

Role of salinity in structuring the intertidal meiofauna of a tropical estuarine beach: Field evidence

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Community structure of meiofauna was studied for 12 months (July 1991-June 1992) on an estuarine intertidal beach at Siridao, Goa (India). The temperature of the surf zone water ranged from 26.5° to 30.7°C; salinity from 8.3 to 34.4 $\times 10^{-3}$; dissolved oxygen from 2.4 to 4.8 ml l⁻¹; particulate organic carbon from 0.11 to 5.00 mg l⁻¹ and chlorophyll *a* 1.04 to 7.51 μ g l⁻¹. Chlorophyll *a* and POC concentrations showed significant variations between the sampling months. Mean monthly meiofaunal density recorded at mid-tide level varied between 3.6 and 211 individuals for every 3cm² (mean = 115.7 \pm 62.6). Fluctuation in meiofaunal density showed significant correlation with salinity fluctuation ($r = 0.607$; $P < 0.05$). Distinct invertebrate communities were associated with different salinity regimes. Since the occurrence and abundance of dominant meiobenthic species were influenced greatly by monsoonal rain, the presence/absence of known species during a particular season could be predicted on the basis of field salinity.

Environmental factors such as seasonal temperature variations, photoperiod, lunar periodicity, salinity and food availability are regarded as important regulators of the reproductive cycle of marine invertebrates¹⁻⁴. Species inhabiting the estuarine environment often experience rapid fluctuations in salinity, which affect their distribution and abundance⁵⁻⁷. Intertidal species have to withstand abrupt, short-term salinity fluctuations which might occur during a tidal cycle or after heavy rains particularly in the tropics^{8,9}.

Estuarine intertidal habitats harbour rich meiofaunal communities, which in turn serve as live food for higher trophic levels^{10,11}. Most of the earlier studies on intertidal meiobenthos have been from boreal latitudes with typical annual temperature regime and nutritional pattern characterized by adverse conditions during winter and favourable conditions only during spring/summer. In comparison, very few studies are on record from the tropics. Unlike intertidal estuarine habitats in temperate region, tropical estuaries are subjected to distinct seasonality in precipitation. Typically, prolonged monsoonal rains occur during the summer season followed by several months of dry weather. However, the effect of continuous precipitation and dryness on beach communities are unknown. Alongi¹² studied the zonation of intertidal

meiobenthos of Australian estuaries and revealed that seasonality of meiobenthic communities was influenced by rainfall. Laboratory studies conducted on some meiobenthic species show that they exhibit a variety of behavioural and physiological responses to short-term salinity changes¹³⁻¹⁶.)

This paper addresses the contention that salinity is an important physical factor regulating the meiofaunal populations on tropical intertidal estuarine beaches. The field study was further supported by laboratory experiments with commonly occurring benthic harpacticoid and turbellarian species.

Materials and Methods

The sampling was from Siridao beach on the northern bank of the river Zuari, located in the central part of Goa. This beach (lat. 15°26' N; long. 73° 51' E) is about 1 km long, delimited at either end by laterite rocky regions (Fig. 1). The site has tropical climate characterized by southwest monsoon (June-September), postmonsoon (October-January) and premonsoon (February-May) seasons. About 90% of the rainfall occurs during the SW monsoon with an annual average of 3000 mm. Heavy swells and beach erosion occur during this season. The maximum tidal amplitude is about 2.3 m and intertidal width of the beach is about

40-50 m. Siridao beach is topographically independent of the surrounding major habitats, and the benthic (meio and macrofauna) assemblages on the beach differ significantly from the neighbouring subtidal bottom assemblages⁷. Most invertebrate phyla are represented on this sandy beach, either as interstitial forms or as members of the macrofauna.

Water samples for the standard hydrographic parameters (i.e., salinity, dissolved oxygen, and pH) were collected during low tide. *In-situ* temperature of surface water and sediment at 2-3 cm depth at mid tide level was recorded. Salinity was analyzed following the standard titration method¹⁷ and dissolved oxygen was estimated by the method of Parsons *et al.*¹⁸. pH and Eh were measured in field using a portable pH meter.

For analysis of particulate organic carbon (POC) and chlorophyll *a* (chl *a*), water samples were collected in 5 liter polythene containers. Immediately after collection, 4 duplicate aliquots of 1 to 2 liter were filtered through precombusted (450 °C for 3 h) and pre-weighed GF/C glass fiber filters. Filters were then washed twice with distilled water to remove salts and kept deep frozen at -20°C until further analysis. The particulate matter left on the filter was analyzed for POC and chl *a* estimates. POC was analyzed following the method described by Parsons *et al.*¹⁸. Sediment organic carbon was analyzed by the method of El Wakeel & Riley¹⁹.

Meiobenthic samples were collected monthly

(from July 1991 to June 1992) from intertidal region of the beach at Siridao. Triplicate samples were collected at mid-tide level using a plastic corer that covers an area of 3 cm². All the samples were preserved in 5% neutralized Formalin-Rose Bengal solution. In the laboratory, samples were washed with filtered seawater through a 63 μm mesh sieve and the contents of the sieve were fixed in 70% alcohol. All the meiofauna were sorted, counted and identified to major taxon under the stereomicroscope.

Results

Hydrology of the environment—Most rainfall occurs during southwest monsoon with a maximum rain fall of 1138 mm recorded during August 1991. The precipitation decreased gradually during the postmonsoon and the climate remains almost dry during premonsoon. Heavy land run-off during the monsoon affects the salinity of the estuarine waters (Fig. 2). The monthly water temperature recorded at the low tide level ranged between 26.5 and 30.7°C. The annual mean temperature estimated from 12 sampling months was 28.4 ± 1.4°C. The salinity of water fluctuated seasonally during low tide (Fig. 2). Salinity values ranged between 8.3 to 34.4 × 10⁻³ with an annual mean of 27.4 ± 6.4 × 10⁻³. Higher values were found during the premonsoon (May) and lower values during monsoon (July). The pH values ranged between 6.8 and 8.3 (Fig. 3). The values decreased sharply during the monsoonal months

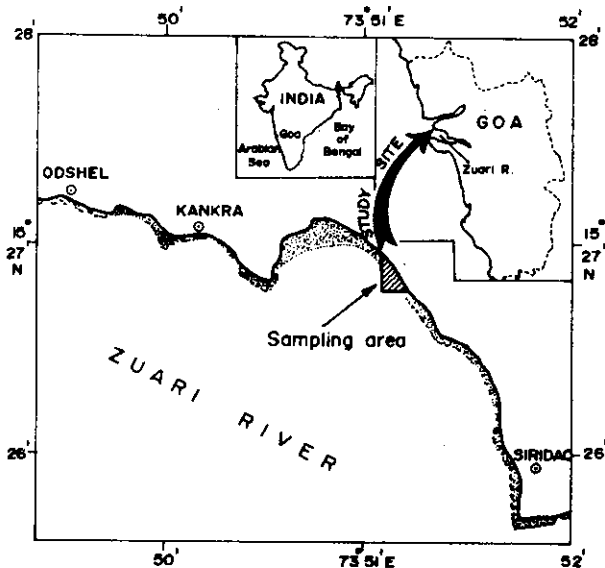


Fig. 1—Location of the sampling area

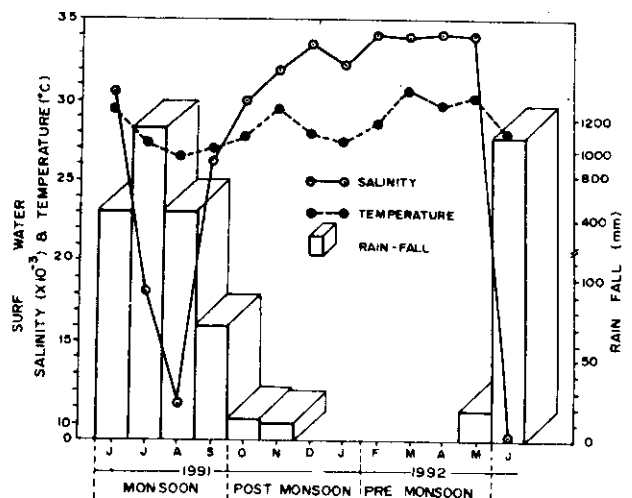


Fig. 2—Effect of rain fall on the surface water salinity and temperature

coinciding with peak precipitation. The dissolved O₂ values ranged between 2.4 to 4.8 ml l⁻¹. High DO values were recorded during the southwest monsoon months of June to September (Fig. 3).

The values for chlorophyll *a* in surf zone water showed significant seasonal variations. The monthly mean values ranged between 0.55 and 8.60 µg l⁻¹ (Fig.3), with the highest values during the premonsoon and lowest during the monsoon season. Particulate organic carbon at surf zone was found to vary between 0.11 and 4.00 mg C l⁻¹ (Fig.3).

Sediment properties - Sediment temperature ranged between 26.8 to 30.0°C with an annual mean of 28.6°C. Sediment pH concentration showed much less variation and the values fluctuated between 7.0 to 7.6 (Table 1). The values for reducing or oxidizing potential of the sediment, measured as redox potential (*Eh*), varied greatly from season to season and ranged between +16 to +61 mv. This shows that the sediment was mostly in reduced condition which is the characteristic feature of the intertidal sediments. Mean grain size ranged between 2.03 - 2.23φ with an annual mean of 2.54±0.28. Organic carbon value ranged between 0.96-1.66 mg g⁻¹ (mean=1.39±0.24). Sediment chlorophyll *a* showed very high fluctuations which were mainly due to the seasonal changes in the light conditions. The values ranged between 1.04 to 7.51 µg l⁻¹, with the annual mean of 4.17 µg l⁻¹. The monthly mean percentage of sediment organic carbon (1.33 to 2.73%; mean 1.94%) showed high values during monsoon and lower values during postmonsoon.

Meiofaunal composition and distribution - The percent composition of meiofauna is presented in Fig.4. Meiofauna of the Siridao beach comprised nematodes (59.2%), turbellarians (12.3%), oligochaets (9.6%), harpacticoids (9.2%), gastrotrichs (4.7%) and halacarids (1.5%) Other groups, (ostracods, tardigrades, kinorhynchs, isopods, poly-

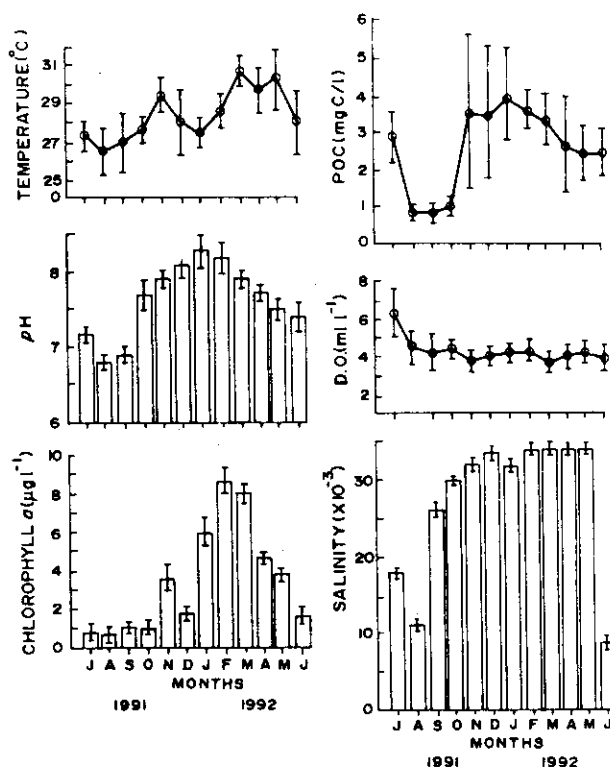


Fig. 3—Hydrological parameters (mean±sd) of the surface water collected from the intertidal zone (error bars are the ± sd)

Table 1—Sediment properties recorded at midtide level at Siridao beach Goa(n = 5; ± sd).

Month	Temp. (°C)	pH	<i>Eh</i>	Chl <i>a</i> (µg g ⁻¹)	Org.C (mg g ⁻¹)
July 1991	26.8±1.0	7.24±0.16	+57±5.10	1.04±0.28	1.92±1.34
August	27.0±1.0	7.48±0.24	+77±2.10	1.46±0.39	2.73±1.24
September	28.3±0.3	7.29±0.18	+27±7.03	1.52±0.39	2.49±1.14
October	29.8±0.8	7.40±0.26	+61±3.65	1.89±0.78	1.75±0.11
November	29.2±0.2	7.51±0.25	+58±3.19	3.61±1.04	2.16±0.38
December	28.3±0.3	7.36±0.20	+28±1.0	4.76±2.48	1.93±0.19
January 92	28.3±0.4	7.17±0.22	+47±4.66	5.89±2.73	1.33±0.12
February	29.2±0.2	7.13±0.25	+39±1.30	7.32±2.66	1.75±0.38
March	30.1±0.3	7.06±0.15	+18±3.51	7.51±1.28	2.00±0.29
April	28.8±1.6	7.20±0.20	+16±4.04	6.21±1.80	1.50±0.37
May	29.1±1.2	7.10±0.11	+24±1.53	4.98±1.50	1.72±0.12
June	28.1±0.4	7.49±0.08	+39±6.03	3.86±2.15	2.00±0.63

chaetes, and tanaids) comprised 3.5% of total meiofauna. Monthly variation in faunal density of major meiofaunal groups is presented in Fig. 5. The nematodes were the most abundant and were recorded throughout the study period. Their density varied between 7-143 no/3cm². Harpacticoid copepods were abundant only during the pre- and postmonsoon months. Turbellarians, oligochaetes and gastrotrichs were present throughout the year, however, in general their abundance was also more during pre- and postmonsoonal months.

Temporal variability of meiofauna—Monthly mean meiofaunal density values varied between 3.6 to 211 no/3 cm² (mean=115.7±62.6). Minimum values were recorded during monsoon months (July-August). Seasonally, the premonsoon was found most suitable for colonizing of the meiofauna in intertidal sediment. Two maxima of faunal abundance occurred during the study period, first being in December 1991, and second in March 1992, corresponding to the reproductive peaks of pre- and postmonsoon season (Fig.6).

Discussion

Many studies have described the seasonal variations in meiofaunal population of sub-littoral soft bottom^{6,20-22}. However, correlation analysis between faunal density and environmental variables are rare. Temperature is considered to be an important factor controlling the meiofauna in the boreal region²³. In the tropical estuarine environment, the distribution and abundance of meiofauna are greatly influenced by salinity variations^{9,12,22}.

At the intertidal beach of Siridao,Goa, considerable fluctuations in meiofaunal densities occurred throughout the study period (Fig. 6). The population started increasing in September 1991 and peaked in December. Meiofaunal density fell slightly in January 1992, but started increasing again in February and second peak in faunal density was recorded in March 1992. The density suddenly decreased and the minimum values were observed in July. Thus, it can be summarized that mean meiofaunal density was highly variable, exhibiting seasonal differences and interaction effects. Since the physical parameters to which a species is exposed have significant impact on its physiology⁴, one may expect significant variations in

the population density of particular species during monsoon and premonsoon due to significant differences in salinity and other ambient parameters.

Fluctuations in meiofaunal density were positively correlated with salinity fluctuations ($P<0.05$, Table 2). In an earlier laboratory investigation Ingle¹⁴ demonstrated that decrease in salinity induces the breeding activity of brackish-water turbellaria *Macrostomum orthostylum*.

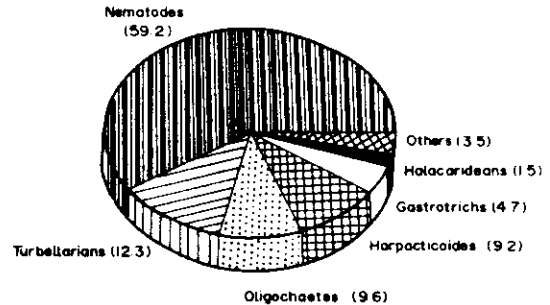


Fig. 4—Percent composition (annual mean) of major meiofaunal taxa recorded from Siridao beach

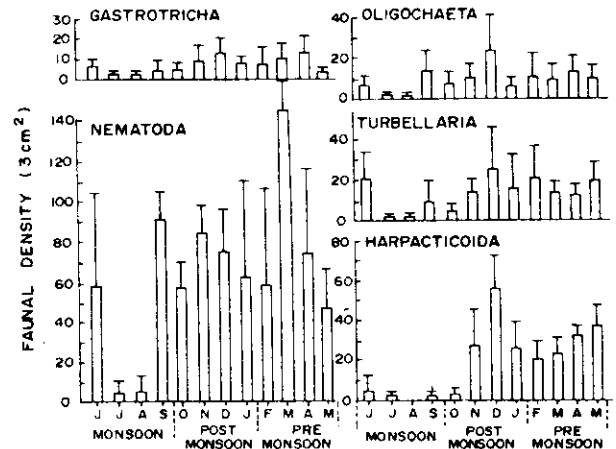


Fig. 5—Monthly variation in mean density of major meiofaunal groups (error bars ± sd)

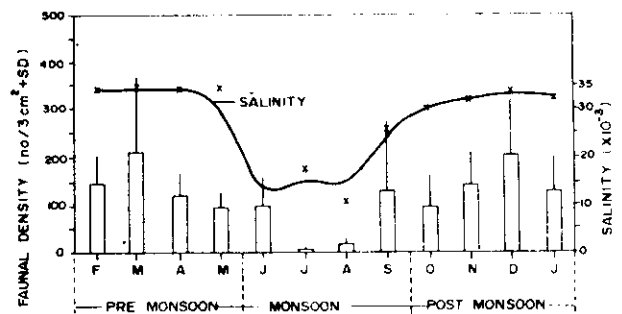


Fig. 6—Seasonal variation in salinity and meiofaunal density (error bars ± sd)

Increased salinity (up to certain extent) may be favorable to other meiofaunal groups such as harpacticoid copepods^{13,15,24}. Some of the harpacticoid species (*Scottolana longipes*; *S. bulbosa*; *Amphiscooides subdebilis*; *Nitocra spinipes*) inhabiting the Siridao beach are known to tolerate high salt concentrations up to 45×10^{-3} . The optimum salinity for normal reproduction of all the above harpacticoid species was around $30 - 33 \times 10^{-3}$. Hence, the observed high variations in meiofaunal density were due to the seasonal reproductive peaks in particular group of taxa. This effect was evident when density counts of individual taxa were subjected for correlation matrix analyses with hydrological parameters (Table 2). Turbellarians and nematodes showed inverse relationship ($P < 0.05$) with dissolved oxygen, indicating their sensitivity to the oxygen tension. Whereas, harpacticoid copepods showed positive relationship with the salinity ($P < 0.01$).

In temperate waters, where temperature cycles over a wide range, peak of seasonal abundance of meiofauna correlate positively with temperature²⁵. However, air temperature, surface water temperature and sediment temperature fluctuated over a narrow range at Siridao (Table 1, Fig. 3), indicating that temperature conditions are favorable to meiofauna all year round, as expected in a tropical environment. As compared to the temperature, salinity fluctuated over a very high range (Fig. 2). The salt content in surrounding water is known to affect the osmoregulation in certain

meiofaunal species²⁶. Therefore, in tropical estuarine environment, salinity could act as a community regulator determining the physiological activity of marine organisms.

The laboratory culture experiments revealed that euryhaline turbellarian *M. orthostylum* and the brackishwater harpacticoid, *A. subdebilis* can tolerate wide variations in salinity, but reproductive success is generally normal within a narrow range^{14,16} (Fig. 7). Although *A. subdebilis* survives and reproduces in lower salinities, the reproductive

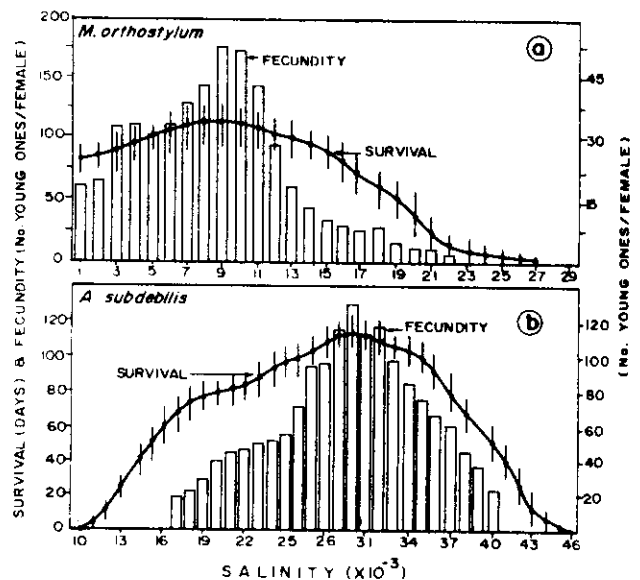


Fig. 7—Laboratory studies on the reproductive behaviour of *Macrostomum orthostylum* (a—unpublished data) and *Amphiscooides subdebilis* (b—redrawn from Ingole¹⁶) studied in different salinities (at 24°C) with excess food

Table 2—Correlation matrix of sediment parameters and dominant meiofauna during June 1991- July 1992.

	Temp	pH	Chl	OC	DO	Sal	Har	Tur	Nem	Oli	Tot
Temp	—										
pH	-0.355	—									
Chl	0.614*	-0.635*	—								
OC	-0.367	0.528	0.368	—							
DO	-0.648*	-0.070	0.395	-0.531	—						
Sal	0.719*	-0.595*	-0.523	0.616*	-0.553	—					
Har	0.047	0.084	-0.137	0.269	-0.222	-0.282	0.699**	—			
Tur	0.093	0.040	-0.263	0.469	-0.268	-0.582*	0.102	0.637*	—		
Nem	0.808**	-0.169	-0.475	0.452	-0.079	-0.673*	0.524	0.096	0.121	—	
Oli	0.419	0.018	-0.448	0.324	-0.129	-0.556	0.636*	0.770*	0.367	0.505	—
Tot	0.708**	-0.099	-0.495	0.522	-0.165	-0.748**	0.607*	0.540	0.450	0.883***	0.790**

* $p < 0.05$; ** $p < 0.1$; *** $p < 0.01$, Temp.=Temperature; Chl=Chlorophyll; C=Organic carbon, DO=Dissolved-oxygen; Sal=Salinity; Har=Harpacticoida; Tur=Turbellaria; Nem=Nematoda; Oli=Oligochaeta; Tot=Totalmeiofauna

ratio, was higher under polyhaline conditions ($28-31 \times 10^{-3}$ S). The results shown in Fig. 7, indicate that the minimum salinity required for normal reproduction of *A. subdebilis* was above 17×10^{-3} whereas, survival and reproductive output of *M. orthostylum* was much higher in lower salinities (ca. $8-10 \times 10^{-3}$). Undoubtedly, a variety of environmental factors are important in the control of reproductive processes of estuarine species. In this regard the laboratory study on different copepod species shows that reproduction of harpacticoids is favored at higher salinities^{13,15,16} and suggest that decreasing field salinity in monsoon is a clue for decreased harpacticoid population.

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