containing silty material. The penetration of mercury concentration is revealed from depthwise analysis of cores taken along the length of the creek/harbour (Fig. 3). The vertical distribution shows that the mercury enriched layer (sediment containing more than 0.2 ppm) decreases in thickness from about 20 cm at Station 2 and only 2 cm at Station 19. The core from Station 21 did not show any significant enrichment which may be due to dredging operations. It therefore appears that most mercury sediment contamination is restricted to the creek region. At the head of the creek, the sediment down to 12 cm contains 1 ppm mercury and at 20 cm, 0.5 ppm. Below this depth the concentration decreased and remained almost constant at 0.3 ppm. At Station 9, the depth of substantial mercury contamination was 12 cm and decreased to 8 cm at Station 13. This pattern represents gradual accumulation of mercury in the sediments for a sufficient length of time to deposit and to disperse the mercury enriched material downstream.

The data were used to calculate the amount of mercury in excess of the natural background. It is assumed that the distribution is continuous between sample sites and that sediment density is constant (1.45 g cm⁻³). From Table 3 it is clear that the creek sediment contains about 14 tonnes of mercury in excess of natural amounts by assuming the background level to be 0.15 ppm (wet wt).

Biological samples

Results of zooplankton and benthos analysis are summarized in Table 4. A sample of sufficient size of one group of organisms was not available for species-specific differ-

TABLE 4
Mercury in some biological materials

Station	Sample	Abundant groups	Water content (%)	Mercury ppm (dry wt)
6	Zooplankton	Copepods Chaetognaths Decapod larvae	86	0.95
12	Zooplankton	Copepods Chaetognaths Decapod larvae	79	0.49
13	Zooplankton	Copepods Chaetognaths Decapod larvae	84	0.87
6	Benthos	Crabs Polychaetes Bivalves	90	2.61
12	Benthos	Crabs Polychaetes Bivalves	90	3.03

ences, hence, organisms from a particular station were pooled together for analysis. The average mercury content of 0.73 ppm in zooplankton is higher than 0.2 ppm found in plankton from open ocean (Knauer & Martin, 1972) and in nearshore regions of North Carolina and New York (Cocoros *et al.*, 1973). Average mercury contents of 0.5 ppm have been found in zooplankton samples off the eastern coast of the United States between Cape Hatteras and Cape Cod (Windom *et al.*, 1973). In a polluted Norwegian Fjord, concentrations of 0.52–25.21 ppm have been reported by Skei *et al.* (1976). The uptake mechanisms and possible transformation reactions of mercury in aquatic ecosystem have been discussed (Gavis & Ferguson, 1972; Fagerstrom & Jernelov, 1972). The average concentration of 2.82 ppm in benthos indicate bioaccumulation when compared to the levels in the organisms from the unpolluted regions of the Baltic (Nuorteva & Hasanen, 1975). Mercury content of 0.09–0.21 ppm (wet wt) has been recently reported in the fishes of the Arabian Sea and the Bay of Bengal (Kureishy *et al.*, 1979).

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Bothner, M. H. & Carpenter, R. (1972). Sorption-desorption of mercury with suspended matter in the Columbia River. IAEA Symposium on the interaction of radioactive contaminants with constituents of the marine environment. Seattle.

Cocoros, G., Cahn, P. H. & Siler, W. (1973). Mercury concentrations in fish, plankton and water from three Western Atlantic estuaries. *J. Fish. Biol.*, **5**, 641–647.

Crecelius, E. A., Bothner, M. H. & Carpenter, R. (1975). Geochemistries of arsenic, antimony, mercury and related elements in sediments of Puget Sound. *Environ. Sci. Technol.*, **9**, 325–333.

Fagerstrom, T. & Jernelov, A. (1972). Aspects of the quantitative ecology of mercury. *Wat. Res.*, **6**, 1193–1202.

FAO (1975). Manual and methods in aquatic environment research. Part I – Methods of detection, measurement and monitoring of water pollution. FAO. pp. 201, Rome.

Fitzgerald, W. F. & Lyons, W. B. (1975). Mercury concentrations in open ocean waters: Sampling procedure. *Limnol. Oceanogr.*, **20**, 468–471.

Gavis, J. & Ferguson, J. F. (1972). The cycling of mercury through the environment. *Wat. Res.*, **6**, 989–1008.

Goldberg, E. D. (1963). The oceans as a chemical system. In: *The Sea*, Vol. 2, pp. 3–25, M. N. Hill (Ed.). Interscience, New York.

Grasshoff, K. (1976). *Methods of Sea Water Analysis*. Verlag Chemie, Weinheim, New York.

Harsanyi, E., Polos, L. & Pungor, E. (1973). Enhancement of sensitivity for the determination of mercury in waters. *Anal. Chim. Acta*, **67**, 229–233.

Keches, S. & Miettinen, J. K. (1972). Mercury as a marine pollutant. In: *Marine Pollution and Sea Life*, pp. 276–289, Ruivo (Ed.). Fisheries News (Books), London.

Klein, D. H. & Goldberg, E. D. (1970). Mercury in the marine environment. *Environ. Sci. Technol.*, **4**, 765–768.

Knauer, G. A. (1976). Immediate industrial effects on sediment mercury concentrations in a clean coastal environment. *Mar. Pollut. Bull.*, **7**, 112–115.

Knauer, G. A. & Martin, J. H. (1972). Mercury in a marine pelagic food chain. *Limnol. Oceanogr.*, **17**, 868–872.

Kureishy, T. W., George, M. D. & Sen Gupta, R. (1979). Total mercury content in some marine fish from the Indian ocean. *Mar. Pollut. Bull.*, **10**, 357–360.

Lindberg, S. E., Andren, A. W. & Harriss, R. C. (1975). Geochemistry of mercury in the estuary environment. *Estuar. Res.*, **1**, 64–107.

Loring, D. H. & Bewers, J. M. (1978). Geochemical mass balances for mercury in a Canadian Fjord. *Chem. Geol.*, **22**, 309–330.

NIO (1978). Studies on waste water disposal and submarine outfall around Bombay. National Institute of Oceanography, Project Report.

Nuorteva, P. & Hasanen, E. (1975). Bioaccumulation of mercury in *Myoxocephalus quadricornis* (L.) (Teleostei, Cottidae) in an unpolluted area of the Baltic. *Ann. Zool. Fennici*, **12**, 247–254.

Omang, S. H. (1971). Determination of mercury in natural waters and effluents by flameless atomic absorption spectrophotometry. *Anal. Chim. Acta*, **53**, 415–420.

Singhal, S. Y. S., Sanzgiri & Sen Gupta, R. (1978). Total mercury concentrations in the Arabian Sea waters off the Indian coast. *Ind. J. mar. Sci.*, **7**, 124–126.

Skei, J. M., Saunders, M. & Price, N. B. (1976). Mercury in plankton from a polluted Norwegian Fjord. *Mar. Pollut. Bull.*, **7**, 34–36.

Windom, H. L. & Cutshall, N. (1976). Atomic absorption spectrophotometry. In: *Strategies for Marine Pollution Monitoring*, pp. 161–184, E. D. Goldberg (Ed.). Wiley, New York.

Windom, H. L., Taylor, F. & Stickney, R. (1973). Mercury in North Atlantic plankton. *J. Cons. Int. Expl. Mer.*, **35**, 18–21.

Zingde, M. D., Trivedi, S. K. & Desai, B. N. (1979). Physico-chemical studies on coastal pollution off Bombay. *Ind. J. mar. Sci.*, **8**, 271–278.

Ocean Dumping of Seafood Wastes in the United States

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In the United States fish wastes can be ocean dumped without an Ocean Dumping Permit if the wastes contain no additives (flocculating or preserving agents, etc.). Fish wastes are currently ocean dumped off American Samoa, Louisiana and Puerto Rico. Fish wastes are characteristically high in proteins, fats, dissolved and suspended organic

materials. Water quality parameters affected by these wastes are biochemical oxygen demand, total dissolved solids, chemical oxygen demand, oil and grease, pH, and turbidity. Other key factors include organic and nutrient enrichment, the attractant of undesirable predator species (i.e. sharks) and the natural oxygen regeneration processes.