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Distribution, abundance and ecology of the meiofauna in a tropical estuary along the west coast of India

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Abstract

The distribution and abundance of subtidal meiofauna in Mandovi estuary of Goa were studied from June 1983 to June 1984. Monthly faunal abundance ranged from 491 to 2791/10 cm^2 and dry weight biomass from 0.16 to 2.80 mg 10 cm^2. Free living nematodes were the dominant group contributing over 75% of the total density and 30 to 42% of the total biomass. Among nematodes the deposit feeders were more abundant in fine muddy substratum while epigrowth feeders dominated in sandy substratum.

Harpacticoids were next, comprising 6.9 to 8.7% of the total meiofauna number, followed by turbellaria (3.8–4.5%), polychaeta (2.8–3.2%) and ostracods (1.6–4.5%) The contribution of other groups to faunal density was 4.5–6.2%. In the biomass the ostracods contributed most (29.8–54.7%), followed by nematodes (23.8–34.6%). Over 60% of the fauna occurred in the top 2 cm of the sediment and the faunal density reduced significantly with increasing depth in the sediment. The vertical distribution of meiofauna was positively correlated to the vertical distribution of Eh, chlorophyll *a* and interstitial water. Seasonality was greatly influenced by the south-west monsoon and the fauna quickly repopulated after the monsoon. Salinity, temperature and food influenced the faunal abundance.

Introduction

Our understanding of the mechanisms that control the abundance of tropical subtidal meiofauna is necessary for developing hypotheses. Analysis of meiofauna variability within a given ecosystem has not yielded comparative ecological inferences (Coull & Bell, 1979; Rudnick *et al.*, 1985). Studies on the mechanisms that control the abundance and biomass of meiofauna in estuarine ecosystem have been done mainly in the temperate and subtropical zones and are reviewed by Coull (1973). Descriptive papers on tropical estuarine meiofauna are available from India (Azis & Nair, 1983; Ansari *et al.*, 1984; Kondalarao & Murty, 1988). and other areas (see Alongi, 1990). Despite these studies, no clear pattern regarding meiofaunal abundance and its seasonality is available for the tropical estuarine ecosystems.

Unlike temperate waters the estuaries in tropics are subjected to distinct seasonality due to monsoonal precipitation. In this study we report on the quantitative meiofaunal abundance, and their temporal and spatial distribution as influenced by tropical monsoon and associated hydrographical parameters. Estimates of food/energetics of meiofauna is also attempted.

Materials and methods

Three stations one each in the lower, middle and upper reaches of the Mandovi estuary were monitored monthly (Fig. 1). Samples for meiofauna were taken by a small gravity corer (Ankar & Elmgren, 1976) having a sampling area of 7.06 cm^2. The thickness of the core wall was 1 mm and total weight 6 kg. Five cores were taken from each station at monthly interval during June 1983 through June 1984 in order to study the seasonal distribution of meiofauna, sedimentary organic matter, sedimentary pigment, pH, Eh of the sediment, interstitial water content and sediment granulometry. Vertical distribution of meiofauna in the upper 10 cm portion of the core was studied by taking five 2 cm section from a separate core. Meiofauna samples were preserved separately in 5% formalin Rose Bengal solution.

Water overlying the sediment was collected with a Niskin sampler. Temperature was measured with a reversing thermometer. Salinity and oxygen was determined by standard titration methods (Strickland & Parsons, 1972).

In the laboratory the meiofauna samples were passed through a set of two sieves; the top one with a mesh opening of 0.5 mm and the bottom one with a mesh opening of 0.062 mm. Animals retained on the lower mesh were considered as meiofauna and were enumerated under a dissecting microscope. Meiofauna biomass was calculated from estimates of individual weight. Representative taxa of different sizes were picked up from different samples under microscope and average dry weight of the major taxa was estimated by weighing 30–50 specimens of a taxa on a Sartorius microbalance after drying at 60 °C. The average mass per individual was 0.0003 mg for nematodes, 0.0013 mg for harpacticoids, 0.0012 mg for turbellarians, 0.012 mg for ostracods, 0.0022 mg for polychaetes and 0.0004 mg for other groups.

The Organic content of the sediment was determined by the method of El Wakeel & Riley

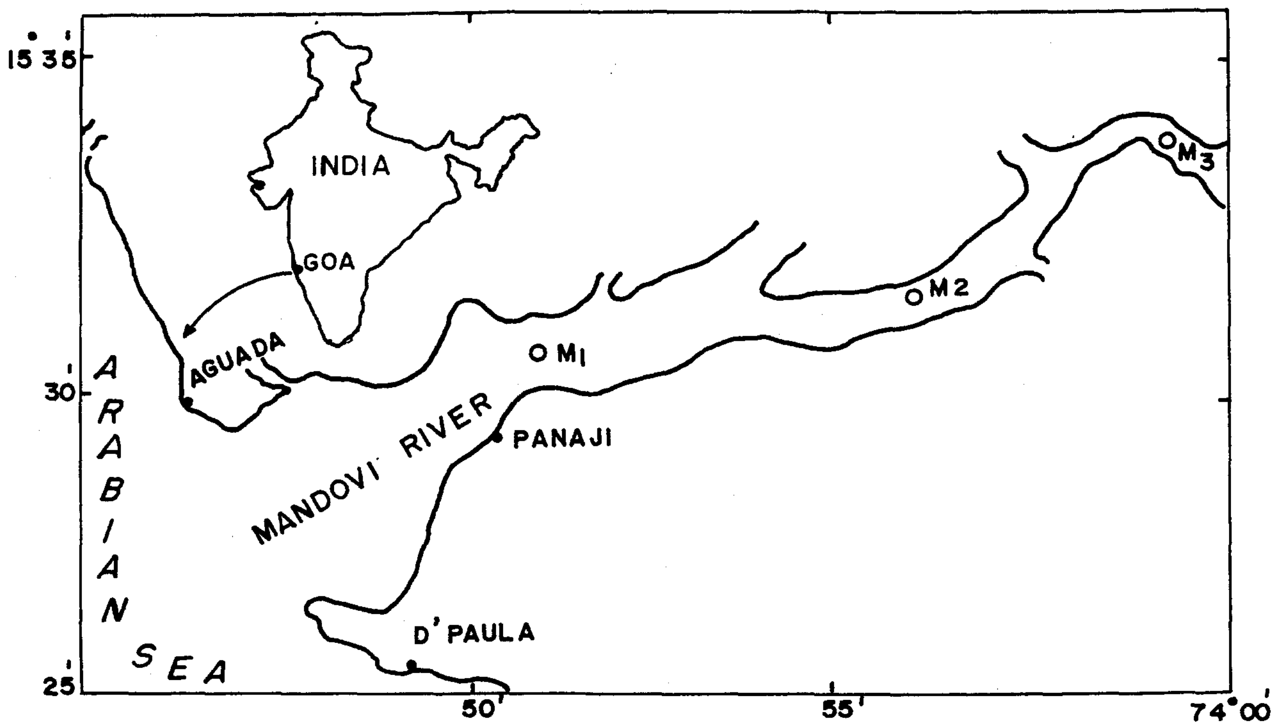

Fig. 1. Estuary of Mandovi river showing stations position.

(1956) Sedimentary pigment estimates were done following the method of Tietjen (1968) and pH and Eh were measured in the field using combination electrode on a pH meter. Mechanical properties of the sediment were analysed by the method of Folk (1968) and interstitial water content was measured by the method of Tietjen, (1969).

Relationship of meiofaunal density with environmental parameters was examined using Pearson's product moment correlation coefficient (*r*). A two way analysis of variance (ANOVA) was used to test seasonal fluctuations by pooling data for each season. Density was log $(x + 1)$ transformed.

Results

Environmental parameters

Environmental data are presented in Table 1 and Fig. 2. The heavy precipitation and large runoff during south-west monsoon (June–Sept) bring dynamic changes in the physico-chemical characteristic of the study area. This is followed by fair and stable conditions in the post monsoon (Oct–Jan) period and during the pre-monsoon period (Feb–May) marine conditions prevail in the major estuarine part.

The three stations were similar in temperature regime to the overlying water due to well mixing in the water column. The annual cycle of temperature exhibits two peaks, one in October and the

Table 1. Data on sediment characteristics to a depth of 10 cms from June 1983 to June 1984. Values presented for interstetial water, organic carbon, Eh and Chlorophyll *a* are average values for five 2 cm core depth. Other values result of single measurements.

Variables	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
							M1						
Median grain size (mm)	0.06	0.09	0.07	0.05	0.08	0.07	0.06	0.05	0.03	0.02	0.04	0.05	0.03
% silt clay	58.8	60.6	55.5	61.3	60.6	66.8	62.2	64.7	67.3	69.5	62.3	60.5	55.2
Sorting coefficient (O)	0.72	1.09	0.91	0.63	0.55	0.82	0.52	0.74	0.92	1.13	0.84	0.8	0.65
Interstitial water (%)	48.6	44.2	42.5	43.5	49.2	42.8	47.6	40.9	42.5	46.2	40.5	49.2	47.3
Organic carbon (%)	2.7	2.42	2.76	2.95	2.28	1.77	1.56	2.25	1.72	1.6	1.5	1.7	2.3
pH	7.3	7.5	7.6	7.2	7.3	7.3	7.1	7.2	6.9	7.2	7.4	6.9	7.2
Eh (mv)	+49	+162	+105	+47	+49	+52	+107	+40	+12	+14	+16	+22	+99
Chl *a* ($\mu g\ g^{-1}$ sed.)	4.3	2.6	2.9	5.6	4.8	6.8	9.5	12.5	12.8	11.4	12.5	18.6	6.9
							M2						
Median grain size (mm)	0.16	0.19	0.2	0.19	0.14	0.12	0.12	0.08	0.09	0.12	0.07	0.09	0.12
% silt clay	16.5	18.02	23.5	19.8	19.2	20.4	22.5	21.7	20.5	22.4	19.6	20.2	19.8
Sorting coefficient (O)	0.8	1.02	0.72	1.05	0.5	0.82	0.89	0.78	0.77	0.65	0.95	0.72	0.79
Interstitial water (%)	30.7	28.9	28.6	27.5	32.6	34.8	30.9	31.3	29.8	32.2	30.5	28.4	29.3
Organic carbon (%)	2.35	3.62	2.92	3.47	2.45	1.93	1.38	1.8	0.9	1.28	1.55	1.19	2.44
pH	7.3	7.4	7.6	7.6	7.2	7.3	7.0	7.2	7.4	6.9	6.8	7.0	7.2
Eh (mv)	+69	+225	+181	+167	+118	+57	+82	+45	+44	+20	+48	+24	+89
Chl *a* ($\mu g\ g^{-1}$ sed.)	5.2	2.2	2.3	4.3	4.4	3.9	9.2	9.6	10.3	12.7	16.4	17.3	4.5
							M3						
Median grain size (mm)	0.05	0.06	0.08	0.06	0.05	0.04	0.03	0.04	0.05	0.06	0.02	0.06	0.08
% silt clay	71.2	78.4	74.7	73.8	76.4	81.3	75.2	77.4	74.9	82.4	76.2	77.8	79.8
Sorting coefficient (O)	0.36	0.5	0.93	0.7	0.79	0.81	0.73	0.49	0.75	0.92	0.87	0.56	0.83
Interstitial water (%)	29.6	25.3	25.4	22.4	24.2	23.8	21.6	28.2	30.4	25.6	29.2	27.8	29.5
Organic carbon (%)	1.72	2.2	2.46	2.25	1.7	1.38	0.85	0.92	1.26	0.9	1.5	1.35	1.17
pH	6.9	7.4	7.0	7.3	7.1	7.3	7.2	7.5	7.0	6.8	6.9	7.0	7.0
Eh (mv)	+99	+102	+105	+49	+47	+52	+107	+40	+72	+94	+78	+72	+99
Chl *a* ($\mu g\ g^{-1}$ sed.)	2.45	1.80	0.92	2.83	2.53	2.17	6.27	8.3	8.45	11.32	14.8	14.55	4.22

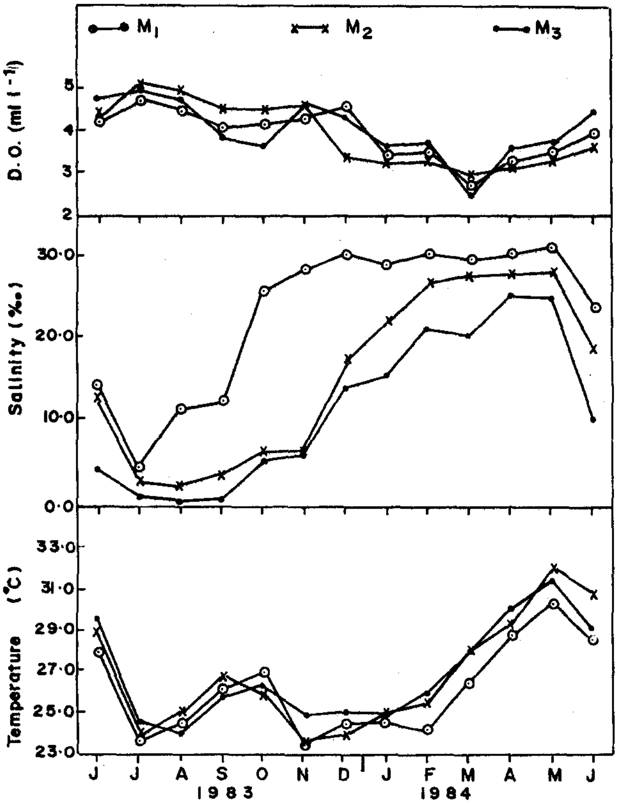

Fig. 2. Monthly variations in temperature, salinity and dissolved oxygen of bottom water at the study stations.

other in May. Unlike temperature the annual variation in salinity of the bottom water of Mandovi estuary was very large and the values fluctuated from 0.2‰ to 32.8‰, suggesting nearly fresh to marine water conditions. Such changes are to be expected in a tropical estuary subjected to heavy monsoonal precipitation. There was a conspicuous decrease in the salinity along the transect stations during the monsoon period. The values gradually increased in the post monsoon period with a maximum value in the pre monsoon period. Dissolved oxygen values in the overlying water were similar at the transect stations. Annual variations were more or less identical at the three stations.

Sediment granulometry

The sediment characteristics are given in Table 1. Stations M1 and M3 had fine to very fine grain size and the bottom deposits were predominantly silt and clay while at station M2 the sediment was characterised by fine sand. The sorting coefficient (measure of uniformity of sorting) varied narrowly, falling in the category of moderately to poorly sorted sediment, the feature of estuarine sediment. The sediment pH also did not show any appreciable difference at these stations.

The interstitial water content exhibited variability at and between the three stations which was due to differences in pore space of the sediment. The mean organic carbon content also differed among the stations. Sedimentary organic carbon in the Mandovi estuary is generally derived from both autochthonous and allochthonous sources (Sirodkar, 1984). The Eh and chlorophyll *a* values also differed at the three stations. The values were high in the 0–2 cm and decreased with increasing depth.

The meiofauna

Composition

The nematodes, harpacticoids, turbellarians, polychaetes, and ostracods were the important meiofaunal taxa. Tardigrads, gastrotrichs, foraminiferans, oligochaetes, kinorhynchs, lamellibranchs and crustacean nauplii were other groups recorded in the samples. Nematodes were the most abundant group of the population numerically, contributing over 75% of the total density followed by harpacticoids (6.9–8.7%) and turbellarians (3.8–4.5%). The polychaetes contributed from 2.8–3.2% while the ostracod contribution was 1.6–4.5%. The other groups accounted between 4.5 and 6.2% of the total faunal density.

Abundance and biomass

Monthly density and dry weight biomass of meiofauna and their monthly variations are shown in Fig. 3. Monthly total numerical abundance fluctuated between 854 and 2791, 629 and 2505 and 491 and 2043/10 cm^2 and the average meiofaunal density was 1702, 1492 and 1292/10 cm^2 at stations M1, M2 and M3 respectively. Total population density was lowest during the south-west

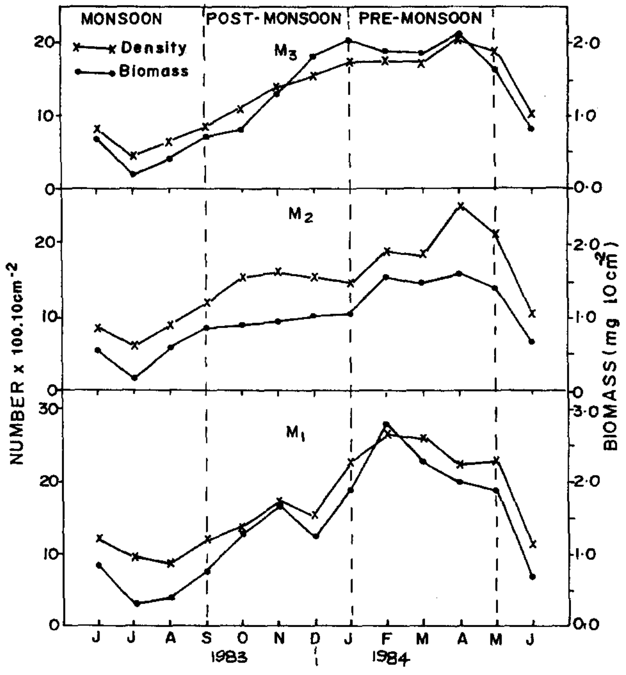

Fig. 3. Monthly variation in total meiofaunal density and dry weight biomass at the study stations.

monsoon and highest during the premonsoon period. A sudden increase in the fauna was observed immediately after the cessation of the monsoon during October–November. Total faunal density exhibited positive correlation with salinity ($r = 0.82$), temperature ($r = 0.64$) and chlorophyll *a* ($r = 0.69$) of the overlying water.

Monthly biomass fluctuated between 0.33–2.80, 0.16–1.61 and 0.19–2.12 mg 10 cm^2 at M1, M2 and M3 respectively. The total annual average biomass was 15.7 mg 10 cm^2. Station M1 recorded the maximum biomass followed by M3 and M2 had the lowest biomass. Fluctuation in biomass values was more pronounced at Station M1 and M3 due to the presence of large number of nematodes and ostracods. The ostracods alone contributed from 29.8 to 54.7% of the total biomass followed by nematodes (23.8–34.6%), harpacticoids (8.9–16.8) and polychaetes (6.7–10.2%). Total biomass values showed seasonal variation with lowest values recorded during monsoon and highest in the pre and post mon-

Table 2. Monthly density of meiofauna (No./10 cm^2), June 1983 through June 1984.

Faunal group	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Total	%
							M1								
Nematoda	947	799	796	915	1015	1375	1268	1692	1826	1898	1640	1815	878	16865	76.1
Copepoda	72	12	34	62	96	103	132	170	266	192	210	178	66	1593	7.2
Turbellaria	32	25	0	78	95	64	43	125	165	185	79	75	43	1009	4.5
Polychaeta	47	0	0	18	50	25	24	67	65	130	92	72	35	625	2.8
Ostracoda	25	0	12	20	56	60	52	70	125	80	75	72	20	667	3.0
Others	97	128	12	88	120	104	24	57	244	120	41	52	89	1376	6.2
							M2								
Nematoda	658	555	795	819	1125	1278	1130	1076	1466	1440	1910	1745	860	14857	76.6
Copepoda	64	13	25	67	95	109	142	165	220	205	320	185	80	1690	8.7
Turbellaria	63	0	0	127	52	84	97	28	35	44	74	97	44	745	3.8
Polychaeta	26	0	34	66	34	52	41	58	82	61	74	49	38	615	3.2
Ostracoda	12	0	22	18	20	18	22	25	52	47	30	37	15	318	1.6
Others	63	61	40	116	224	85	107	128	73	80	97	47	48	1164	6.0
							M3								
Nematoda	632	465	542	591	912	1107	1132	1270	1260	1282	1654	1544	845	12936	77.0
Copepoda	42	0	18	32	66	58	108	145	215	174	105	155	52	1170	6.9
Turbellaria	25	0	0	32	45	72	121	79	62	57	40	62	46	641	3.8
Polychaeta	12	18	9	22	27	47	75	62	88	52	72	28	29	541	3.2
Ostracoda	34	0	17	35	30	62	87	105	85	90	108	72	34	756	4.5
Others	90	8	54	52	46	52	45	101	59	104	64	56	20	751	4.5

soon period, respectively. Monthly fluctuation was similar to that of density.

Seasonal fluctuation

Monthly population density variation of dominant taxa is given in Table 2. All major groups exhibited temporal changes in the abundance over the annual cycle.

Nematoda
Of the six dominant group recorded, largest fluctuations appeared in the nematodes which showed significant increase in the total number, at all stations in the post and pre-monsoon period (ANOVA, $p < 0.05$). Their density ranged from 796 to 1898, 555 to 1910 and 465 to 1654/10 cm^2 at M1, M2 and M3, respectively.

Nematode feeding type
The grouping proposed by Wieser (1953) was used in the present work to study the feeding types in nematodes. The selective and non-selective deposit feeders are combined as deposit feeder.

The variations in different feeding types are shown in Fig. 4. Deposit feeders were dominant at M1 and M3 while epigrowth feeders dominated at M2. Fluctuation in the abundance of these two groups were evident particularly during post and pre-monsoon period. The predators/omnivores did not show any seasonality and were present in low numbers.

Copepoda
Harpacticoids were next to nematodes in order of abundance. Their density showed wide fluctuation from month to month, ranging between 12 and 266, 13 and 320 and 0 and 215/10 cm^2 at M1, M2 and M3 respectively. The copepod density was significantly higher in the post and pre-monsoon period (ANOVA, $p < 0.05$). The significant peaks were observed in February at M1, in April at M2 and in February at M3. Their density was positively correlated with salinity ($r = 0.79$) and temperature ($r = 0.62$) of the overlying water.

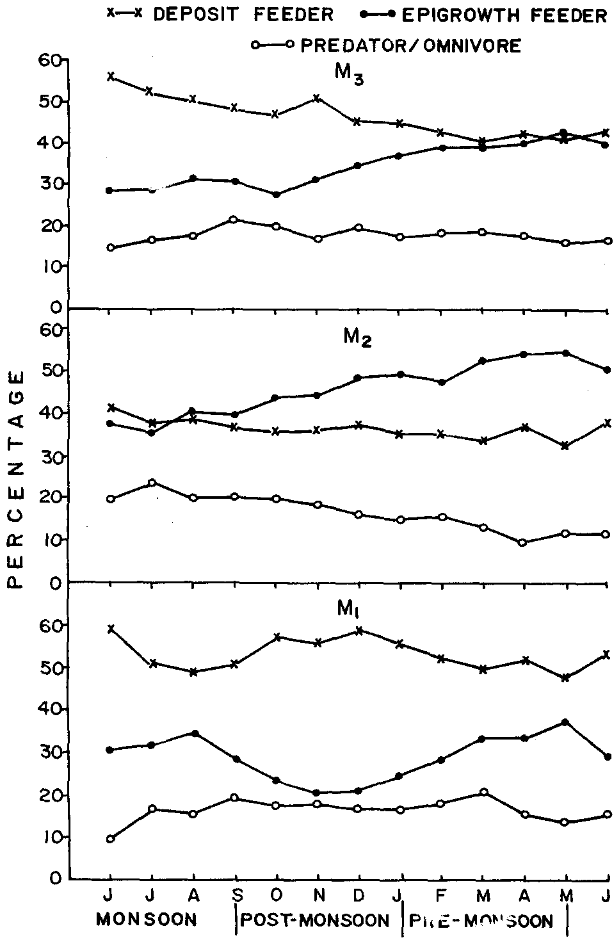

Fig. 4. Abundance of nematode feeding types (percentage) at the study stations.

Polychaeta
Several inconsistent and fluctuating trends were observed in the occurrence of polychaetes. The density fluctuated between 0–130, 0–82 and 9–88/10 cm^2 at M1, M2 and M3 respectively. The peak abundance was observed in March at M1, in February at M2 and February at M3. Overall seasonal variations were significant (ANOVA, $p < 0.05$) and the total count yielded significant correlation with salinity ($r = 0.69$) and temperature ($r = 0.67$) of the overlying water.

Turbellaria
Density of turbellarians ranged between 0–185, 0–127 and 0–121/10 cm^2 at M1, M2 and M3 respectively. Maximum density was recorded in

March at M1, in November at M2 and in December at M3. The seasonal variation tested insignificant (ANOVA, $p > 0.05$) and there was no significant correlation with salinity and temperature.

Ostracoda

Ostracods were not abundant numerically and their density varied between 0–125, 0–52 and 0–108/10 cm^2. Maximum density was recorded in the month of February at M1, in February at M2 and in April at M3 respectively, with very low counts during the monsoon period. Stations M3 and M1 recorded higher density as compared to station M2.

Other groups

Contribution of other meiofaunal group was insignificant and inconsistent. However, together they formed significant portion of meiofauna. Noticeable changes in their the spatial or temporal distribution were not evident except crustacean

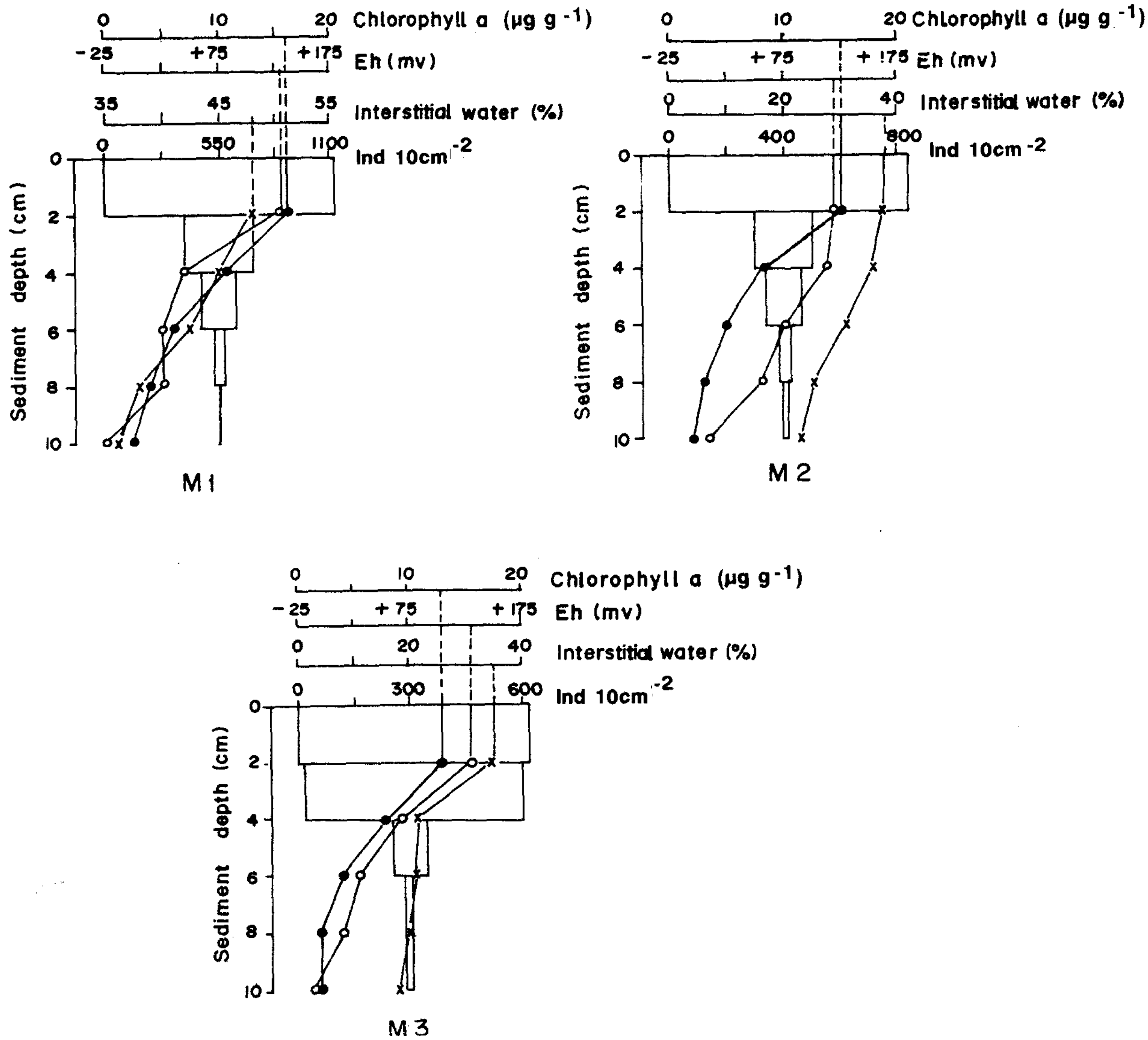

Fig. 5. Vertical distribution of meiofauna, interstitial water, Eh and chlorophyll *a* at the study stations.

nauplii which were consistently present during the study period.

Spatial distribution

Meiofaunal abundance at the study stations was moderate to high, suggesting that all areas were capable of supporting meiofauna populations. There were, however, some qualitative differences among the stations. Among nematoda members of family Chromadoridae and Desmodoridae were common in fine sandy deposit at M2 and Monhysteridae and Comasomatidae were more abundant in muddy deposit. The common genera were *Neochromadora*, *Desmodora*, *Metachromadora*, *Chromadorita*and *Theristus* sp. The most important feature was the dominance of epigrowth feeders at M2 station and deposit feeders at M1 and M3.

Among harpacticoids the dominant species were *Stenhelia longifurca*, *Halectinosoma curticorne*, *Longipedia coronata*, *Scottolana bulbifera* and *Nitocra spinipes*. Harpacticoid density was higher in coarser sediment. High number of turbellarians were recorded in the lower reaches of the estuary. The ostracods were more abundant in fine silty sediment of M1 and M3 than in the sandy deposits at M2. The polychaetes showed variation in abundance and the density was high in the lower and middle reaches and low in the upper reaches of the estuary. Most common species were *Paraheteromastus tenuis*, *Prionospio pinnata*, *Sabella* sp. and *Pisione* sp. The juveniles of *Diopatra neapolitana* and *Onuphis* sp. were recorded in the lower reaches of the estuary. kinorhynchs and gastrotrichs were more common in the lower (M1) part and crustacean nauplii were more abundant in the middle and upper region. However, the seasonal pattern of these group was not consistent.

Table 3. Vertical distribution of meiofauna (No./10 cm^2). Values are annual means (13 observations) (± SD).

Faunal group	0–2	2–4	4–6	6–8	8–10
			M1		
Nematoda	887 ± 92	252 ± 24	105 ± 12	38 ± 6	12 ± 2
Copepoda	125 ± 18	43 ± 9	12 ± 3	0	0
Polychaeta	22 ± 6	12 ± 5	8 ± 3	2 ± 0.5	0
Turbellaria	25 ± 7	18 ± 5	13 ± 4	0	0
Ostracoda	26 ± 9	8 ± 2	4 ± 0.5	0	0
Others	43 ± 9	22 ± 7	7 ± 2	3 ± 0.5	0
			M1		
Nematoda	652 ± 72	302 ± 38	175 ± 11	34 ± 6	16 ± 5
Copepoda	75 ± 14	44 ± 12	16 ± 7	0	0
Polychaeta	12 ± 3	10 ± 3	8 ± 2	4 ± 2	0
Turbellaria	14 ± 4	26 ± 7	6 ± 2	0	0
Ostracoda	9 ± 3	4 ± 0.4	0	0	0
Others	60 ± 13	21 ± 7	8 ± 2	0	0
			M1		
Nematoda	516 ± 192	458 ± 42	84 ± 19	16 ± 5	19 ± 5
Copepoda	32 ± 8	56 ± 12	0	0	0
Polychaeta	12 ± 3	6 ± 3	5 ± 0.5	0	0
Turbellaria	26 ± 9	8 ± 3	0	0	0
Ostracoda	14 ± 3	25 ± 8	3 ± 0.5	0	0
Others	18 ± 4	32 ± 10	4 ± 0.5	0	0

Vertical distribution

A summery of the data on the vertical distribution of the meiofaunal groups is given in Table 3. Over 60% of the fauna was restricted to the top 2 cm layer of the sediment. By contrast, the fauna in the 2–4, 4–6, 6–8 and 8–10 cm layer averaged only 24, 10, 2 and 1% respectively.

Density of nematodes decreased with increasing depth in the sediment and over 60% were found in the 0–2 cm layer. Although nematodes were present in the entire core, significant differences in the total number was observed between 0–4 and 4–10 cm layer ($P<0.05$). The vertical distribution of nematode was positively correlated with vertical distribution of Eh ($r=0.87$), chlorophyll *a* ($r=0.84$) and interstitial water ($r=0.79$).

Benthic copepods, sensitive to oxygen tension, were restricted to the upper layers of the sediment. Between 55 and 69% of the total copepods occurred in the top 0–2 cm layer and no copepods were observed below 4–6 cm layer. Their density was positively correlated with chlorophyll *a* ($r=0.84$) and Eh ($r=0.90$).

Polychaetes were recorded up to 8 cm deep in the sediment. Their density significantly reduced in the lower depth of the sediment. The distribution of turbellarians, ostracods and other groups was restricted to the top 6 cm layer of the sediment. Dispersion pattern of meiofauna taxa was calculated according to Morisita's Index (Iδ) (Elliot, 1977). Index values less than one indicate a regular distribution, values equal to one a random distribution and values greater than one a contagious distribution. Values of Iδ presented in Table 4 indicate a contagious or clumped distribution for most of the meiofaunal group.

Table 4. Values of Morisita's Index for most abundant meiofauna taxa.

Taxa	Station		
	M1	M2	M3
Total meiofauna	1.22*	1.08*	1.24*
Nematoda	1.02*	1.14*	1.11*
Copepoda	1.33*	1.17*	1.23*
Turbellaria	1.22*	1.15*	1.62*
Polychaeta	1.54*	1.47*	1.28*

* Significant at 5% level.

Discussion

The subtidal meiofauna of the Mandovi estuary showed considerable fluctuations, in occurrence, abundance and standing stock biomass. The faunal density which was lowest in July–August (monsoon season), increased progressively and reached its peak in the pre-monsoon season especially during April and May. Similar trends in abundance of meiofauna have been reported earlier from Indian coast (Damodaran, 1973; Kondalarao & Murty, 1988). The seasonality was greatly influenced by the monsoonal rain. The erosion and resuspension of the sediment surface and lowering of the salinity during monsoon causes mortality. Such detrimental effect of monsoon on meiofauna have been reported by earlier workers (Ansari *et al.*, 1984; Reddy & Hariharan, 1985; Kondalarao & Murty, 1988) from both east and west coast of India. Alongi (1987), however, reported increase in meiofaunal density in the summer wet season from a tropical mangrove estuary, Australia. The sudden rise in the population density after monsoon season indicates the ability of meiofauna to quickly and continually repopulate disturbed sediment. Alongi (1990) predicted rapid recovery of meiobenthic organisms to disturbance due to their high resilience.

Seasonality in the meiofaunal abundance is attributable to excess food sources particularly the phytobenthos and rapid rise in water temperature and salinity during the summer (pre-monsoon) period. In temperate waters, rise in temperature during late spring and summer, accompanied by excess food resources, is responsible for meiofaunal seasonality (Tietjen, 1969; Bouwman *et al.*, 1984; Rudnick *et al.*, 1985). Increase in meiofaunal density in response to warmer temperature has also been reported from other tropical estuaries (Alongi, 1987; Kondalarao & Murty, 1988).

The Nematoda exhibited marked seasonal changes in abundance which was associated with changes in the feeding types. The epigrowth feeders reached maximum density during the premonsoon period which coincided with maximum pigment concentration in the bottom deposits. Tietjen (1969) observed a significant increase in epigrowth feeders during spring-summer and attributed this to benthic primary production. The deposit feeders have wide range of food and therefore fluctuations are less. Cantelmo (1978) observed no fluctuation in the deposit feeding nematodes of a shallow subtidal area of a temperate estuary.

Distribution of copepods, polychaetes and turbellarians followed certain seasonal pattern and their density was generally higher during pre and post-monsoon period. Significant increase in the density of polychaete has been reported during the period of increased water temperature when breeding takes place (Cantelmo, 1978). Ostracods are deposit feeders and therefore prefer fine silty substratum. Their high density in the fine sediment at M1 and M3 during summer period was also reported by Damodaran (1973) and Kondalarao & Murty (1988) from India.

Faunal abundance showed increasing trend, both in density and species richness, from the upper low saline to high saline region of the estuary. The seaward increase in meiofaunal density is due to the preponderance of euryhaline taxa in the estuarine benthic fauna (Coull, 1973) and this is responsible for horizontal zonation of meiofauna along salinity gradient of an estuary (Capstick, 1959; Dye & Furstenburg, 1978).

Meiofaunal individuals tended towards an aggregated distribution and the assemblage often zoned horizontally (Heip & Engels, 1977). Patchy distribution may result from clumped food resources and/or selective predation (Coull & Bell, 1979). However, Heip (1975) suggested that aggregation is not mechanical but active process, resulting from two opposing forces; one where the need for enough food results in a more even partitioning of space and one where the need for contact between individuals result in aggregation. Heterogeneity in the distribution of meiofauna is a direct consequence of granulometric properties also (Jansson, 1967).

Result of ANOVA (Table 5) shows that the seasonal differences were significant ($p<0.05$). Consequently one may say that the fluctuation in meiofaunal density was stronger and the season affected the fauna. This inference reconfirms that in tropics the monsoonal rain influences the meiofaunal seasonality (Kondalarao & Murty, 1988; Alongi, 1990). Differences between stations were not significant which indicate that horizontal distribution were well within the limit of expectations. Seasonality in temperature zone is related to severe winter and summer.

The decline in number of organisms with increasing depth in the sediment (Coull & Bell, 1979) has been confirmed in this study. Figure 4 shows the vertical distribution of meiofauna with vertical profile of interstitial water content, Eh and chlorophyll *a*. The correlation in most instances were positive and significant. Zones of high productivity such as the 0–2 cm layer might provide a greater variety of food which can sup-

Table 5. Two way analysis of variance of total meiofauna counts after log transformation (x + 1), Mandovi estuary.

Source of variation	df	SS	MS	F
Stations	2	0.011	0.0055	$3.92^{n.s.}$
Season	2	0.2951	0.1475	105.35*
Interaction	4	0.0056	0.0014	

* F0.05(2,4) = 6.94; n.s. = not significant.

Table 6. Estimates of annual benthic production in Mandovi estuary.

Taxon	Mean standing[a] stock biomass $g\,C\,m^{-2}$	Assumed annual[b] P/B	Production $g\,C\,m^{-2}\,yr^{-1}$
Nematoda	0.105	8	0.84
Harpacticoida	0.045	18	0.81
Polychaeta	0.028	3	0.084
Turbellaria	0.020	10	0.20
Ostracoda	0.17	4	0.68
Others	0.007	8	0.056

[a] Meiofauna biomass was first converted into ash free dry weight as 80% of the dry weight and then C estimated as 40% of the ash free d weight.

[b] P/B ratios were taken from Rudnick *et al.* (1985).

port high density in the upper layer of the sediment. The decrease in interstitial water content will lead to anoxia at depth in the sediment. The redox potential discontinuity layer acts as a barrier for many meiobenthic organisms. Most meiofauna can not tolerate the reducing conditions and are thus restricted to the oxidized sediment zone above it (McLachlan, 1978). The deep penetration of nematodes can be explained by the fact that they can withstand near anaerobic conditions (Wieser & Kanwisher, 1961).

Rough estimate of meiobenthic production was made using P/B ratios given in Rudnick *et al.*, (1985). The annual meiofaunal production is estimated to total 2.67 g C m^{-2} y^{-1} (Table 6). This value is lower than the value of 4.5 g C m^{-2} $year^{-1}$ speculated by Parulekar *et al.* (1980) for the Mandovi Zuari estuarine complex but very close to 2.74 g C m^{-2} reported by Damodaran (1973) in the mud bank region of Kerala. Its overall contribution in the total secondary production (zooplankton + benthos) will be about 16% in the Mandovi estuary. There are earlier reports which have documented low meiobenthic production (Anker & Elmgren, 1976; Dye & Furstenburg, 1981). Thus the energetic importance of meiofauna is not likely to be similar to that of the macrofauna in this estuary.

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