

Ecology of Mandovi & Zuari Estuaries, Goa: Distribution of Foraminiferal Assemblages

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Sediment samples (14) collected from Mandovi and Zuari estuaries have been analysed for benthic Foraminifera. The living population is poorly represented in the lower reaches of both the estuaries but, in general, relatively higher concentrations of total Foraminifera (live + dead) and high species diversity are noted in the Zuari estuary. Ratio of live to total population in per cent is higher in the upper reaches of Mandovi and Zuari rivers suggesting relatively rapid rate of sedimentation in those areas. In the areas where organic carbon content is high due to certain types of pollution, species diversity is low and *Ammonia beccarii* group and arenaceous Foraminifera are dominant.

STUDIES on Foraminifera of the estuarine and the brackish water environs of India are very recent and therefore, information available on the subject is still much limited. Ramanathan^{1,2} has studied Foraminifera from Vellar estuary at Porto Novo and Siebold³ from Cochin backwaters. A great deal of work has to be done on this group of protozoans since some of the species by their relative abundance are useful indicators of regions of heavy pollution and consequently help ecological monitoring in different estuaries. The present study, part of the research project on 'Environmental study of Mandovi-Zuari estuaries' undertaken by the Institute involves investigations on different assemblages of Foraminifera in determining ecological features of the two estuaries and also on certain problems connected with pollution as observed in different localities of the area studied.

Materials and Methods

The Panjim island in Goa is bounded on the north by Mandovi river and on the south by Zuari river. The two rivers are connected on the eastern side of the island by a narrow Cumbarjua canal which is about 10 km long. The average depth of the rivers is about 6 m and the tides in both the estuaries are of semidiurnal type with a range of about 2 m. Sediment samples (14) were collected in March 1972, with the Van-veen grab from the Mandovi-Zuari estuarine system in Goa. The sampling localities are shown in Fig. 1. The physico-chemical characteristics of water and sediment are given in Tables 1 and 2. For calculation of percentages of individual species, 200 specimens of Foraminifera were counted from each sample. Shannon formula was chosen for the calculation of species diversity in the present study. It is as follows :

$$D = - \sum_{i=1}^N p_i \log_2 p_i$$

where p_i is probability of the i th species occurring in the population and N is total number of species.

TABLE 1—PHYSICO-CHEMICAL CHARACTERISTICS OF BOTTOM WATER

Station No.	Temp. °C	Salinity ‰	Phosphate µg at/litre
1a	27.8	33.68	0.58
1b	27.8	33.91	0.39
2a	27.3	30.92	0.50
2b	27.5	31.95	0.50
3	27.9	27.67	0.39
4	28.8	22.07	0.47
5	28.2	25.28	0.52
6	29.0	26.93	0.84
7	28.8	33.17	0.67
8	29.6	33.73	0.78
9	29.0	33.84	0.68
10	29.0	33.10	1.23
11	28.8	33.91	0.91
12	28.7	35.15	0.78

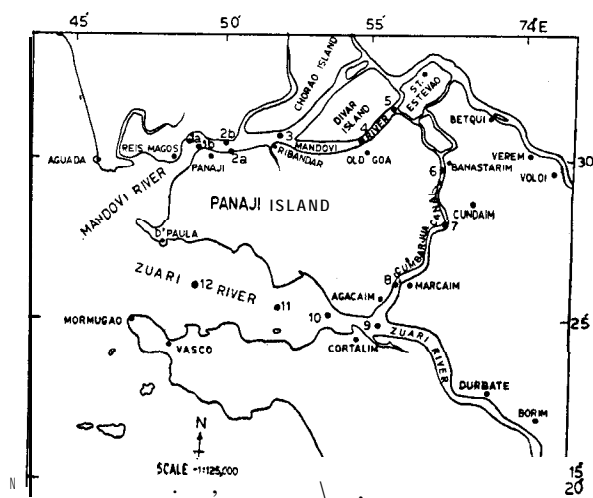


Fig. 1 — Location of stations

TABLE 2 — GRAIN SIZE CHARACTERISTICS AND ORGANIC CARBON CONTENT OF THE SEDIMENTS

Station No.	Depth m	Sand %	Silt %	Clay %	Md ϕ	$\sigma\phi$	Sediments organic C mg/g dry mud
				14			
1a	8.5	46	40	49	4.15	2.15	0.60
1b	7.5	25	26		7.60	2.66	9.00
2a	4.0	57	24	19	3.75	2.41	10.95
2b	10.5		27	11	3.65	2.01	1.83
3		62	18	5			
4	5.5	77	20	8	2.30 2.40	1.57	2.5 7.35
5	5.0	61	26	7	2.45	1.58	2.85
6	3.5	82	29	10	1.90	2.97	2.40
7			15	3			
8	5.0		15	5	2.10	1.77	16.50
9	3.0	18	12	3			
10	5.0	7	70	23	5.60	1.11 2.55	11.6-15
11	4.0	60	25	15	2.80	3.15	16.05
12	4.0	71	20	9	2.40	0.96	1.95

Living specimens were recognized by staining with rose bengal.

Results and Discussion

Grain size characteristics of sediments — The bottom sediments of the upper reaches of Mandovi and Zuari rivers are composed of sand while those of lower reaches are of clayey sand and silty sand. Md ϕ of the sediments collected ranges from 2.3 to 7.6 in Mandovi river, from 2.4 to 5.6 in Zuari river and 1.9 to 2.3 in Cumbarjua canal. Based on the nature of sediments, relatively high Md ϕ values have been observed for the sediments in the lower reaches and these values are somewhat uniformly low for the samples in the upper reaches of the two rivers. $\sigma\phi$ is used for sorting conditions of the sediments and the $\sigma\phi$ values obtained for the samples in the present study can be grouped under 4 categories of sorting, viz. moderately sorted (station 12), poorly sorted (stations 3, 4, 5 and 7), very poorly sorted (stations 1a, 1b, 2a, 2b, 8, 9 and 10) and extremely poorly sorted (stations 6 and 11). From the nature of the deposits, viz. the deposits of sand, clayey sand and silty sand, it can be inferred that the action of tidal currents is very strong in these estuaries. Further, the clayey sand and silty sand sediments are richer in Foraminifera than the deposits of sands.

Distribution and abundance of benthic Foraminifera — Thirty-two species of benthic Foraminifera have been observed (Figs. 2 to 33) of which 14 species are living. The living species observed are: (1) *Ammodiscus gullmarensis*, (2) *Textularia earlandi*, (3) *Miliammina fusca*, (4) *Quinqueloculina seminulum*, (5) *Quinqueloculina vulgaris*, (6) *Trochammina globigeriniformis* var. *pygmaea*, (7) *Trochammina inflata*, (8) *Fissurina lucida*, (9) *Nonion boueanum*, (10) *Nonion scapha*, (11) *Elphidium articulatum*, (12) *Bolivina nobilis*, (13) *Ammonia beccarii* (Linne') var. *parkinsoniana* and (14) *Ammonia beccarii* (Linne') var. *tepida*. The living population of Foraminifera, in general, is very poor in the lower reaches of both rivers but fairly rich in the Cumbarjua canal and in the upper reaches of the estuaries. The more common living species found in the uprivers and the Cumbarjua canal are: (1) *Trochammina inflata*, (2) *Trochammina globigeriniformis* var. *pygmaea*, (3) *Miliammina*

fusca and (4) *Ammonia beccarii* var. *tepida*. Some calcareous living Foraminifera belonging to *Ammonia beccarii* group are observed near the mouths in both the rivers suggesting that these forms which are characteristic of the estuaries and marsh areas must have been drifted by bottom transport into the above areas and also indicate presence of euryhaline conditions because of the intrusion of river waters into the Arabian Sea. The living *Elphidium*-miliolid fauna which is a characteristic assemblage in the nearshore waters of the coastal regions is found to predominate in the lower reaches of the two rivers and this distribution can be attributed to the approach of marine environment. *Ammonia beccarii* group is the most widespread living group of Foraminifera in the present study.

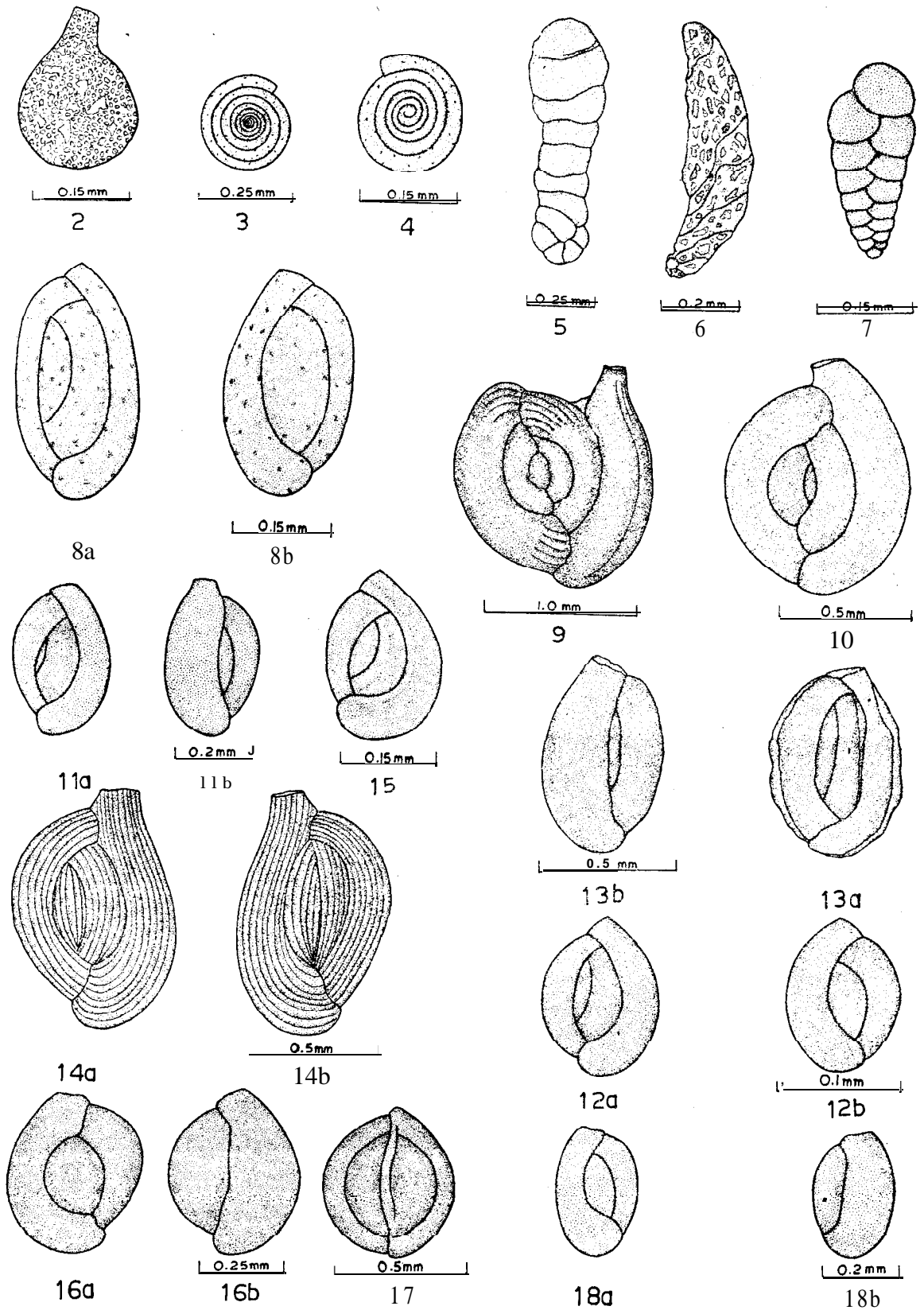
It has been observed, based on analysis of uniform samples, that in comparison with Mandovi river, high concentrations of total Foraminifera (live+dead) are present in the Zuari river. In the Mandovi river, the total population varies from 700 to 6400 specimens, in the Cumbarjua canal from 2200 to 3400 specimens while in the Zuari river from 3600 to 13100 specimens per sample.

In total population, some foraminiferal specimens are quite predominant e.g., *Ammonia beccarii* var. *parkinsoniana*, *Ammonia beccarii* var. *tepida*, *Trochammina inflata*, *Trochammina globigeriniformis* var. *pygmaea* and *Nonion boueanum*. Others which include both arenaceous and calcareous forms are rare, they being *Psammospaera fusca*, *Ammodiscus catinus*, *Ammodiscus gullmarensis*, *Ammobaculites crassus*, *Ammobaculites cassis*, *Textularia earlandi*, *Spiroloculina costifera*, *Spiroloculina planissima*, *Quinqueloculina costata*, *Quinqueloculina dimidiata*, *Fissurina lucida* and *Elphidium articulatum*.

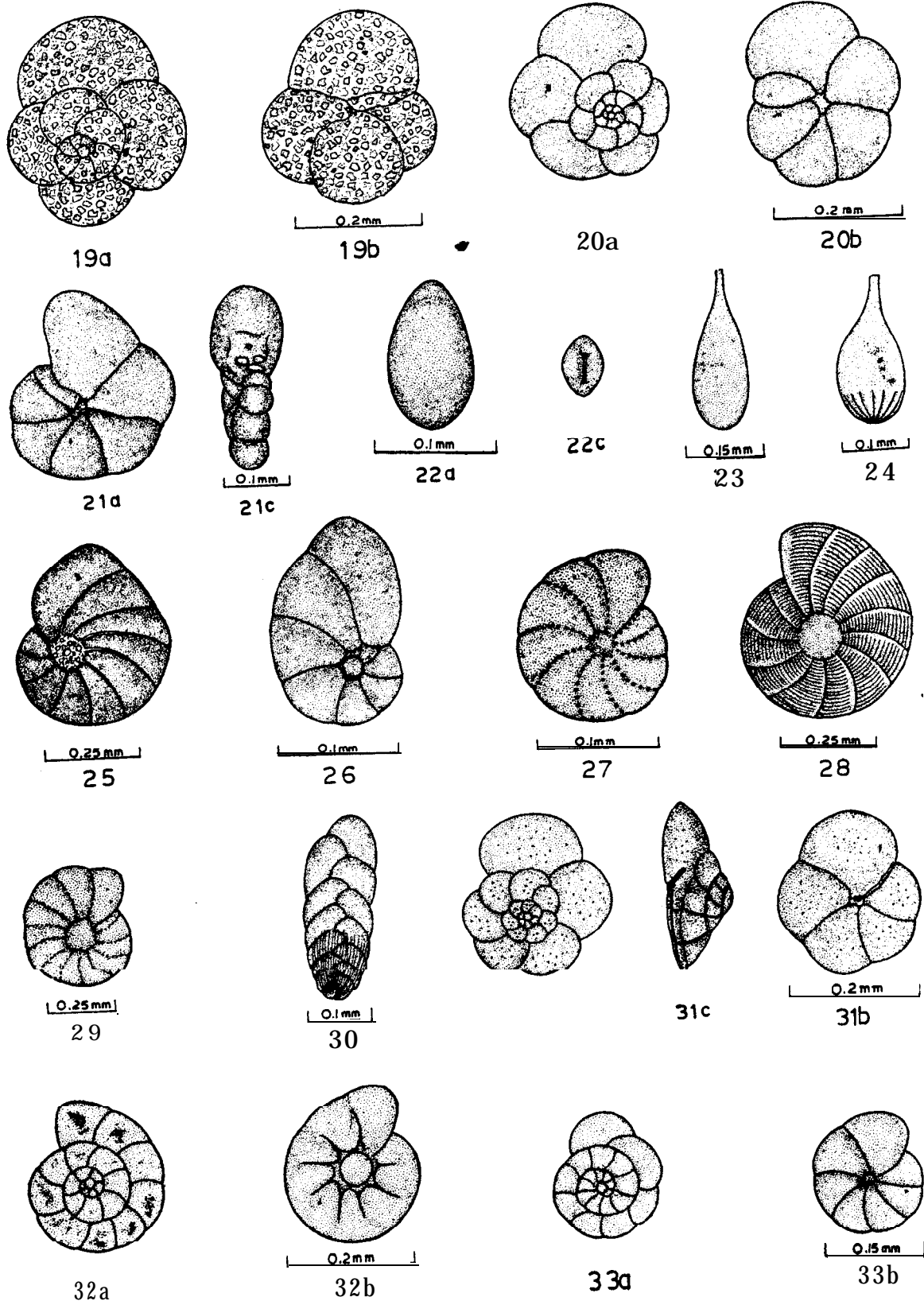
No planktonic foraminiferal species have been observed at the stations covered in the estuaries.

Diversity of the species in both the estuaries varies from 1 to 19.7 (Table 3) and in general, the diversity is relatively high in the Zuari river because of the prevalence of more marine conditions.

Several workers⁴⁻⁸, used the ratio of living to total population (L/T) of Foraminifera to indicate relative rates of sedimentation. High live to total population of Foraminifera is a sign of rapid rate of sedimentation. In the present study, it has been found that the ratio of L/T is higher in the upper reaches



Figs. 2 to 18 — Foraminiferal species [(2) *Psammospaerduca*, (3) *Ammodiscus catinus*, (4) *Ammodiscus gullmarensis*, (5) *Ammobaculites crassus*, (6) *Ammobaculites cassis*, (7) *Textularia earlandi*, (8) *Miliammina fusca*, (9) *Spiroloculina costifera*, (10) *Spiroloculina planissima*, (11) *Quinqueloculina seminulum*, (12) *Quinqueloculina vulgaris*, (13) *Quinqueloculina lamarckiana*, (14) *Quinqueloculina costata*, (15) *Quinqueloculina dimidiata*, (16) *Triloculina trigonula*, (17) *Triloculina tricarinata*, and (18) *Triloculina oblonga*. a, dorsal view and b, ventral view]



Figs. 19 to 33 — Foraminiferal species [(19) *Trochammina globigeriniformis* var. *pygmaea*, (20) *Trochammina inflata*, (21) *Jadammina macrescens*, (22) *Fissurina laevis*, (23) *Lagena laevis*, (24) *Lagena semistriata*, (25) *Nonion boueanum*, (26) *Nonion scapha*, (27) *Elphidium articulatum*, (28) *Elphidium crispum*, (29) *Elphidium incertum*, (30) *Bolivina nobilis*, (31) *Discorbis vilardeboana*, (32) *Ammonia beccarii* var. *parkinsoniana* and, (33) *Ammonia beccarii* var. *tepida*. a, dorsal view; b, ventral view; and c, apertural view]

TABLE 3 --- RELATIVE ABUNDANCE OF FORAMINIFERAL SPECIES IN TOTAL POPULATION

	Station No: la	Mandovi estuary					Cumberjua canal			Zuari estuary				
		1b	2a	2b	3	4	5	6	7	8	9	10	11	12
Total (live + dead) in 100 g wet sediment	6400	2800	1600	1100	—	700	1200	2600	3400	2200	3600	8000	10300	13100
Live in 100 g wet sediment	600	100	200	100	—	200	500	700	600	900	1400	1200	200	700
Live/total (%)	9.4	3.6	12.5	9.0	—	28.6	41.7	26.9	17.7	40.9	38.9	15.0	1.9	5.3
Species diversity	16.0	12.3	3.3	1.0	—	2.9	4.4	5.9	7.4	7.8	8.6	5.0	7.0	19.7
SPECIES														
<i>Psammospaera fusca</i>	—	—	—	—	—	—	—	0.5	—	—	—	—	—	—
<i>Ammodiscus catinus</i>	—	—	—	—	—	—	—	1.0	—	—	—	—	—	—
<i>Ammodiscus gullmarensis</i>	—	—	—	—	—	—	—	0.5	—	—	—	—	—	—
<i>Ammobaculites CASSYS</i>	—	—	—	—	—	—	—	—	0.5	—	—	—	—	—
<i>Ammobaculites cassis</i>	—	—	—	—	—	—	—	—	0.5	—	—	—	—	—
<i>Textularia earlandi</i>	—	—	—	—	—	—	—	—	—	—	—	—	—	—
<i>Miliammina fusca</i>	—	—	—	—	—	—	—	—	3.5	—	2.5	—	—	—
<i>Spiroloculina costifera</i>	—	—	—	—	—	—	—	—	—	—	—	—	—	0.5
<i>Spiroloculina planissima</i>	—	—	—	—	—	—	—	—	—	—	—	—	—	0.5
<i>Quinqueloculina seminulum</i>	2.5	3.0	—	—	—	—	—	—	—	—	—	1.5	—	—
<i>Quinqueloculina vulgaris</i>	—	—	—	—	—	—	—	—	—	—	—	—	3.0	—
<i>Quinqueloculina lamareckiana</i>	2.0	—	—	—	—	—	—	—	—	—	—	—	—	3.0
<i>Quinqueloculina costata</i>	—	—	—	—	—	—	—	—	—	—	—	—	—	0.5
<i>Quinqueloculina dimidiata</i>	—	—	—	—	—	—	—	—	—	—	—	—	—	0.5
<i>Triloculina trigonula</i>	3.0	—	3.5	—	—	—	—	—	—	—	—	—	—	2.5
<i>Triloculina tricarinata</i>	5.0	2.0	—	—	—	—	—	—	—	—	—	—	—	1.0
<i>Triloculina oblonga</i>	0.5	—	—	—	—	—	—	—	—	—	—	—	—	—
<i>Trochammina globigeriniformis</i> var. <i>pygmaea</i>	—	4.0	—	—	—	15.5	13.0	6.5	8.5	—	3.5	2.5	—	—
<i>Trochammina inflata</i>	—	—	—	—	—	55.0	57.5	81.5	77.5	64.0	72.5	48.0	11.5	—
<i>Jadammina macrescens</i>	—	—	—	—	—	—	—	—	3.0	2.0	—	—	—	—
<i>Fissurina lucida</i>	—	—	—	—	—	—	—	—	—	—	—	—	—	0.5
<i>Lagena laevis</i>	—	1.5	—	—	—	—	—	—	—	—	—	—	—	1.0
<i>Lagena semistriata</i>	2.0	—	—	—	—	—	—	—	—	—	—	—	—	1.5
<i>Nonion boueanum</i>	12.0	12.5	—	—	—	—	—	—	—	1.5	4.0	8.0	14.0	3.0
<i>Nonion scapha</i>	—	3.5	—	—	—	—	—	—	—	2.5	—	—	—	1.0
<i>Elphidium articulatum</i>	—	0.5	—	—	—	—	—	—	—	—	—	—	—	0.5
<i>Elphidium crispum</i>	3.5	—	—	—	—	—	—	—	—	—	—	—	—	1.5
<i>Elphidium incertum</i>	2.0	—	—	—	—	—	—	—	—	—	—	—	—	2.5
<i>Bolivina nobilis</i>	—	—	—	—	—	—	—	—	—	—	2.0	—	—	—
<i>Discorbis vilareboana</i>	—	—	2.5	—	—	—	—	—	—	—	—	—	—	3.5
<i>Ammonia beccarii</i> var. <i>parkinsoniana</i>	55.0	64.5	94.0	100	—	29.5	10.0	—	—	18.0	9.0	21.5	50.0	69.0
<i>Ammonia beccarii</i> var. <i>tepida</i>	12.5	7.5	—	—	—	19.5	19.5	10.0	6.5	12.0	6.5	20.0	19.0	7.5

of Mandovi and Zuari rivers suggesting relatively rapid rate of sedimentation. The ratio of living to total population in per cent ranges from 3.6 to 41.7 in the Mandovi river and from 1.9 to 38.9 in the Zuari river while in the Cumbarjua canal, it varies from 17.7 to 40.9. Very high rates of sedimentation have been observed in the upriver of Mandovi (station 5) and at station 8 on the Zuari side of the Cumbarjua canal.

Foraminiferal facies — The lower reaches of Mandovi and Zuari rivers are characterized by *Ammonia* facies while the upper reaches of the estuaries and the Cumbarjua canal by *Trochammina* facies. In Mandovi river, the *Ammonia* assemblage is dominated by *Ammonia beccarii* var. *parkinsoniana* and also includes other species such as *Textularia earlandi*, *Ammonia beccarii* var. *tepida*, *Nonion boueanum*, *Elphidium crispum*, *Elphidium incertum*, *Triloculina tricarinata*, *Triloculina trigonula*, *Quinqueloculina seminulum*, *Quinqueloculina lamarckiana*, *Lagena semistriata* and *Lagena laevis*.

The river mouth of Zuari is also dominated by the same assemblage with *Ammonia beccarii* var. *parkinsoniana* being the most abundant species; it is distinctly characterized by a greater number of true marine forms belonging to the groups *Miliolids*, *Elphidium*, *Nonion* and *Lagenids*. *Ammonia beccarii* var. *tepida* ranks next high in the abundance of all other species.

The upper reaches of both the rivers are formed by *Trochammina* assemblage with *Trochammina inflata* as the most dominant species. Other forms comprise *Trochammina globigeriniformis* var. *pygmaea* and *Ammonia beccarii* var. *tepida*. The upstream of Zuari estuary includes other additional forms *Bolivina nobilis*, *Nonion boueanum* and *Nonion scapha*.

Cumbarjua canal is mainly dominated by arenaceous forms and is again characterized by *Trochammina* assemblage as in the upper reaches of the two estuaries. *Trochammina inflata* is the most abundant species. Other forms found in this canal are: *Ammonia beccarii* group, *Miliammina fusca*, *Ammobaculites crassus*, *Ammobaculites cassis*, *Ammobaculites catinus*, *Ammodiscus gullmarenis* and *Jadammina macrescens*.

Organic carbon content — Organic carbon content in the sediments of the two estuaries (Table 2) shows a distinct distribution. In the lower reaches

of unpolluted areas, the organic carbon content is low compared to the upstreams of both the rivers. It has been observed that near the stations covered, there are certain sources for different types of pollution. Sewage contains mostly organic matter. Stations 1b and 2a are polluted with sewage wastes from the town of Panjim, with the result high values of organic carbon content have been noted at these sites. Relatively high values of organic carbon content at stations 2a, 4 and 9 can be attributed to the wastes from the piers and discharge from the barges, ferries and other fishing mechanized boats. Sediments from stations 7, 10 and 11 contain a large amount of plant debris derived mainly from the mangrove swamps. Species diversity is relatively low in the areas of high organic carbon content. In the areas where organic carbon content is high, *Ammonia beccarii* group and arenaceous Foraminifera are dominant. It is possible that these forms have got tolerance not only for high levels of organic carbon content but also for other types of organic material, thereby serving as indicators of pollution. Schafer⁹ and Schafer and Sen Gupta¹⁰ have also reported such dominance of *Ammonia beccarii* group in polluted regions of Long Island Sound and estuaries of New Brunswick and Maine.

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