

## **Meiofaunal Stratification In Relation to Microbial Food in a Tropical Mangrove Mud Flat**

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**Abstract :** The vertical gradients of meiofauna mainly in relation to biochemical changes and microbial abundance in the upper 20 cm of deposit of a mangrove mud flat were studied. Strong vertical gradients in the redox potential (Eh), interstitial water and sedimentary organic compounds were recorded. Microbial and phytobenthos also showed clear vertical gradients and a significant number of bacteria were encountered in the 15-20 cm depth. Abundance of meiofauna followed distinct vertical gradient and the number decreased significantly with increasing depth in the sediment. The reducing environment was characterised by high population of nematodes, turbellarians and harpacticoids. Meiofaunal taxa were significantly correlated with Eh and interstitial water of the sediment. Among the meiofaunal food, organic matter, ATP phytobenthic abundance and bacterial counts were positively correlated with meiofaunal density. Biochemical constituents did not yield any significant correlation with meiofauna. Food availability played a supporting role while physical environmental parameters were more important in meiofaunal dispersion in mangrove mud flats.

**Résumé :** Les gradients verticaux de la meiofaune principalement en relation avec les changements biochimiques et l'abondance microbienne ont été étudiés dans les 20 cm superficiels d'un dépôt de vase de mangrove. Des gradients verticaux importants dans le potentiel redox (Eh), l'eau interstitielle et les composés organiques sédimentaires ont été enregistrés. L'activité microbienne et le phytobenthos montrent aussi des gradients verticaux nets et un nombre significatif de bactéries se rencontrent entre 15 et 20 cm. L'abondance de la meiofaune suit un gradient vertical distinct et le nombre diminue significativement avec la profondeur dans le sédiment. L'environnement réducteur est caractérisé par une population élevée de nématodes, turbellariés et harpacticoides. Les taxons meiofauniques sont significativement corrélés au Eh et à l'eau interstitielle du sédiment. Pour l'alimentation de la meiofaune, la matière organique, l'abondance phytobenthique de l'ATP et le nombre de bactéries sont positivement corrélés à la densité meiofaunique. Les constituants biochimiques n'indiquent aucune corrélation significative avec la meiofaune. La disponibilité alimentaire joue un rôle de support tandis que les paramètres de l'environnement physique sont plus importants dans la dispersion de la meiofaune de la vase des mangroves.

**Resumen :** Se estudiaron los gradientes verticales de la meiofauna principalmete en relación a los cambios bioquímicos y abundancia microbiana en los 20 cm superiores del depósito de un manglar pantanoso. Se registraron fuertes gradientes verticales en el potencial redox (Eh), el agua intersticial y los compuestos orgánicos sedimentarios. Los microbios y el fitobentos también mostraron gradientes verticales claros y se encontró un número significativo de bacterias entre los 15-20 cm de profundidad. La abundancia de la meiofauna siguió un gradiente vertical distinto y el número disminuyó significativamente con el

incremento en la profundidad del sedimento. El ambiente reducido se caracterizó por una alta población de nemátodos, turbelarios y harpacticoides. Los taxa de la meiofauna estuvieron correlacionados significativamente con el Eh y el agua intersticial del sedimento. Entre el alimento de la meiofauna, la materia orgánica, la abundancia de ATP fitobéntica y los conteos de bacterias estuvieron correlacionados positivamente con la densidad de la meiofauna. Los constituyentes bioquímicos no produjeron ninguna correlación significativa con la meiofauna. La disponibilidad de alimento jugó un papel importante mientras que los parámetros físicos ambientales fueron más importantes en la dispersión de la meiofauna en el manglar.

*Resumo:* Os gradientes verticais da fauna intersticial (meiofauna) foram estudados em relação às mudanças bioquímicas e à abundância microbiana nos 20 cm da camada superior de um depósito lodoso plano de um mangal. Os fortes gradientes verticais no que concerne ao potencial redox (Eh), água intersticial e compostos orgânicos sedimentares foram registrados. A população microbiana e fitobêntica mostrou igualmente gradientes verticais claros e um número significativo de bactérias foram encontradas nos 15-20 cm de profundidade. A abundância da fauna intersticial seguiu um gradiente vertical distinto e o seu número decresceu significativamente com o acréscimo de profundidade no sedimento. O ambiente redutor foi caracterizado por uma elevada população de nemátodos, turbelarianas e harpacticoides. Os taxa da fauna intersticial encontravam-se significativamente correlacionados com o Eh e com a água intersticial do sedimento. Entre a alimentação daquela fauna, a matéria orgânica, a abundância da ATP fitobêntica e a contagem bacteriana estavam positivamente correlacionadas com a densidade da fauna. Os constituintes bioquímicos não revelaram estar significativamente correlacionados com a fauna intersticial. A disponibilidade de alimentação exerceu um papel de suporte enquanto as características físicas do ambiente foram mais importantes na dispersão da fauna na vasa plana do mangal.

*Key Words :* Meiobenthos, microbenthos, metabolites, vertical profile, mangrove sediment.

## INTRODUCTION

Meiofauna are known to have a patchy distribution at spatial and vertical scales (see review by Fleeger & Decho 1987). Many hypotheses for such patchiness have been proposed. There is, however, lack of logistic evidence of such causal effects in the field. The abundance of microbial food and phytobenthos are considered one of the most important factors influencing the meiofaunal patchiness (Montagna *et al.* 1983). There are evidences that meiofaunal distribution pattern are controlled by physico-chemical properties of the sediment (McLachlan 1978; Ansari *et al.* 1980; Dye 1983; Malan & McLachlan 1985). Biochemical constituents of the sediment were never considered in the distribution of meiofauna. The organic metabolites in the sediment are important in influencing microbial flora (Coull 1973). Since microbes are the major components of the food of meiofauna, it is expected that metabolites may play important role in meiofauna distribution.

In the present communication field studies were conducted to quantify the vertical profile of physical, biochemical and biological parameters and to examine their influence on the abundance, composition and dispersion of meiofauna from a tropical mangrove mud flat.

## MATERIALS AND METHODS

In a semi-enclosed area at Chicalim, on the south bank of Zuari estuary of Goa, small mangrove mud flat extending over a kilometer in length, was considered for the present study. The sediment was loose mud comprising of silt and detritus derived from mangrove foliage. There were sparse mangrove trees dominated by *Avicinnia officinalis* and *Sonneratia alba*, located in the supralittoral zone. Thin bed of rock oyster, *Saccostrea cucullata* was present at low tide on the scattered rocks around the mud flat. This area was primarily selected for a sponsored work during April-May 1991. The present paper is an outcome of the same study.

Samples were collected twice during April-May 1991. All collections were made during low tide from the lower part of the mangrove mud flat (Fig. 1). Sediments were collected by a hand operated core tube (8 cm diameter, 30 cm length) and 20 cm long cores were taken from 4 predetermined sites

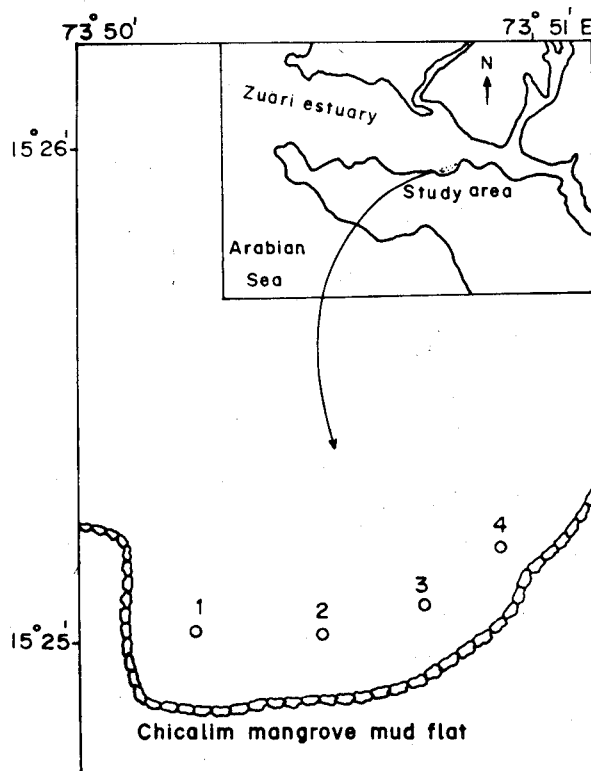


Fig. 4

Fig. 1. Location of station position in Zuari river estuary.

selected by random number method. 5 replicates were collected on each sampling date and 40 samples were used for meiofauna analysis. Core samples were divided at 5 cm intervals thus giving rise to 4 subsamples from each core samples. Meiofauna samples were preserved separately in Rose Bengal formalin buffered solution. Separate core samples were taken for the analyses of grain size, chlorophyll *a*, microbial biomass and biochemical components. Eh was measured in the field using platinum electrode and interstitial water content was determined by taking wet sediment of known weight and drying to a constant weight. Wet weight minus dry weight was considered as weight of interstitial water.

Meiofauna was analysed by the method given in Hulings & Gray (1971). Biomass was determined by taking average weight of individuals of different groups and multiplying it with total density. Sediment organic carbon was determined by titration after digestion in chromic acid (El Wakeel & Riley 1956) and organic matter was determined by multiplying the organic carbon values with 1.724. Biochemical constituents were analysed following the methods of Dubois *et al.* (1956) for carbohydrate, Herbert *et al.* (1971) for protein and Bligh & Dyer (1959) for lipid. Adenosin triphosphate (ATP) was measured by bioluminescence technique (Strehler 1968).

Chlorophyll *a* of the sediment was determined spectrophotometrically after overnight extraction in 90% acetone (Parsons *et al.* 1984). Diatoms were counted under microscope by taking small aliquots of sediment samples in formalin solution. For microbial counts freshly collected sediment samples were immediately stored in cool flask, transferred to laboratory and plated within 3 hours for viable counts at room temperature, using estuarine water agar. The plates were counted after incubation for 4-7 days. A part of sediment was homogenized by diluting 1 g sediment + 4.5 ml sterile water and viewed under epifluorescence microscope for total counts of bacteria using 1% Acredine Orange.

## RESULTS

### *Sediment*

Data on sediment parameters of the mud flat are summarised in Table 1. In general the mud flat had very fine clayey silty sediment with a near symmetrical size distribution. The sand particles were fine and their contribution was 11% on an average basis. Similarly the average percentage of silt and

TABLE 1. Average values of sediment parameters at the study sites.

Station No.	Sand %	Silt %	Clay %	Median (mm)	Sorting 0	Eh (mv)	Interstitial water (%)
1	7.4	66.2	26.27	0.04	2.7	+72	33
2	13.8	51.1	34.8	0.03	2.2	+58	36
3	5.5	74.7	19.6	0.04	3.1	+69	32
4	17.7	49.2	32.7	0.03	2.3	+77	35

clay was 60.4 and 28, respectively. The median particles ranged from 0.039 to 0.047 mm and the sorting was poor. Most of the stations showed a slight increase in particle size between sediment depth of 10 and 20 cm. The redox potential (Eh) values and interstitial water content are the average values for entire 20 cm depth. There was however, a strong vertical gradient in their distribution as shown in Fig. 2.

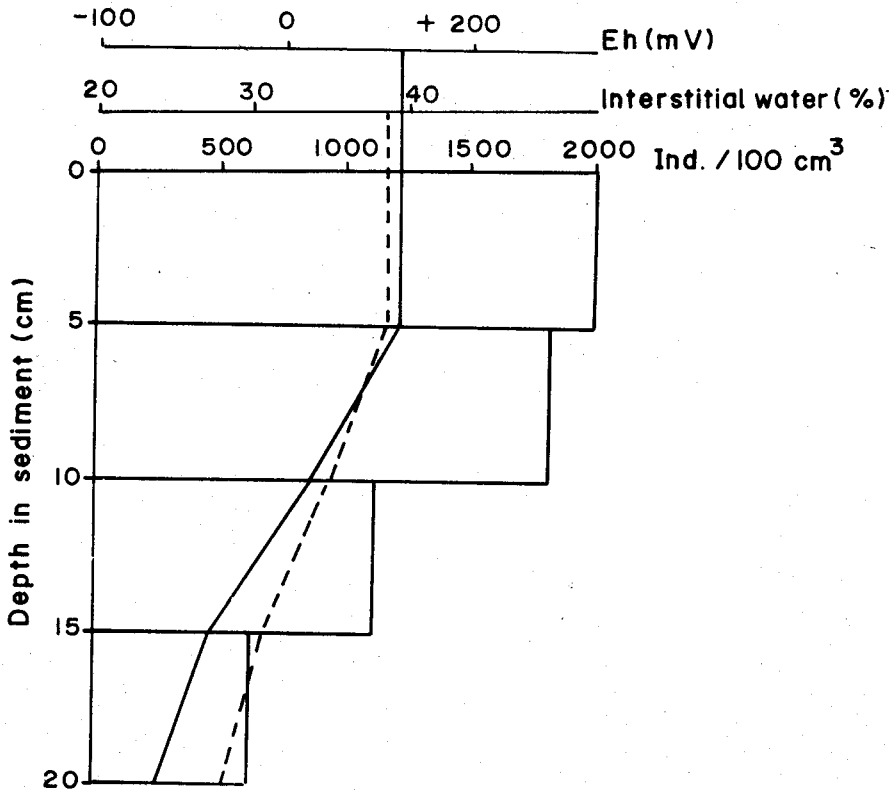


Fig. 2. Vertical distribution of meiofauna, Eh and interstitial water in the sediment.

#### *Biochemical components*

The results of the analysis of biochemical constituents of sediment are given in Table 2. Although the values were high at the surface, no consistent pattern was observed. organic matter ranged from 22.41 to 55.68 mg g<sup>-1</sup> dry sediment. Vertical profile of protein and lipid were very similar and the

values ranged from 0.87 to 3.07 mg g<sup>-1</sup> and 0.40 to 1.2 mg g<sup>-1</sup> for protein and lipid respectively. Carbohydrate ranged from 6.10 to 18.06 mg g<sup>-1</sup> dry sediments. The values showed abrupt changes in relation to depth in the sediment.

TABLE 2. Average value of organic matter and biochemical compounds at different depth intervals. All values are expressed in terms of mg g<sup>-1</sup> dry sediment. ATP are in ng g<sup>-1</sup> sediment.

St. No.	Depth (cm)	Total organic matter	Protein	Lipid	Carbohydrate	ATP
1	0-5	50.6±6.2	0.9±0.2	0.8±0.2	16.2±2.3	15.2±4.6
	5-10	52.2±8.8	2.0±0.6	0.7±0.2	12.0±1.6	16.0±5.8
	10-15	24.8±2.9	1.2±0.4	0.6±0.2	11.2±1.8	9.2±3.3
	15-20	22.6±2.9	1.0±0.3	0.7±0.2	18.0±2.6	7.0±2.6
2	0-5	48.9±6.5	3.0±1.0	1.2±0.3	15.8±2.3	19.1±7.2
	5-10	51.6±9.2	2.3±0.3	0.8±0.3	16.8±2.5	20.2±6.9
	10-15	22.4±3.7	1.4±0.5	0.5±0.2	18.0±3.4	6.1±2.3
	15-20	21.2±3.5	1.2±0.5	0.4±0.2	12.3±2.2	5.5±2.6
3	0-5	27.5±4.3	1.2±0.3	0.6±0.3	9.5±1.6	15.2±5.5
	5-10	26.7±3.2	1.3±0.3	0.5±0.3	10.5±1.8	9.6±2.9
	10-15	24.1±2.8	0.9±0.2	0.6±0.2	7.3±1.5	5.1±1.6
	15-20	20.1±2.5	1.0±0.3	0.5±0.2	8.6±2.3	3.1±0.8
4	0-5	35.3±4.6	1.5±0.4	0.4±0.2	7.1±1.8	8.1±2.5
	5-10	28.6±3.5	1.3±0.4	0.5±0.1	8.1±1.9	5.3±1.8
	10-15	26.0±2.9	0.8±0.2	0.4±0.1	10.7±2.4	4.6±1.3
	15-20	21.2±2.6	1.2±0.3	0.6±0.1	6.9±2.3	3.0±1.2

#### *Chlorophyll a and diatom*

The results of the analyses of chlorophyll *a* and diatom abundance are given in Table 3. Chlorophyll *a* concentration was high at the surface and decreased progressively with increasing depth in the sediment. The values differed significantly ( $P < 0.05$ ) between 0-10 and 10-20 cm layers. An acid factor was obtained by dividing phaeopigment with chlorophyll *a* multiplied by 100 (Malan & McLachlan 1985). High values indicated that most of chlorophyll is in the degraded form (Malan & McLachlan 1985). Diatom count ranged between  $0.3 \times 10^3$  and  $1.9 \times 10^5$  g<sup>-1</sup> sediment. Vertical profiles of diatom numbers were similar to chlorophyll *a* gradient (Table 3) but the counts fluctuated greatly between the replicates.

TABLE 3. Average value of chlorophyll *a*, phaeopigment and microbial counts at study sites.

St. No.	Depth (cm)	Concentration ( $\mu\text{g/g}$ sediment)		Acid ratio	Bacteria (No./g sed.)	Diatom (No./g sed.)
		Chl. <i>a</i>	Phaeo			
1	0-5	1.57 $\pm$ 0.43	2.51 $\pm$ 0.43	159	6.9 x 10 <sup>8</sup> $\pm$ 1.2 x 10 <sup>4</sup>	1.6 x 10 <sup>5</sup> $\pm$ 0.47 x 10 <sup>5</sup>
	5-10	1.72 $\pm$ 0.28	2.63 $\pm$ 1.39	152	5.2 x 10 <sup>7</sup> $\pm$ 1.6 x 10 <sup>4</sup>	1.9 x 10 <sup>5</sup> $\pm$ 0.23 x 10 <sup>5</sup>
	10-15	1.05 $\pm$ 0.46	1.32 $\pm$ 0.18	125	11.4 x 10 <sup>5</sup> $\pm$ 1.8 x 10 <sup>3</sup>	1.8 x 10 <sup>3</sup> $\pm$ 0.33 x 10 <sup>3</sup>
	15-20	0.75 $\pm$ 0.28	0.85 $\pm$ 0.13	113	11.2 x 10 <sup>4</sup> $\pm$ 1.2 x 10 <sup>3</sup>	0.4 x 10 <sup>3</sup> $\pm$ 0.14 x 10 <sup>3</sup>
2	0-5	1.56 $\pm$ 0.19	3.12 $\pm$ 1.06	200	10.2 x 10 <sup>8</sup> $\pm$ 1.5 x 10 <sup>5</sup>	1.5 x 10 <sup>4</sup> $\pm$ 0.26 x 10 <sup>4</sup>
	5-10	1.66 $\pm$ 0.23	2.25 $\pm$ 0.62	135	7.4 x 10 <sup>6</sup> $\pm$ 0.6 x 10 <sup>3</sup>	1.8 x 10 <sup>5</sup> $\pm$ 0.52 x 10 <sup>5</sup>
	10-15	0.77 $\pm$ 0.12	1.40 $\pm$ 0.32	181	6.1 x 10 <sup>3</sup> $\pm$ 1.2 x 10 <sup>3</sup>	3.7 x 10 <sup>3</sup> $\pm$ 1.10 x 10 <sup>3</sup>
	15-20	0.53 $\pm$ 0.12	0.98 $\pm$ 0.14	184	2.4 x 10 <sup>3</sup> $\pm$ 1.8 x 10 <sup>3</sup>	1.8 x 10 <sup>3</sup> $\pm$ 0.31 x 10 <sup>3</sup>
3	0-5	1.46 $\pm$ 0.16	1.36 $\pm$ 0.28	93	7.2 x 10 <sup>7</sup> $\pm$ 0.5 x 10 <sup>7</sup>	2.5 x 10 <sup>4</sup> $\pm$ 0.43 x 10 <sup>4</sup>
	5-10	1.05 $\pm$ 0.21	0.52 $\pm$ 0.14	49	11.2 x 10 <sup>5</sup> $\pm$ 1.8 x 10 <sup>5</sup>	1.9 x 10 <sup>3</sup> $\pm$ 0.27 x 10 <sup>3</sup>
	10-15	0.63 $\pm$ 0.29	0.32 $\pm$ 0.08	50	9.0 x 10 <sup>4</sup> $\pm$ 2.5 x 10 <sup>4</sup>	0.7 x 10 <sup>3</sup> $\pm$ 0.16 x 10 <sup>3</sup>
	15-20	0.35 $\pm$ 0.06	0.25 $\pm$ 0.05	71	5.2 x 10 <sup>4</sup> $\pm$ 2.2 x 10 <sup>5</sup>	0.3 x 10 <sup>3</sup> $\pm$ 0.13 x 10 <sup>3</sup>
4	0-5	1.08 $\pm$ 0.25	0.84 $\pm$ 0.09	77	5.9 x 10 <sup>6</sup> $\pm$ 3.4 x 10 <sup>4</sup>	1.8 x 10 <sup>5</sup> $\pm$ 0.42 x 10 <sup>5</sup>
	5-10	0.85 $\pm$ 0.14	0.94 $\pm$ 0.22	110	5.0 x 10 <sup>5</sup> $\pm$ 2.7 x 10 <sup>3</sup>	1.3 x 10 <sup>4</sup> $\pm$ 0.28 x 10 <sup>4</sup>
	10-15	0.43 $\pm$ 0.04	0.63 $\pm$ 0.23	146	3.8 x 10 <sup>3</sup> $\pm$ 0.9 x 10 <sup>3</sup>	0.7 x 10 <sup>3</sup> $\pm$ 0.18 x 10 <sup>3</sup>
	15-20	0.27 $\pm$ 0.04	0.35 $\pm$ 0.15	129	3.0 x 10 <sup>3</sup> $\pm$ 1.4 x 10 <sup>3</sup>	0.6 x 10 <sup>3</sup> $\pm$ 0.15 x 10 <sup>3</sup>

#### Microbial count

Bacterial counts were high in the sediment (Table 3) which is not uncommon in an area dominated by detritus. The values were generally high at the surface but fluctuated abruptly with increasing sediment depth, thus showing no distinct pattern. Total counts ranged between 3.0 x 10<sup>3</sup> and 10.2 x 10<sup>8</sup> g<sup>-1</sup> sediment and the counts were invariably high in the surface.

TABLE 4. Meiofaunal taxa, biomass, abundance and percentage composition.

St. No.	Depth (cm)	Biomass (mg dry wt. 100 cm <sup>-3</sup> )	Total density (100 cm <sup>-3</sup> )	Meiofaunal taxa (%)					
				Nematoda	Turbellaria	Harpacticoida	Oligochaeta	Gastrotricha	Others
1	0-5	1.05	2340±240	53.8	14.9	14.1	5.1	2.1	9.8
	5-10	1.08	2420±185	51.4	16.3	11.7	8.8	1.7	9.9
	10-15	0.47	1060±305	59.4	10.3	4.7	11.3	-	14.1
	15-20	0.25	575±101	66.6	10.5	-	7.0	-	15.8
2	0-5	0.97	2160±238	57.0	12.5	20.8	2.3	1.4	6.0
	5-10	1.00	2225±301	57.5	14.4	10.7	5.8	5.0	6.6
	10-15	0.43	972±175	53.6	13.4	3.0	12.3	5.1	12.3
	15-20	0.15	355±85	62.8	17.1	-	5.7	-	14.3
3	0-5	0.84	1870±204	49.7	16.5	19.2	4.2	1.6	8.5
	5-10	0.59	1323±165	54.5	17.4	11.3	3.0	10.6	3.0
	10-15	0.35	785±125	53.8	16.6	-	6.4	2.5	20.5
	15-20	0.15	356±63	91.4	-	-	4.5	-	4.0
4	0-5	0.79	1778±343	41.2	14.7	12.4	7.9	9.0	14.7
	5-10	0.77	1720±245	53.5	14.5	5.2	7.0	7.0	12.8
	10-15	0.38	850±270	61.1	3.5	-	14.1	2.3	18.8
	15-20	0.17	392±96	64.1	-	-	24.0	-	20.5



TABLE 5. Simple correlation matrix of hydrobiological parameters and biochemical components at the study sides.

	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12
P1	0.92 <sup>***</sup>	0.55 <sup>*</sup>	0.62 <sup>***</sup>	0.04 <sup>ns</sup>	-0.09 <sup>ns</sup>	0.35 <sup>ns</sup>	-0.29 <sup>ns</sup>	0.81 <sup>***</sup>	0.51 <sup>*</sup>	0.64 <sup>**</sup>	0.66 <sup>**</sup>
P2	-	0.77 <sup>***</sup>	0.50 <sup>*</sup>	0.53 <sup>*</sup>	0.06 <sup>ns</sup>	0.22 <sup>ns</sup>	0.02 <sup>ns</sup>	0.74 <sup>***</sup>	0.55 <sup>*</sup>	0.53 <sup>*</sup>	0.58 <sup>*</sup>
P3	-	-	0.36 <sup>ns</sup>	0.80 <sup>***</sup>	0.26 <sup>ns</sup>	-0.25 <sup>ns</sup>	0.47 <sup>ns</sup>	0.31 <sup>ns</sup>	0.61 <sup>*</sup>	0.44 <sup>ns</sup>	0.19 <sup>ns</sup>
P4	-	-	-	-0.02 <sup>ns</sup>	0.05 <sup>ns</sup>	-0.06 <sup>ns</sup>	-0.13 <sup>ns</sup>	0.28 <sup>ns</sup>	0.66 <sup>**</sup>	0.77 <sup>***</sup>	0.09 <sup>ns</sup>
P5	-	-	-	-	0.28 <sup>ns</sup>	-0.37 <sup>ns</sup>	0.70 <sup>**</sup>	-0.05 <sup>ns</sup>	0.64 <sup>**</sup>	0.12 <sup>ns</sup>	0.15 <sup>ns</sup>
P6	-	-	-	-	-	0.66 <sup>**</sup>	0.83 <sup>***</sup>	-0.39 <sup>ns</sup>	0.90 <sup>***</sup>	0.22 <sup>ns</sup>	-0.15 <sup>ns</sup>
P7	-	-	-	-	-	-	-0.74 <sup>***</sup>	0.67 <sup>**</sup>	-0.66 <sup>**</sup>	0.11 <sup>ns</sup>	0.38 <sup>ns</sup>
P8	-	-	-	-	-	-	-	-0.58 <sup>*</sup>	0.93 <sup>***</sup>	-0.25 <sup>ns</sup>	-0.15 <sup>ns</sup>
P9	-	-	-	-	-	-	-	-	-0.34 <sup>ns</sup>	0.40 <sup>ns</sup>	0.55 <sup>*</sup>
P10	-	-	-	-	-	-	-	-	-	0.72 <sup>***</sup>	0.01 <sup>ns</sup>
P11	-	-	-	-	-	-	-	-	-	-	0.62 <sup>**</sup>

P1=total density, P2=nematode numbers, P3=turbellaria numbers, P4 harpacticoid numbers, P5=total organic matter, P6=protein %, P7=carbohydrate %, P8=lipid %, P9=ATP, P10=chl *a*, P11=diatom numbers, P12=bacterial counts  
 \*\*\*=P 0.01, \*\*= P 0.05, \* = P 0.1, ns= not significant

### *Meiofauna*

Vertical profile of meiofaunal density in the sediment column are given in Table 4. In general, the density was greater near the surface and decreased with increasing depth into the sediment. At all stations, the meiofauna was dominated by nematodes which accounted for more than 50% of the total abundance. Next in order of abundance were turbellarians, harpacticoids, oligochaetes and gastrotrichs. The remaining group consisted of low number of polychaetes, kinorhynchs, tardigrades and larvae of insects and crustaceans. Vertically all groups except nematodes and oligochaetes were restricted to the upper 10-15 cm and showed vertical compositional changes. Nematodes were consistently present in the entire 20 cm core, although their density decreased progressively with increasing depth in the sediment. The population density of meiofaunal organisms were significantly higher in the top 10 cm layer than the below depth (Wilcoxon sign test,  $P < 0.05$ ). The meiofaunal biomass ranged between 0.157 and 1.089 mg 100 cm<sup>-3</sup>. Maximum biomass was in the top layer and lowest in the bottom 15-20 cm layer of the sediment.

Linear correlation techniques were used to correlate food abundance and biochemical constituents with the density of meiofaunal taxa. Table 5 summarises the result of linear regression analyses. Main taxa were strongly interrelated positively. Nematodes being the dominant taxon, were closely correlated with the total counts, turbellarians and harpacticoids. Total density showed strong positive correlation with ATP, diatom numbers and bacterial counts but weakly correlated with chlorophyll *a*. Nematodes were strongly correlated with ATP. Turbellarians showed significant correlation with organic matter and harpacticoids were positively correlated with chlorophyll *a* and diatom number. Number of meiofauna also showed strong correlation with total organic C and chlorophyll *a*. However, major organic constituents and bacterial counts did not yield any significant correlation with meiofauna, suggesting no separate effect of these parameters on meiofauna. Protein, carbohydrate and ATP were interrelated. Chlorophyll *a*, diatom number and bacterial counts were also interrelated.

### DISCUSSION

The environmental parameters revealed high total organic matter, low Eh, and sediment comprised of high silt clay content and fine but poorly sorted grain size. It characterises a detritus accumulating environment where the particulate organic matter is abundant. It supports high microbial biomass which not only form the food of meiofauna but also help in nutrient regeneration through degradation process (Coull 1973).

Meiofauna in the present study showed some features that are typical of the intertidal meiofauna. Nematodes were the dominant taxa at all sites and at densities generally within the range recorded from other mangrove environments (Sultan Ali *et al.*: 1983; Dye 1983; Hodda & Nicholas 1985; Alongi 1987). The density of other taxa were more variable between replicates thus showing high degree of variability in population counts, a feature true of meiofauna (Coull & Bell 1979). There were strong vertical gradient in number and biomass which were in response to vertical gradient of physical environment (McLachlan 1978). Meiofauna are sensitive to microhabitat changes and are able to select narrow areas within a relatively homogeneous substrate (Coull 1973). The vertical profile of Eh and interstitial water was closely related to vertical distribution of meiofauna (Fig. 2).

It suggests that the faunal composition, as well as abundance, is related to the gradients of redox potential discontinuity (RPD) layer. Many authors have reported Eh as the most important factor in controlling vertical movement of meiofauna (McLachlan 1978; Montagna *et al.* 1983). The presence of nematodes down in sediment in significantly higher number is indicative of the fact that they are capable of moving down in obviously reducing conditions while the more sensitive groups such as harpacticoids and turbellarians avoid RPD and remain in the upper more oxic part of the sediment.

Among biochemical components, only total organic matter and ATP gave a positive significant correlation with meiofaunal number. The organic matter may provide ideal food for the selective and non-selective deposit feeders such as oligochaetes, polychaetes and nematodes. It is reported that a number of meiofaunal taxa are greatly dependent on the availability of the particulate organic matter in the sediment (Faubel & Meyer Reil 1981). The vertical profile of ATP showed consistent and progressive decrease in concentration with increasing depth in the sediment. It is believed that the patchy distribution of meiofauna is responsible for variation of ATP in the sediment (Tenore *et al.* 1982). These authors found a positive correlation between ATP of microbial biomass and nematode abundance. It has been reported that nematode ATP accounts for 68 to over 90% of total sediment ATP (Sikora *et al.* 1977). Since nematodes are the major constituents of meiofauna in the present study, a positive correlation was not unexpected. Major biochemical components seem to be degraded and utilized at microbial level and are directly not influential in meiofaunal distribution.

Densities of meiofauna were highest near the surface and the abundances were related to food availability such as chlorophyll *a* concentration and diatom numbers and bacterial counts (Table 5). This corroborates the hypotheses proposed earlier by Teal & Wieser (1966) and others (see Coull & Bell 1979 and Fleeger & Decho 1987). Algal food has been reported as important factor in the distribution of meiofauna in mangrove estuaries (Dye 1983; Hodda & Nicholas 1985). It is believed that the spatial distribution of certain algal types may also influence the distribution of meiofaunal species (Decho & Castenholz 1986). Positive correlation between meiofaunal density and diatom abundance observed in the present study has also been reported by others (Montagna *et al.* 1983).

Various types of association of meiobenthos with microbial flora in estuarine mud are known (Coull 1973). There is an evidence that meiofauna can grow on algal plus its associated bacterial flora (Tietjen 1980). The present study also suggests a similar type of association between meiofauna and microbial population in mangrove mud. Montagna *et al.* (1983), however found insignificant correlation between microflora and meiofauna. They believed that meiofauna are not always capable of affecting the bacterial population and that the meiofauna consumes a variety of other food items. On the other hand, Decho & Castenholz (1986) have proved that meiofauna are closely associated with microbial food which they consume.

We may conclude that microbial flora are important in governing the distribution of many meiobenthic forms within the system, directly or indirectly. ATP may provide important clue in the patchy distribution but other biochemical constituents do not seem to be directly involved in the distribution of meiofauna. It appears that physical environmental factors influence both meiofauna and their microbial food in the same fashion and are apparently more important than their biological counterparts in controlling the distribution of meiofauna in the mangrove mud flats.

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## REFERENCES

- Alongi, D.M. 1987. Intertidal zonation and seasonality of meiobenthos in tropical mangrove estuaries. *Marine Biology* **95**: 447-458.
- Ansari, Z.A., A.H. Parulekar & T.G. Jagtap. 1980. Distribution of sublittoral meiobenthos off Goa coast. *Hydrobiologia* **74**: 209-214.
- Bligh, E.G. & W.J. Dyer. 1959. A rapid method of total lipid extraction and purification. *Canadian Journal of Biochemistry and Physiology* **37**: 911-917.
- Coull, B.C. 1973. Estuarine meiofauna : A review : Trophic relationship and microbial interactions. pp. 499-512. *In*: H. Stevenson & R.R. Colwell (eds.) *Estuarine Microbial Ecology*. University of South Carolina Press, Columbia.
- Coull, B.C. & S.S. Bell. 1979. Perspective of marine meiofauna ecology. pp. 189-216 . *In*: R.J. Lvington (ed.) *Ecological Processes in Coastal and Marine System*. Plenum Publishing Corporation, New York.
- Decho, A.W. & R.W. Castenholz. 1986. Spatial pattern and feeding of meiobenthic harpacticoid copepod in relation to resident microbial flora. *Hydrobiologia* **131**: 87-96.
- Dubois, M., K.A. Gilles, J.K. Hamilton, P.A. Rebers & F. Smith. 1956. Colorimetric determination of sugars and related substances. *Analytical Chemistry* **28**: 350-356.
- Dye, A.H. 1983. Vertical and horizontal distribution of meiofauna in mangrove sediments in Transkei estuary, Southern Africa. *Estuarine Coastal Shelf Science* **16**: 590-598.
- El Wakeel, S.K. & J.P. Riley. 1956. The determination of organic carbon in marine muds. *Journal Du Conseil perm International Exploration De la Mer* **22**: 180-183.
- Faubel, A. & L.A. Meyer Reil. 1981. Enzymatic decomposition of particulate organic matter by meiofauna. *Kieler Meeresforschung, Sonderheft* **5**: 429-430.
- Fleeger, J.W. & A.W. Decho. 1987. Spatial variability of interstitial meiofauna : A review. *Stygologia* **3**: 35-54.
- Herbert, D., P.J. Phipps & R.C. Strange. 1971. Chemical analysis of microbial cells. 5B: pp.244-252. *In*: J.R. Nortis & D.W. Ribbons (eds.) *Method in Microbiology*. Academic Press, London.
- Hodda, M. & W.L. Nicholas. 1985. Meiofauna associated with mangroves in the Hunter River estuary and Fullerfon Cove, South-eastern Australia. *Australian Journal of Marine and Freshwater Research* **36**: 41-50.
- Hulings, N.C. & J.S. Gray. 1971. *A Manual for the Study of Meiofauna*. Smithsonian Contribution in Zoology, No. 78.
- Malan, D.E. & A. McLachlan. 1985. Vertical gradients of meiofauna and bacteria in subtidal sandy sediment from two high energy surf zones in Algoa Bay, South Africa. *South African Journal of Marine Science* **3**: 43-53.
- McLachlan, A. 1978. A quantitative analysis of the meiofauna and the chemistry of the redox potential discontinuity zone in a sheltered sandy beach. *Estuarine Coastal Marine Science* **7**: 275-290.
- Montagna, P.A., B.C. Coull, T.L. Herring & B.W. Dudley. 1983. The relationship between abundances of meiofauna and their suspected microbial food (diatoms and bacteria). *Estuarine Coastal Shelf Science* **17**: 381-394.
- Parsons, T.R., Y. Maita & C.M. Lalli. 1984. *A Manual of Chemical and Biological Method for Seawater Analysis*. Pergamon Press, New York.
- Sikora, J.P., W.B. Sikora, C.W. Erken Brecher & B.C. Coull. 1977. Significance of ATP, Carbon and caloric content of meiobenthic nematodes in partitioning benthic biomass. *Marine Biology* **44**: 7-14.
- Strehler, B.L. 1968. Bioluminescence assay, principle and practice. *Method in Biochemical Analysis* **18**: 99-181.
- Sultan Ali, M.A., K. Krishnamurthy & M.J.P. Jeyaseelan. 1983. Energy flow through the benthic ecosystem of the mangroves with special reference to nematodes. *Mahasagar-Bulletin of the National Institute of Oceanography* **16**: 317-325.
- Teal, J. & W. Wieser. 1966. The distribution and ecology of nematodes in a Georgia salt marsh. *Limnology Oceanography* **11**: 217-222.

- Tenore, K.R., I.F. R.M. Boyer, J. Corral, C. Garcia, N.Gonzales, E. Gonzales, R.B. Hanson, J. Inglesias, M. Krom, E. Lopez, J. McLain, M.M. Pamatmat, A. Perez, D.C. Rhodes, T. Santiago, J. Tietjen, J. Westrick & J.R.L. Windom. 1982. Coastal upwelling in the Rias Rajas, N.W. Bay Spain, Contrasting the benthic regimes of the Rias de Arosa and de Muros. *Journal of Marine Research* **40**: 701-772.
- Tietjen, J.H. 1980. Microbial-meiofaunal interrelationship: A review. *Microbiology* **1980**: 335-338.

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