

Analysing a few surface samples, collected between 26° and 28°S in the Indian Ocean, Chester *et al.*⁶ have reported values varying from 9-52 ng/litre. This area being somewhat north of the subtropical convergence in the Indian Ocean, lies close to the sources of origin of the north Indian Ocean Deep Water. Values between non-detectable limit and 60 ng/litre are observed in the present study from the area 8° to 12°N at depths having a similar water mass (Table 1). This agreement is interesting and the slight variation obtained between the 2 sets of values may be due to some mixing with overlying and underlying water masses. This is only a conjecture as the values are too few to draw any definite conclusions.

Variations of mercury with depth have been studied at st 873 where sampling has been done up to 2000 m. Concentrations decrease with depth. This is attributable to different characteristics of the water masses as noted above or to the general cycle of mercury in the marine environment.

In the Laccadive Sea, mercury values in general at the surface increase from north to south. A similar trend has been observed in the coastal regions of the Arabian Sea in the same season (premonsoon)⁸.

In general, the surface mercury concentrations decrease as we move offshore. This is in agreement with the observations in the Arabian Sea made earlier⁸.

A high mercury concentration at the surface was observed during the 16th cruise at st 326. This solitary high value was left out for further confirmation as it was suspected that this might be the effect of some contamination⁸. Mercury deposits were observed in crustal rocks of the hinterland between Calicut and Karwar¹². This might affect the surface concentration of mercury in this area due to weathering and atmospheric flux. To test this idea further, close sampling was made during the 31st cruise in that area at about 50 m isobath (sts 875-881). Surface concentrations ranged from 100-204 ng/litre (av. 156 ng/litre). The values, excluding one, were not higher than those from the other stations. Hence, the leaching of the mercury from the hinterland did not appear to be very significant. The existence of one isolated high value, however, remains unexplained.

Average surface mercury concentration in the Laccadive Sea was 91 ng/litre (range 60-120 ng/litre). In the coastal waters of the Arabian Sea the average surface value was 136 ng/litre⁸ and for the entire Arabian Sea the average value at the surface was 120 ng/litre. Pooling the observations of all the cruises the average concentration at the surface for the northern Indian Ocean would be 106 ng/litre.

There are very few observations on the mercury concentrations from the surface waters of the open ocean. The reported range values (ng/litre) are:

Atlantic^{6,7}, 0.5-225; Pacific⁵, 12-153; Southern Indian Ocean, 9-74; China and Japan Seas⁶, 6-51; and northern Indian Ocean, 0-221.

Kureishy *et al.*¹³ have analysed a few edible fishes from the Indian Ocean and obtained a concentration of 0.09-0.21 ppm (wet weight basis) of mercury. This range is far below the limit of acceptability (0.5 ppm). Combining present observations for the water, with their data, for the edible fishes, it can be concluded that the Indian Ocean is almost free from mercury pollution.

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Trace Metals in the Laccadive Sea

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Concentrations of Cu, Fe, Mn, Zn, Co and Ni, measured both in dissolved and particulate forms at 5 stations in the Laccadive Sea, were within the range reported for other areas of the world ocean. Only one station away from the islands, showed somewhat higher values for most of the metals. Dissolved Cu showed a decrease with depth. Dissolved Fe and Mn, on the other hand, showed a marked increase at a depth of 500 m.

The metals Cu, Fe, Mn, Zn, Co, Ni occur in sea water in different forms. These metals can become toxic to marine life when they exceed certain levels of concentration. To predict the trace metals acting as pollutants, it is necessary to have data of their baseline concentrations. Metals in particulate forms occur in

the sediments and their presence is closely linked with the chemical and hydrological properties of the sea. The particulate forms also form a part of food of some detritophagus organisms.

Samples were collected with utmost care to avoid contamination in PVC van Dorn samplers with rubber sealed end-caps. The minimum depth was fixed as 10 m so as to avoid contamination due to the 3.5 m ship's metallic hull.

Samples were filtered through 0.45 μm millipore filters under vacuum. The filtrate was transferred to acid-washed polythene carboys and acidified to pH 3-4 with 1 N HCl. The filter papers having the suspended material were refrigerated in flat plastic containers. The containers with the filtrate and the filters were transferred to the shore laboratory for analysis.

To determine the concentrations of dissolved metals, each sample was divided into 4 aliquots of 400 ml each. Using the method of Brewer *et al.*¹ these were spiked with known concentrations of standard solutions of different metals, chelated with ammonium pyrolydine dithiocarbamate (APDC) and solvent-extracted with methyl isobutyl ketone (MIBK). The concentration of each metal was estimated by atomic absorption spectrophotometry (Hilger Watts Atomspek model H 1550).

Dissolved manganese remained unextracted with APDC-MIBK combination. Hence, it was separately extracted by chelation with sodium diethyl dithiocarbamate at pH 5-6 and solvent extraction with MIBK. It was found to give maximum recovery at this pH range.

The filter papers with the suspended matter and blank filters were dried in a desiccator containing silica gel and weighed. The filters were then transferred to conical flasks and to each 1 ml perchloric acid was added. When digestion was complete and the substance got dried on a hot plate, it was further treated with 2 aliquots of conc. HNO_3 (2 ml each time). When all the NO_2 was expelled and the residue became dry, a drop of conc. HCl was added and the whole residue was dissolved in 0.1 N HCl, heated to boiling, cooled and then made up to 10 ml in each case. Known standards and blanks were similarly treated and all samples were analysed by atomic absorption spectrophotometry.

In the present study only a few selected stations at pre-determined depths were sampled. The station number, their sampling depths and concentration of different metals in dissolved and particulate forms are given in Table 1. Average values of metals along with standard errors are also given in Table 1.

At 10 m depth (surface) most of the metals were higher at st 857, away from the islands, than at the stations close to the islands. This shows that there is no land influence on the metal concentration. The

concentration of dissolved Fe at 500 m depth at st 857 was almost double the average concentration of Fe at the same depth at the stations around the islands. The concentration of dissolved Mn at 500 m depth at st 857 was almost half the average concentration of Mn at the same depth at the other stations.

Dissolved oxygen at all stations decreased with depth reaching its minimum at 500 m. The concentrations of Fe had a similar distribution. The average concentration of Fe at 1000 m depth at most of the stations was greater than that at 500 m depth (Table 1).

The present data are insufficient to correlate the concentrations of different metals to their chemical speciation. Hence, it is not possible to discuss the chemistry of metals under study. However, a tentative prediction can be made of their speciation, considering the values of the dissolved and the particulate forms of the metals, the temperature, salinity, dissolved oxygen and pH of the water.

The average concentration of Cu was found in the upper layer (10 m depth) to be nearly 13.3 ± 1.1 $\mu\text{g/litre}$ and no particular pattern in its distribution was observed with depth. The values were, however, well within the range 0.2-22 $\mu\text{g/litre}$ given by Pytkowicz and Kester² for sea water. Dissolved copper is controlled by the redox conditions of the sea water³, as the solubility of complexes depends on redox conditions.

At most of the stations, dissolved Cu was higher towards the upper layers than in the middle layers (Table 1), indicating that the release of Cu occurs due to organic decomposition towards the surface and that optimum redox conditions are lacking in the middle layers. The concentration of particulate Cu was appreciable in deeper layers than in the upper layers. Due to metal- $\text{H}_2\text{O}-\text{CO}_2$ system about the coral base, which renders carbonates stable solid phases, the material in suspension is enriched with the metal. This explains the higher surface value for Cu, 13.3 ± 1 $\mu\text{g/litre}$, compared to an earlier reported value 4.7 ± 0.4 $\mu\text{g/litre}$ in the Arabian Sea⁴ in the same season.

The average concentration of dissolved Fe at stations around the islands was 25.3 $\mu\text{g/litre}$ whereas that at st 857 was 36.5 $\mu\text{g/litre}$. Higher concentration of dissolved Fe further away from the islands and lower values of particulate Fe correspond with the low oxygen value observed away from the islands. At almost all stations in the Laccadive Sea, higher concentrations of particulate Fe indicate the predominance of colloidal Fe^{3+} and organic matter, for the concentration of Fe present in sea water is a measure of organic matter⁵. An increase in the concentration of dissolved iron was observed at 500-1000 m depth region, in accordance with the low oxygen concentration present at this depth range. Fe

Table 1—Concentrations of Metals along with Average and SE Values in Dissolved and Particulate Form in the Laccadive Sea with the Corresponding Oxygen and pH Values

Depth m	Dissolved oxygen ml/l	pH	[Metal concentrations expressed in µg/litre (dissolved form) and µg/g (particulate form)]											
			Cu		Fe		Mn		Zn		Co		Ni	
			D	P	D	P	D	P	D	P	D	P	D	P
St 857 (12°13.5'N, 72°22'E)														
10	4.09	8.17	16.1	420	36.5	1422	16.6	271	29.7	3085	1.3	—	13.1	203
100	2.80	8.1	5.6	162	14.5	2125	23.4	284	4.7	1178	1.1	—	7.5	87
250	0.49	7.8	4.6	656	85	—	75	46	1.2	147	ND	42	1.3	24
500	0.29	7.78	11.9	533	55.5	583	20.8	89	8.7	516	ND	ND	16.1	13
St 867 (10°05'N, 72°56'E)														
10	4.58	7.93	19.9	146	43.2	2104	13.5	130	8.4	3901	ND	ND	16.3	38
100	3.63	7.91	5.7	22	27	751	16.2	24	1.9	309	6.7	ND	1.9	ND
500	0.67	7.47	12	11	10.5	873	23.7	30	3.0	155	2.2	ND	2.0	58
1000	0.54	7.45	15.7	411	26.7	692	40.2	24	11.0	1086	1.9	ND	1.9	138
St 869 (9°16.5'N, 72°35'E)														
10	5.19	8.23	9.4	130	18.6	2116	7.7	107	4.6	580	5	86	2.7	46
100	3.85	8.19	3.9	51	17.2	430	37	129	3.2	467	ND	ND	ND	54
500	0.47	7.72	13.4	240	10.8	909	80	80	13.6	224	3.8	144	7.0	ND
1000	0.66	7.69	6.9	328	96	4600	28.7	84	9.7	1280	1	ND	5.6	152
St 871 (8°32'N, 73°26.5'E)														
10	4.64	8.14	—	32	—	7603	—	192	—	92	—	ND	—	127
100	3.14	8.07	3.7	35	13	1798	3.8	28	1.8	4356	ND	ND	0.6	44
500	0.59	7.68	2.1	48	28.2	1648	26.7	55	4.9	1128	ND	ND	ND	35
1000	0.91	7.66	1.9	118	15.7	2121	41	94	11.2	768	ND	74	3.9	16
1500	1.59	7.67	8.9	67	21	2622	12.3	64	2.0	599	1.7	30	2.7	72
St 873 (9°26'N, 73°45'E)														
10	5.42	8.2	8.0	87	14.2	2584	10.3	349	2.9	765	ND	74	8.2	70
100	4.18	8.13	16.9	18	25.2	1133	5.2	63	4.7	446	ND	ND	2.7	34
500	0.62	7.62	2.1	—	49.5	2557	41.5	80	6.0	840	ND	ND	1.3	18
1000	1.06	7.62	6.9	76	35.2	2765	1.8	106	7	583	ND	ND	3.4	ND
1500	2.06	7.62	8.1	169	8.5	1338	2.0	53	9	1045	ND	ND	4.0	123
2000	—	—	3.4	66	10.5	1402	2.7	15	8.5	609	ND	100	2.5	52
Average values with SE														
10	4.78	8.13	13.3	163	28.1	3166	12	210	11.4	1685	ND	ND	10.1	97
	±0.31	±0.14	±1.1	±5	±1.7	±21	±0.9	±4	±1.6	±17			±1.1	±3
100	3.52	8.08	7.2	58	19.4	1247	17.1	106	33	1351	ND	ND	2.5	44
	±0.31	±0.14	±1	±3	±1.1	±9	±1.6	±4	±0.5	±17			±0.7	±2
500	0.47	7.65	8.3	208	30.9	1314	38.5	67	7.2	573	ND	ND	5.3	25
	±0.16	±0.14	±1	±7	±1.9	±12	±2.1	±2	±0.8	±9			±1.1	±2
1000	0.70	7.60	7.8	233	43.4	2544	27.9	77	9.7	929	ND	ND	3.7	76
	±0.18	±0.13	±1.1	±5	±2.6	±17	±2	±2	±0.6	±7			±0.6	±4

ND, not detectable; D, dissolved; P, particulate; SE, standard errors

occurs in the form of Fe²⁺ and Fe³⁺. However, in the sea, Fe²⁺ gets converted to Fe³⁺ by dissolved oxygen and under alkaline conditions, Fe³⁺ appears either in a soluble complex or in colloidal form⁶. Mn on the contrary exists in Mn²⁺ and Mn⁴⁺. The oxidation of Mn²⁺ to Mn⁴⁺ by dissolved oxygen appears to be slow under weak alkaline conditions. The study of both Fe and Mn has received a greater attention among the heavy metals because they have a tendency to form hydrous oxides with dissolved oxygen in the presence of water and these hydrous oxides are the chief carriers of the other heavy metals like Zn, Co, Ni, Cu⁶.

The average concentration of dissolved Mn at the

surface increased with depth, and the highest value was recorded at 500 m and 1000 m depth (Table 1). At st 873, low concentration of dissolved Mn was observed at all depths except at 500 m (Table 1). At depths > 1000 m, very low concentrations of dissolved Mn were found showing that in deeper layers redox conditions are not optimum to bring Mn into soluble form. The concentration of dissolved metals are also likely to be controlled by insoluble carbonates. Particulate Mn was appreciably lower than particulate Fe at all depths and at all stations.

Zn concentrations at stations nearer to the islands were lower than at the station away from islands.

Highest concentration of dissolved Zn was at st 857 (29.7 $\mu\text{g/litre}$). Surface values of dissolved Zn ranged from 2.9-29.7 $\mu\text{g/litre}$. This range is lower than that observed earlier in the Arabian Sea⁴. Particulate zinc made a significant fraction in the Laccadive Sea. Except at st 857, dissolved Zn was significantly lower at the surface than in deeper waters. Zirino and Yamamoto⁷ observed that Zn speciation is markedly pH dependent. At pH 8.1 Zn(OH)° is the predominant form whereas Zn^{2+} is found when the pH is lower than 7.8.

At most of the stations Co was below the detection limit of the method used. However, in the Laccadive Sea both dissolved, and particulate, Co was below the detection limit. Dissolved Ni concentrations at surface ranged from 13.1-16.3 $\mu\text{g/litre}$ whereas its value in particulate form was greater.

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Biochemical Studies on Zooplankton from the Laccadive Sea (Lakshadweep)

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Carbohydrate, protein and lipid were estimated in copepods, euphausiid sp. and mysid sp. collected from the Laccadive Sea. Protein formed the major biochemical constituent followed by lipid. Carbohydrate content was the least (<6%). The differences in various biochemical components of neritic and oceanic forms were negligible.

The assessment of secondary production from marine ecosystem necessitates the study of physiology and

biochemistry of zooplankton along with the information on biomass and species composition. Considerable information is available on the above aspects of zooplankton from temperate, boreal and polar seas¹⁻⁷. Very few reports are available on the biochemistry of tropical zooplankton. Bogorov *et al.*⁸ have discussed the biochemistry of Indian Ocean plankton. Nair *et al.*⁹ and Gopalakrishnan *et al.*¹⁰ have studied the biochemistry of neritic zooplankton organisms of the Cochin region.

Biochemical composition of some dominant zooplanktonic groups from the Laccadive Sea, collected during the 31st cruise (March-April 1978) of *R V Gaveshani* is presented in this paper.

Zooplankton were collected by vertical hauls (200 m to surface) using an IOS net¹¹, and were frozen immediately at -10°C in a deep freeze. Biochemical analysis was carried out later in the laboratory. Copepods (*Euchaeta marina*, *Undinula vulgaris*), mysids (*Siriella* sp.) and euphausiids (*Euphausia diomediae*) were the dominant groups present in the samples. Adult animals were sorted out after thawing the samples for the determination of various biochemical constituents. Excess water from the specimens was removed gently by a filter paper before determining their wet weight. In order to compare the present results with the published data, the values were converted into constituents on a dry weight basis. Drying to constant weight was done by keeping the animals in an oven at 70°C .

The major biochemical constituents, viz. carbohydrate, protein and lipid were estimated using the method described by Raymond *et al.*² and the results are given in Table 1. Triplicate analysis was made and the average value taken. Owing to the small number of specimens only carbohydrate, protein and lipid fractions were estimated and the values for ash and chitin together were calculated from the difference.

The carbohydrate content was low in all the organisms with a maximum of 5.13% in copepod, *Euchaeta marina* and 4.65% in mysids, *Siriella* sp. As in all zooplankton species so far investigated from different marine areas⁷ carbohydrate was the lowest. Nair *et al.*⁹ reported the carbohydrate content of copepods from Cochin backwater as 3.8% and 2.7% for mysids which are slightly lower than the present values. Their observations are on *Acartia* sp. from the Cochin backwater, an environment which is subjected to varying hydrographic conditions, whereas the present study is on *Undinula vulgaris*, *Euchaeta marina* and *Oncaea* sp., which are mainly oceanic. The higher values noted may be due to the variation in the species and in the environment. Gopalakrishnan *et al.*¹⁰ reported 4.1% of carbohydrate for *Acartia* sp. from the same area, which is higher than the average values