

Role of environmental heterogeneity in structuring the macrobenthic community in a tropical sandy beach, west coast of India

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Abstract

In most ecosystems, community structure emerges as a result of the complex interaction between biotic and environmental variables. Sandy beaches connected to adjacent ecosystem like estuaries/creeks provides an opportunity to understand the role of environment on the community. Kalbadevi beach along the central west coast of India, invaded by creeks on the north and south end, provides an opportunity to investigate the role of environmental heterogeneity in structuring the intertidal macrofaunal communities. Further, the annual tropical rainfall brings about drastic changes in the environmental parameters. Seasonal survey was carried out at 10 transect covering the entire ~5 km beach of Kalbadevi for environmental and macrofaunal studies. We quantified the abundance, biomass, assemblage structure and distribution of macrofauna at different spatio-temporal scales. The univariate and multivariate analyses showed significant spatio-temporal variability in the biotic and abiotic variables. BIOENV analyses showed the best correlation with OC, phaeopigment and grain size. High abundance of macrofauna in the north and south was due to food availability, influenced by the creek. The low abundance during monsoon and subsequent increase in post monsoon can be attributed to annual spawning and recruitment of tropical fauna. Therefore, the present research suggests that the other environmental variables also play an important role in structuring the macrofauna of sandy beach. This supports our hypothesis that environmental heterogeneity influences the structuring of macrofaunal community.

Keywords: Heterogeneity; macrobenthos; placer; sandy beach; spatio-temporal, tropical; west coast, India.

1 Introduction

Environmental heterogeneity refers to the variations of abiotic factors over time and space. Understanding the complex interplay between biotic and abiotic environmental factors have been developed in most of the ecosystems, including those of the oceans (Cisneros et al 2011 and references therein). However considerable gap exist in our understanding of this complex interaction from sandy beaches. Sandy beaches comprise approximately three-quarters of the world's shorelines (Bascom 1980). They provide an environment of high physical stress and were considered as "biological desserts". However, they are important coastal ecosystems and provide shelter to the diverse taxonomic groups that form links in the marine food web (Brown and McLachlan 1990).

The result of most studies reflected that the sandy beach macrofaunal communities are controlled by physical conditions (McLachlan et al. 1993). Species richness, total abundance and biomass of macrofauna tend to increase from reflective beaches (narrow beaches with steep slopes and coarse sand) to dissipative beaches (beaches with flat slopes and fine sands; Short and Wright 1983). Beaches with intermediate morphodynamics represent a balanced state between organic inputs (high in dissipative beaches) and aerobic interstitial conditions (characteristics of reflective beaches) which are ideal conditions for macrofaunal community (McLachlan and Turner 1994). However, few studies have considered other environmental variables (nutrients, food availability) in structuring the macrofaunal community of sandy beach (Lastra et al 2006; Rodil et al 2007; Cisneros et al. 2011). These studies suggested that the macrofaunal community was not only structured by physical factors, other environmental factors such as nutrients, food availability were important drivers.

Sandy beaches connected to adjacent ecosystem like rivers/estuaries provide an opportunity to study the effect of these environmental gradients in structuring the community of the beaches. Since sandy beaches have little biogenic structure, the community depends upon allochthonous source (Cisneros et al. 2011). Therefore, macrofaunal community structure of sandy beach can be influenced by nutrients and organic matter flux from adjacent ecosystem. Because of the geographical position and various physio-chemical features, Kalbadevi, a micro-tidal beach along west coast of India is an excellent habitat to study the benthic communities and to understand a complex interaction of the ecosystem. The Kalbadevi beach is invaded by creeks fringed with rich mangrove vegetation, on the northern and southern side which can increase the nutrients and food for animals, including the beach macrofauna. Thus, assuming a gradient in the environmental variables due to the creeks, we test the hypothesis that the macrofaunal community variables (abundance, biomass, species richness and diversity) will vary with environmental heterogeneity of the beach.

Furthermore, we also assume, the annual tropical monsoon brings drastic changes in the environmental conditions (including increased discharge from adjacent ecosystem) as well as physical characteristics of beach which can play an important role in structuring the macrofauna. Therefore, the aim of the present study is to investigate the environmental heterogeneity at spatio-temporal scale and their concurrent effects on macrofaunal diversity and abundance from a tropical sandy beach.

2 Materials and methods

2.1 Sampling Location

The Kalbadevi beach (17° 02' 68" to 17° 04' 07" N latitude) and (73° 16' 93" to 73°17' 32" E longitude) is ~ 5 km long and ~250 m wide (Fig. 1). It is an arcuate bay with Are creek in the north and Kalbadevi in the south. The occurrence of superior quality, commercial grade placer minerals deposits has been reported from the beach and their offshore extension (Gujar et al. 1988; 2011). In fact, Siddiquie et al. (1979) indicated the extension of placers to be about 9 to 12 m in depth and from 2 to 5 km offshore. The inferred reserves of ilmenite to a depth of 1 m are estimated to be 2 Mt (Siddiquie et al. 1979) and hence the area is considered a potential site for future mining along the west coast.

2.2 Beach Morphology

Beach profiling was carried out at three transect established on the north, central and south of the study area during pre monsoon (February 2004), Monsoon (August 2004) and Post monsoon (November 2004). Bench mark pillars were set up at all the three transect. Ceeducer DGPS (Differential Global Positioning System) was used for obtaining the horizontal location (Geographical co-ordinates) of these benchmarks. The values were recorded initially in WGS – 1984 (World Geodetic System) datum and later were converted to Indian datum (India-Nepal). The vertical control of these benchmarks was done by observing the tidal observations of that particular day (two high waters and two low waters) and later reduced to mean sea level. Vertical spot heights along the profiles were determined using an automatic level instrument (Carl Zeiss), a graduated staff of 4 meters length with leveling shoes and marker lines were used. The calculations of the beach sediment volume variations were performed using the software programme (Ganesan 2006).

2.3 Sample collection

Intertidal sampling was carried seasonally at ten stations covering the entire beach (Fig. 1). Stations 1-3 (Northern transect), Stations 4-7 (Central transect) and Stns 8-10 (Southern transect). At each transect, macrofaunal samples were collected at high-, mid- and low tide in duplicate using

a quadrat (0.0625 m²). About 60 quadrats (area 3.75 m²) were sampled on every occasion. Sediment was sieved through 500µm sieve and the materials retained on the sieve were preserved in neutralized 5% seawater formalin-rose Bengal. In the laboratory, the samples were again washed, sorted, identified and counted. Biomass was determined by wet weight method.

Sediment samples were also collected from each tide level and station for sediment texture, chlorophyll *a* (Chl *a*), phaeopigment and organic carbon (OC). Chl *a* and phaeopigment was analysed by acetone extraction method (Holm-Hansen 1978) and organic carbon by wet oxidation method (El Wakeel and Riley 1957). Grain size analysis was carried out by sieving method (Folk 1968).

2.4 Data Processing

Two-way ANOVA analysis was performed to find out the significance of spatial and temporal variation on the environmental and biological parameters of pooled tidal data from each station. When the interaction was significant, the main factors were only explored further if, they showed a strong main effect in the interaction plot. In cases where ANOVA result was significant, Student-Newman-Keuls (SNK) post hoc test was performed. Margalef's species richness (*d*), Shannon-Wiener diversity (*H'*), Pielou's evenness (*J'*), was calculated. Non-Multidimensional scaling (nMDS) and Bray-Curtis similarity index was constructed based on macrofaunal abundance after square root transformation. The macrofaunal data was square root transformed to balance the contribution from the very abundant and rare species (Clarke and Warwick 1994). Following the division into groups from clusters, the species having the greatest contribution to this division were determined using SIMPER (SIMilarity PERcentage). To compare macrofaunal communities between station and season, two-way analysis of similarities (ANOSIM) was used. ANOSIM is a permutations test based on rank similarities of samples (Clarke and Green 1988; Clarke 1993). The BIOENV (BIO-ENV) was performed on the Bray-Curtis similarity matrix of the macrofauna and the normalised Euclidean distance matrix of the environmental data (Clarke and Warwick 2001). The test performs Spearman's rank correlation analysis of the two similarity matrices by successively testing for every possible combination of environmental parameters that best explains the observed macrofaunal community patterns. The Pearson's correlation was carried out in order to show the strength of association between the individual species and the subset of environmental parameters detected by BIOENV. The α (0.05) value was modified after Bonferroni correction. The analysis was carried out using Statistica 10 and Primer 6. Sediment samples were analysed for their composition and median grain size (D_{50}) using Gradistat 5 (Blott and Pye, 2001).

3 Results

3.1 Beach Environment

The details of beach morphology of Kalbadevi beach is shown in Figure 2. The beach width at different stations varied from 70 to 170 meters. The amount of sand deposited and lost in the study area during pre monsoon, monsoon and post monsoon are shown in Figure 2b. Overall, central transect was found to be accreting during all the seasons. Even though the amount of erosion during monsoon period was around 0.2 m³, the accretion after the monsoon was about 0.3 m³ more, when compared with the pre monsoon period. At southern transect, the beach was gradually eroding during monsoon and post monsoon period, when compared with pre monsoon period. A volume of about 0.88 m³ was either washed away or eroded at southern transect during post monsoon period when compared with pre monsoon period. The highest erosion was found at northern transect during monsoon period, resulting to loss of volume of sand upto 2.17 m³, which is 130% less than the first sampling (pre monsoon period) observation.

The sediment median grain size was finer in the north and south compared to the central transect (Table 1). In general, D₅₀ value showed significant seasonal and season x station variation ($p < 0.001$; Table 2a). Significant interaction effect indicates that grain size differences among stations varied in different season. Based on one-way ANOVA and SNK test, median grain size showed coarse sand at Stn. 5 and 6 during post monsoon and monsoon, respectively (Table 2b). Sediment Chl *a* ranged from 0.08-0.36 $\mu\text{g g}^{-1}$ and season, station and season x station interaction ($p < 0.001$) showed significant variation. One-way ANOVA detected significant difference between stations in the pre monsoon season (Table 2b). Sediment Chl *a* showed significant variation at Stn. 8 ($F = 82.69$; $p < 0.001$) and 10 ($F = 39.35$; $p < 0.001$) located in the southern transect and SNK test detected high values during pre monsoon (Table 2b). Phaeopigment showed a similar trend to that of Chl *a* with significantly high values during pre monsoon (0.006-0.2 $\mu\text{g g}^{-1}$) and decrease during monsoon (0- 0.02 $\mu\text{g g}^{-1}$). One-way ANOVA for season indicated significant variation during pre monsoon ($F = 7.59$; $p < 0.01$) while station showed significant variation for Stn 8 ($F = 51.69$; $p < 0.001$) and 10 ($F = 39.35$; $p < 0.001$). OC also followed the same trend as pigments with (Table 1) high values during pre monsoon (0.1-1%) and decrease during monsoon (0-0.5%). One-way ANOVA was significant for monsoon and Stn 5 had highest values (Table 2b). Stn 1- 2 and 5 showed significant variation in OC and high values were observed during post monsoon and monsoon, respectively (Table 2b).

3.2 Macrobenthic Community structure

The intertidal macrobenthic community was represented by 56 taxa belonging to 4 phyla and 8 classes. Crustaceans, gastropods and polychaete dominated the community in the area (Table 3). Macrofaunal group showed temporal variation in their dominance in all the three transect. In the north, crustaceans dominated during pre and post monsoon, but gastropods dominated during monsoon. Crustacean and polychaetes were dominant in the central transect. Crustaceans dominated during pre monsoon, but during monsoon polychaetes were present in similar proportion. A shift in dominance of polychaetes was seen during the post monsoon. Gastropod dominated the community structure in the southern transect except during post monsoon when polychaetes were also equally dominant. Abundance ranged from 16-6932 ind m⁻² and showed significant spatio-temporal variation (Table 4a and b). The ANSOIM result showed that macrofaunal abundance differs significantly among the seasons (R= 0.24; P= 0.1%), while no significant variation was observed between the stations (R= 0.08; P= 7%).

Umbonium vestiarium was the most dominant taxa, however their distribution was restricted to the north and south transect. Abundance of *U. vestiarium* was highest (avg. 2364 ind m⁻²) in the south during pre monsoon (Table 3). The abundance and distribution of this species in northern transect showed significant variation compared to the south. The abundance of *U. vestiarium* was highest during monsoon (avg. 1082 ind m⁻²). Vertically, it occupied the entire intertidal expansion, except the high tide region. In general, the presence of *U. vestiarium* observed at 30 m from the high tide mark and was more pronounced between the mid- and low tide.

Mediomastus sp. was the most dominant polychaete species. Similar to *U. vestiarium*, abundance of *Mediomastus* sp. varied temporally and the highest value was in post monsoon at southern (avg. 1057 ind m⁻²) and central transect (avg. 870 ind m⁻²). *Scolelepis squamata* was next in order of dominance. High abundance of this species was found in northern transect during post monsoon (avg. 595 ind m⁻²) with low values in monsoon. *Scoloplos (Scoloplos) marsupialis*, *Levinsenia* sp., *Saccocirrus* sp. and *Lumbrineris impatiens* were the other dominant polychaetes.

Crustacean was represented by Isopoda, Amphipoda, Mysidacea, Decapoda and Harpacticoida. The abundance of isopod, *Eurydice* sp. was higher in the northern (0- 500 ind m⁻²) and central transect (16-568 ind m⁻²) with highest values recorded during post monsoon (Table 3). Abundance of *Cyathura* sp., was highest in the southern (74-211 ind m⁻²) and northern transect (17-277 ind m⁻²) with highest abundance seen during pre monsoon. Abundance of *Sphaeroma* sp. was highest at the northern (24-476 ind m⁻²) during the all the three sampling period. Among the amphipods, *Urothoe* sp. was the most dominant (9-184 ind m⁻²). *Gastrosaccus* sp. was recorded in very high abundance

(372 ind m⁻²) at the central transect, during monsoon. Nemertea and Nematoda were also recorded but in low abundance (Table 3).

The nMDS analysis (Fig. 3a) performed on the macrofaunal abundance, suggested that the community could be grouped into three broad categories: Group I, containing the north and central transect during pre monsoon. The SIMPER analysis detected the dominance of the isopod *Eurydice* sp. and *Sphaeroma* sp. which separated it from the other groups. Similarly, the northern and central transect during post monsoon formed the Group II, dominated by *Eurydice* sp. and *Donax cuneatus*. The dominance of the gastropod, *U. vestiarius* in the south transect during all the three seasons and north transect during monsoon (Group III) separated them from rest of the group. Cluster analysis (Fig. 3b) shows that the group III can further divided into two subgroups with one of the group containing the southern transect during monsoon and post monsoon and the second set consisted of southern transect during pre monsoon and northern transect during monsoon with a similarity close to 60%. Central transect during monsoon was dominated by *Saccocirrus* sp. and *Gastrosaccus* sp. hence did not cluster with the other groups (Table 3). The low stress value (0.1) gives a potentially useful two dimensional picture.

Biomass ranged from 0.02-371, 0.47-270 and 1.5-336 g m⁻² during pre monsoon, monsoon and post monsoon respectively (Fig. 4). The *U. vestiarius* contributed to 12-100% of the total macrofaunal abundance. Biomass showed a similar trend to abundance with significant spatio-temporal variation (Table 4a). One way ANOVA showed significant station variation during pre monsoon and monsoon (Table 4b). Post monsoon also showed significant variation, however this was not reflected in the SNK post hoc test. One way ANOVA detected significant season variation for Stn.1, 3 and 5-7 and SNK test detected significantly high biomass during post monsoon (Table 4b).

3.3 Macrofaunal Species diversity

Polychaetes dominated in terms of number of species (41%) followed by Bivalvia and Amphipoda (11% each). Species number was high during post monsoon (52 taxa) and low during pre monsoon (25 taxa). Stn 1 (34 taxa) and stn 10 (37 taxa), located in the northern and southern transect, had high species number. ANOVA and SNK post hoc test detected significant spatio-temporal in species number (Table 5). The average species richness was high at stn 10 (7.7) and low at stn 6 (3.8). Seasonally, species richness ranged from 0.68 (pre monsoon) to 1.39 (post monsoon). Stations in southern (stn 8 and 10) area had high species richness throughout the study period. Species richness showed significant spatial and seasonal variation (Table 5). In general, the evenness was low in the area with lowest value of 0.54, during post monsoon and highest during monsoon (0.64). The lower evenness was at stn 1 and 10. None of the main effect or interaction effect of species evenness were significant ($p > 0.05$). Shannon-Wiener diversity indices (H') ranged from

0.93 to 1.3 during monsoon and post monsoon, respectively. The values were low at stn 2 and high at stn 1 and 10 and varied significantly between station ($p < 0.001$) and season ($p < 0.05$), while the interaction effect was non-significant ($p < 0.05$; Table 5).

3.4 Relation between biotic variables and environmental parameters

The best correlation between the macrofaunal community and environmental variables in the BIO-ENV procedure was achieved by the combination of OC, phaeopigment and grain size ($r = 0.74$; $P = 1\%$). Pearson's correlation of dominant species and environmental parameters was analysed. *U. vestiarium* and *Cyathura* sp. showed significant positive correlation with Chl *a* ($r = 0.38$ $p < 0.001$) and phaeopigment ($p < 0.001$). The Isopod, *Eurydice* sp. and *Sphaeroma* sp. showed a non-significant positive relation with grain size.

4. Discussion

The Kalbadevi beach along the central west coast of India provides a unique opportunity to assess the response of macrofaunal community to environmental heterogeneity occurring at spatial and temporal scale. The univariate and multivariate analyses showed significant spatio-temporal variation in the environmental parameters and macrofaunal community.

The significant spatial variation in macrofaunal abundance was directly related to change in the abundance of the dominant species present at each transect. Overall, macrofaunal abundance and biomass was high at the northern and southern transects due to the higher abundance of *U. vestiarium*. The higher abundance of *U. vestiarium* in the both transects can be attributed to the food availability. It has been established that quality of food plays an important role for benthic organism and photosynthetically produced organic matter may represent the main food source (Danovaro 1996; Wieking and Kröncke 2005). Organic carbon, phaeopigment and grain size strongly correlated with the macrofaunal community, as indicated by BIO-ENV. Likewise, Pearson's correlation analysis of dominant species identified Chl *a* and phaeopigment concentration as an important variables for species such as *U. vestiarium* and *Cyathura* sp. *Umbonium vestiarium* is a suspension and surface deposit feeder (Fretter 1977). *Cyathura* species are detritivores isopods and abundance is positively related to organic content and the amount of suspended matter (Cruz et al 2003). Further, the fine sand holds more organic matter and hence supporting the high macrofaunal abundance in the regions. The highest macrofaunal abundance was observed during the pre and post monsoon period coincides with highest Chl *a* and OC in the area. The photopigment and OC was high in the south transect (stn 8 and 10) followed by north (Stn 1-3) during pre and post monsoon period (Table 1). The high Chl *a* during pre monsoon may be related to the natural increase in phytoplankton while increase during post monsoon may be linked to the

enhanced input of nutrients from the creeks during the monsoon and is consistent with the previous study (Semprucci et al. 2009). During monsoon, the food availability in the region increases directly by the influx of organic matter by flooding and indirectly by augmenting the plankton production as nutrient are abundant (Aller and Aller 1986; Justic et al. 2003). The increase Chl a can also be related to the upwelling which further increases the nutrient input and subsequently the primary production (Muraleedharan and Prassna Kumar, 1996). The high nutrient and surf water Chl a (Anon 2004) in the south and north during the pre and post monsoon reflects the influence of the adjacent creeks on the north and south transect of Kalbadevi beach. Moreover, large quantities of drift seaweeds were also observed in the southern transect (Anon 2004) which add to the beach energy and biomass (Colombini and Chelazzi 2003).

Studies in tropical and temperate regions have shown that the grain size play an important role in structuring the macrobenthic community in sandy beaches (McLachlan and Dorvlo 2005). Highest abundance of macrofaunal community is found in fine sand (McLachlan and Dorvlo 2005). Generally, grain size increases from finer to coarser texture, and with increase in wave exposure, crustaceans dominate towards coarser and more exposed areas; while polychaetes and Mollusc increase towards the other side of gradient (Defeo and McLachlan 2005).

The temporal fluctuation in the macrofaunal community, with the lowest abundance during monsoon is consistent with observations in many tropical beaches (Alongi 1990) and is associated with the communities' negative response to tropical monsoonal rains. The impact of monsoon has been reported to cause defaunation or reduction of species due to the mortality caused by reduced salinity (Alongi 1990, Ingole and Parulekar 1998). Severe beach erosion took place during the monsoon period (Fig. 2) in the study area which is a common phenomenon along the west coast of India (Alongi 1990). Therefore, only those species which are capable of migration persist during this period (Alongi 1990). According to Nair (1978), change in sediment texture during monsoon has a direct effect on the distribution of certain faunal groups, especially polychaetes that recover with return of stable conditions. In the present study, sediment grain size showed a shift from fine to coarse sand, especially at the central transect. The changes in sediment texture to coarser sand during and after rainfall period is observed in many beaches due to erosion/accretion (Gujar et al 2011 and references therein). The slope and particle size of an area varies with the degree of exposure to wave action (Defeo and McLachlan 2005). Thus, the wave energy conditions coupled with variable coast line configurations and beach gradients along with littoral and rip currents account for the observed erosion/ accretion trends and reflects the hydrodynamic energy of the area.

Further, drop in salinity in monsoon triggers spawning in species with planktonic larval stage (Broom 1982). Further, the water turbulence created in monsoon suspends the benthic fauna and help in the wide spread dispersal of both larvae and adults (Dobbs and Vozarik 1983). The peak abundance of macrofauna observed during the post monsoon suggesting the recruitment during this period.

The spatio-temporal fluctuation in the macrobenthic community was also reflected in the species diversity indices. This is a typical phenomenon of sandy beach ecosystems wherein species evenness and diversity are influenced by the population dynamic of numerically abundant species (Holland and Polgar 1978, Dexter 1984). There was change in species composition after monsoon and increase in species diversity. Recolonization of a defaunated area usually involves different species compositions with opportunistic or fugitive species becoming abundant in the early stages (Arbugov 1982). In general, the evenness and species richness was low since the community was dominated by a few species. The present study is consistent with previous studies that sandy beach macrofauna are controlled by the interaction between different factors operating at spatio-temporal scale together (McLachlan and Dorvlo 2005).

Therefore the findings of the present study support our hypothesis that the natural environmental gradient influenced by the input from the adjacent creeks and the annual tropical monsoon plays an important role in the heterogeneity observed in the distribution of sandy beach macrofaunal community of Kalbadevi.

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References

1. Aller JY, Aller RC (1986) General characteristic of benthic fauna on the Amazon inner continental shelf with comparison to the shelf Changjiang River, East China Sea. *Cont Shelf Sci* 6:291-310.
2. Alongi D (1990) The ecology of tropical soft-bottom benthic ecosystems. *Oceanogr Mar Biol Ann Rev* 28:381-496
3. Anon (2004) Environmental studies for placer minerals. Tech. Rep. NIO.
4. Arbugov R (1982) Species diversity and phasing of disturbance. *Ecology* 63: 289-293.

5. Bascom W (1980) *Waves and Beaches*. Anchor Press/Doubleday, New York
6. Blott SJ, Pye K (2001) GRADISTAT: a grain size distribution and statistics package for the analysis of unconsolidated sediments. *Earth Surf Proc Land* 26:1237-1248.
7. Broom MJ (1982) Structure and seasonality in a Malaysia mudflat community. *Estuar Coast Shelf Sci* 15:135-150.
8. Brown AC, McLachlan A (1990) *Ecology of Sandy Shores*. Elsevier Scientific Publication, Amsterdam.
9. Cisneros KO, Smit AJ, Laudie J, Schoeman DS (2011) Complex dynamic combination of physical, chemical and nutritional variables controls spatio-temporal variation of sandy beach community structure. *PLoS One* 6(8):e23724.
10. Clarke KR (1993) Non-parametric multivariate analyses of changes in community structure. *Aust J Ecol* 18:117-143
11. Clarke KR, Green RH (1988) Statistical design and analysis for a 'biological effects' study. *Mar Ecol Prog Ser* 46:213-226.
12. Clarke KR, Warwick RM (2001) A further biodiversity index applicable to species lists: variation in taxonomic distinctness. *Mar Ecol Prog Ser* 216:265-278
13. Clarke KR, Warwick RM (1994) *Changes in marine communities: an approach to statistical analysis and interpretation*. Tech Report Plymouth Marine Laboratory, Plymouth, England
14. Colombini I, Chelazzi L (2003) Influence of marine allochthonous input on sandy beach communities. *Oceanogr Mar Biol Ann Rev* 41:115-159.
15. Cruz S, Marques JC, Gamito S, Martins I (2003) Autecology of the Isopod, *Cyathura carinata* (Krøyer, 1847) in the Ria Formosa (Algarve, Portugal). *Crustaceana* 76(7): 781-802
16. Danovaro R (1996) Detritus-bacteria-meiofauna interactions in a seagrass bed (*Posidonia oceanica*) of the NW Mediterranean. *Mar Biol* 127:1-13.
17. Defeo O, McLachlan A (2005) Patterns, process and regulatory mechanism in sandy beach macrofauna: a multiscale analysis. *Mar Ecol Prog Ser* 295:1–20.
18. Dexter DM (1984) Temporal and spatial variability in the community structure of the fauna of four sandy beaches in south-eastern New South Wales. *Mar Freshwater Res* 35(1):663-667.
19. Dobbs FC, Vozarik J (1983) Immediate effects of a storm on coastal infauna. *Mar Ecol Prog Ser* 11:273-279.
20. El Wakeel SK, Riley JP (1957) The organic carbon of marine mud. *J Cons- Cons Int explor Mer* 22:180-183.
21. Folk R.L. 1968. *Petrology of Sedimentary Rocks*. The University for Texas, Austin, Texas.
22. Fretter V (1977) *Umbonium vestiarium*, a filter-feeding trochid. *J Zool* 177(4): 541-552.
23. Ganesan P (2006) Programs to obtain vertical heights from mean sea level and for Computing volume of sand/mineral along beaches: A case study with Kalbadevi beach profiling data and results. NIO/TR-01/2006.

24. Gujar AR, Ganesan P, Iyer SD, Gaonkar SS, Ambre NV, Loveson VJ, Mislankar PG (2011) Influence of morphodynamic variability over seasonal beach sediments and its probable effect on coastal development. *Ocean Coast Manage* 54:514-523.
25. Gujar AR, Nath BN, Banerjee R (1988) Marine Minerals: The Indian perspective. *Mar Min* 7: 317-350
26. Holland AF, Polgar TT (1976) Seasonal changes in the structure of an intertidal community. *Mar Biol* 37:341-348
27. Holm-Hansen O (1978) Chlorophyll 'a' determination: Improvement in methodology. *Oikos* 30:438-447
28. Ingole BS, Parulekar AH (1998) Role of salinity in structuring the intertidal meiofauna of a tropical estuarine beach: Field evidence. *Indian J Mar Sci* 27: 356-361
29. Justic D, Turner RE, Rabalais NN (2003) Climatic influences on riverine nitrate flux: Implications for coastal marine eutrophication and hypoxia. *Estuaries* 26:1-11.
30. Lastra M, de La Huz R, Sánchez-Mata, Rodil IF, Aerts K, Beloso S, López J (2006) Ecology of exposed sandy beaches in northern Spain: Environmental factors controlling macrofauna communities. *J Sea Res* 55:128-140
31. McLachlan A, Turner I (1994) The interstitial environment of sandy beaches. *Mar Ecol* 15:177-211.
32. McLachlan A, Jaramillo E, Donn TE Jr, Wessels F (1993) Sandy beach macrofauna communities and their control by the physical environment: a geographical comparison. *J Coast Res* 15: 27-38
33. McLachlan A, Dorvlo A (2005) Global Patterns in sandy beach macrobenthic communities. *J Coast Res* 21(4):674-687
34. Muraleedharan PM, Prasanna Kumar S (1996) Arabian Sea upwelling- A comparison between coastal and open ocean regions. *Curr Sci* 71(11):842-846
35. Nair A (1978) Production ecology of a tropical sandy beach at Benaulim, Goa. *Indian J Mar Sci* 7:163-167
36. Rodil IF, Lastra M, López J (2007) Macroinfauna community structure and biochemical composition of sedimentary organic matter along a gradient of wave exposure in sandy beaches (NW Spain). *Hydrobiologia* 579:301-316
37. Semprucci F, Boi P, Manti A, Harriague AC, Rocchi M, Colantoni P, Papa S, Balsamo M (2009) Benthic communities along a littoral of the Central Adriatic Sea (Italy). *Helgoland Mar Res* 64(2):101-115.
38. Short AD, Wright LD (1983) Physical variability of sandy beaches. In: McLachlan A, Erasmus T (eds.) *Sandy beaches as ecosystem*. W Junk, The Hague, pp. 133-144
39. Siddiquie HN, Rajamanickam GV, Almeida F (1979) Offshore placers of Ratnagiri, Konkan coast, Maharashtra, India. *Mar Min* 2:91-118.
40. Wieking G, Kröncke I (2005) Is benthic trophic structure affected by food quality? The Dogger Bank example. *Mar Biol* 146: 387-400

Figure Captions

Fig. 1 Location of sampling transects in the intertidal zone of Kalbadevi beach and schematic diagram of sampling design

Fig. 2 (a) Seasonal beach profiling at all the three transects and (b) volume of sand accretion/erosion (Vol. sand computed per meter profile length m^3). Pre M- pre monsoon; Mon- monsoon; Post M- post monsoon.

Fig. 3 (a) Non-Metric multidimensional scaling and (b) Bray-Curtis cluster based on macrofaunal abundance. The dashed horizontal line indicates 50% similarity.

Fig. 4 Spatio-temporal variation of macrofaunal biomass in the study area.

Table 1 Seasonal variation in sediment parameters at the three transects. Pre M- pre monsoon; Mon- Monsoon; Post M- post monsoon.

Transect	Season	Grain size (D ₅₀ μm)	Organic Carbon (%)	Chl <i>a</i> (μg g ⁻¹)	Phaeopigment (μg g ⁻¹)
North	Pre M	170-190	0.1-0.55	0.01-0.02	0.01-0.02
	Mon	63-864	0	0.01-0.18	0-0.018
	Post M	167-243	0.3-0.63	0.05-0.17	0-0.1
Central	Pre M	180-195	0-0.70	0.01-0.3	0.01-0.1
	Mon	218-1071	0-0.40	0-0.18	0-0.1
	Post M	129-234	0.1-0.54	0.03-0.1	0-0.28
South	Pre M	110-255	0.2-0.7	0.1-0.7	0.1-0.63
	Mon	25-845	0.02-0.46	0-0.02	0-0.1
	Post M	138-250	0.2-1.3	0.02-0.1	0-0.1

Table 2a ANOVA results of environmental parameters. S- season; NS- not significant.

Variable	Source of Variation	df	MS	F	p
Grain Size	Season	2	212063	10.12	<0.001
	Stn	9	25409	1.2	NS
	S x Stn	18	73517	3.5	<0.001
Chl a	Season	2	0.18	72.6	<0.001
	Stn	9	0.04	15.8	<0.001
	S x Stn	18	0.05	20.9	<0.001
Phaeopigment	Season	2	0.19	30.2	<0.001
	Stn	9	0.03	4.9	<0.001
	S x Stn	18	0.045	7.3	<0.001
OC	Season	2	0.579	16.5	<0.001
	Stn	9	0.013	0.39	NS
	S x Stn	18	0.097	2.77	<0.01

Table 2b One-way ANOVA results of environmental Parameters. Only the variables that were significant are represented. Pre M- pre monsoon; Mon- Monsoon; Post M- post monsoon; SNK test- Student–Newman–Keuls tests. The station/season showing significantly highest mean values from the SNK test are shown.

Variable	Source of variation		F	P	SNK test
Grain Size	Station	Stn 5	9.72	<0.001	Post M
		Stn 6	16.70	<0.001	Mon
Chl a	Season	Pre M	23.61	<0.001	Stn 9
	Station	Stn 8	82.96	<0.001	Pre M
		Stn 10	33.39	<0.001	Pre M
Phaeopigment	Season	Pre M	7.59	<0.001	Stn 9
	Station	Stn 8	51.69	<0.001	Pre M
		Stn 10	39.35	<0.001	Pre M
OC	Season	Mon	8.38	<0.001	Stn 5
	Station	Stn 1	14.13	<0.01	Post M
		Stn 2	33.39	<0.01	Post M
		Stn 5	13.59	<0.01	Mon

Table 3 Seasonal variation in macrofaunal abundance (average) at the three transects. Pre M- pre monsoon; Mon- Monsoon; Post M-post monsoon.

Taxa	NORTH			CENTRAL			SOUTH		
	Pre M	Mon	Post M	Pre M	Mon	Post M	Pre M	Mon	Post M
Nemertea	5	59	192	19	30	173	16	35	86
Nematoda	0	0	60	0	0	14	0	0	129
Polychaeta									
<i>Pisione</i> sp.	0	0	0	0	68	265	0	0	0
<i>Saccocirrus</i> sp.	0	0	0	0	403	0	0	0	0
<i>Onuphis eremita</i>	0	3	53	2	0	25	2	5	25
<i>Glycera alba</i>	3	5	11	5	0	22	7	11	11
<i>Lumbrineris impatiens</i>	0	5	73	2	2	12	98	108	78
<i>Mediomastus</i> sp.	0	0	103	0	0	869.7	14	0	1057
<i>Levinsenia</i> sp.	49	5	30	55	5	62	4	144	269
<i>Scolecopsis squamata</i>	47	37	595	35	0	117	207	7	70
<i>Scoloplos (Scoloplos) marsupialis</i>	59	73	120	58	2	108	90	60	33
Other Polychaetes	30	3	13	4	60	29	27	12	81
	188	131	998	161	540	1510	449	347	1624
Oligochaeta	10	15	0	0	38	54	1	0	1
Insecta									
Chironomidae	1	160	0	0	0	0	0	0	88
Other Insect	0	0	25	0	0	0	0	0	5
	1	160	25	0	0	0	0	0	93
Bivalvia									
<i>Donax cuneatus</i>	61	11	536	89	43	184	69	183	34
<i>Donax</i> sp.	0	5	25	0	0	20	0	205	18
Other Bivalvia	0	0	0	2	0	0	5	0	4
	61	16	561	91	43	204	74	388	56
Gastropoda									
<i>Umbonium vestiarium</i>	88	1082	749	0	0	5	2364	427	544
Other Gastropod	0	0	0	0	0	0	0	3	3
	88	1082	749	0	0	5	2364	430	547
Crustacean									
<i>Eurydice</i> sp.	496	0	500	122	16	568	55	5	8
<i>Cyathura</i> sp.	277	17	84	44	6	1	211	74	179
<i>Sphaeroma</i> sp.	168	24	476	125	16	10	12	0	0
<i>Urothoe</i> sp.	85	181	184	30	59	9	93	19	39
<i>Synchelidium</i> sp.	0	0	137	0	0	28	0	0	1
Other Amphipods	0	5	68	0	4	3	0	32	39
<i>Gastrosaccus</i> sp.	3	96	12	0	372	1	0	43	16
Harpacticoida	3	64	9	0	17	31	14	120	73
Other crustaceans	3	3	17	20	5	189	63	5	51
	1035	390	1487	341	495	840	448	298	406
TOTAL	1388	1853	4072	612	1146	2799	3352	1498	2942

Table 4a ANOVA results for biological variables. S-season; NS- not significant.

Variable	Source of Variation	df	MS	F	p
Abundance	Season	2	43365239	10.29	< 0.001
	Stn	9	14757634	3.50	< 0.001
	S x Stn	18	19414787	4.61	< 0.001
Biomass	Season	2	71453.9	6.02	< 0.01
	Stn	9	77019.6	6.49	< 0.001
	S x Stn	18	85357.8	7.19	< 0.001

Table 4b One-way ANOVA results of macrofaunal abundance and biomass. Only the variables that were significant are represented. Pre M- pre monsoon; Mon- Monsoon; Post M- post monsoon; NS- not significant; SNK test- Student–Newman–Keuls tests. The station/season showing significantly highest mean values from the SNK test are shown.

Variable	Source of variation		F	P	SNK test
Abundance	Season	Pre M	4.57	< 0.001	Stn 10
		Mon	4.90	< 0.001	Stn 1
		Post M	3.42	< 0.01	NS
	Station	All stations		< 0.01	Post M
Biomass	Season	Pre M	7.83	< 0.001	Stn 9
		Mon	4.90	< 0.001	Stn 1
		Post M	4.12	< 0.001	NS
	Station	Stn 1	18.29	< 0.001	Post M
		Stn 3	10.58	< 0.001	Post M
		Stn 5	5.43	< 0.01	Post M
		Stn 6	4.77	< 0.01	Post M
	Stn 7	7.09	< 0.01	Post M	

Table 5 ANOVA results for macrofaunal diversity indices. S- season; NS- not significant. Post M- post monsoon; SNK test- Student–Newman–Keuls tests. The station/season showing significantly highest mean values from the SNK test are shown.

Variable	Source of variation	df	MS	F	p	SNK Test
Species number	Season	2	215.31	22.55	<0.001	Post M
	Stn	9	25.01	2.62	<0.05	Stn 8
	S x Stn	18	8.92	0.93	NS	
Species richness (d)	Season	2	9.41	22.63	<0.001	Post M
	Stn	9	1.38	3.31	<0.01	Stn8
	S x Stn	18	0.52	1.24	NS	
Species Evenness (J')	Season	2	0.50	2.72	NS	
	Stn	9	0.13	0.73	NS	
	S x Stn	18	0.18	0.99	NS	
Species Diversity (H')	S	2	6.87	15.75	<0.001	Post M
	Stn	9	0.91	2.08	<0.05	NS
	S x Stn	18	0.67	1.54	NS	

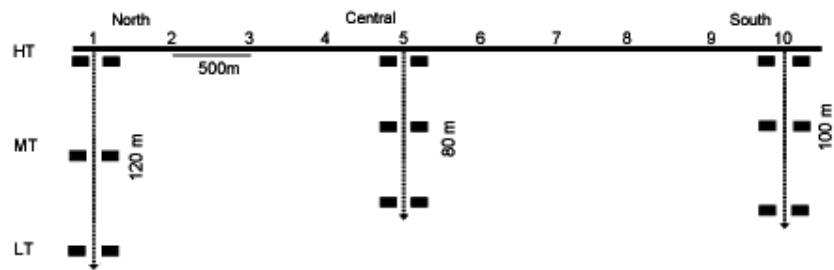
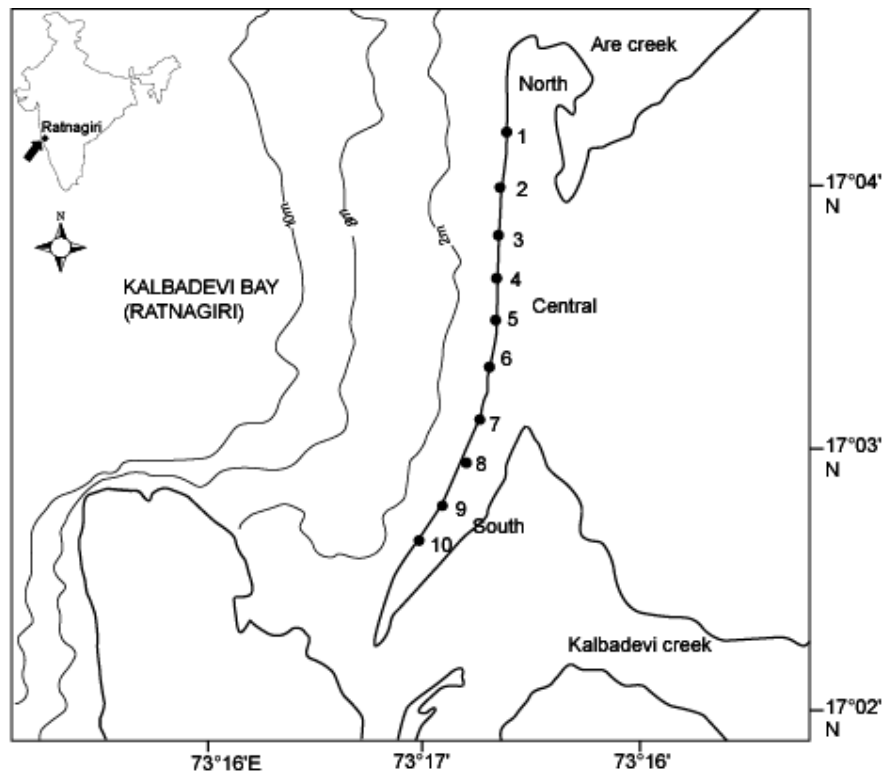


Fig. 1

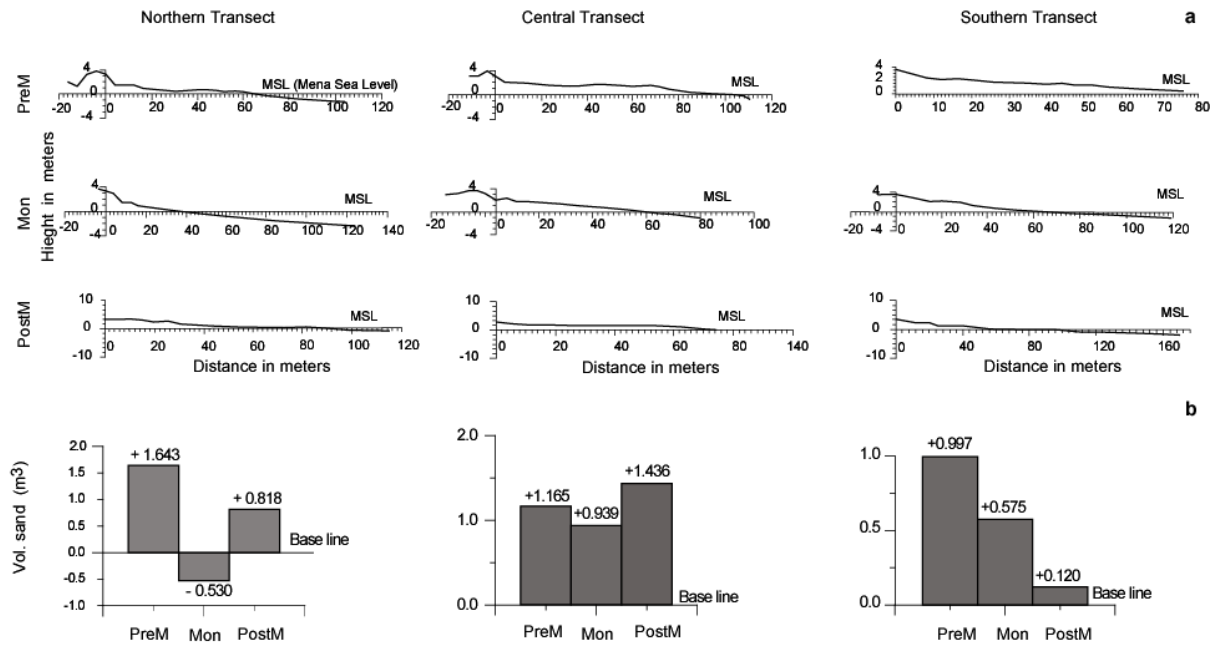
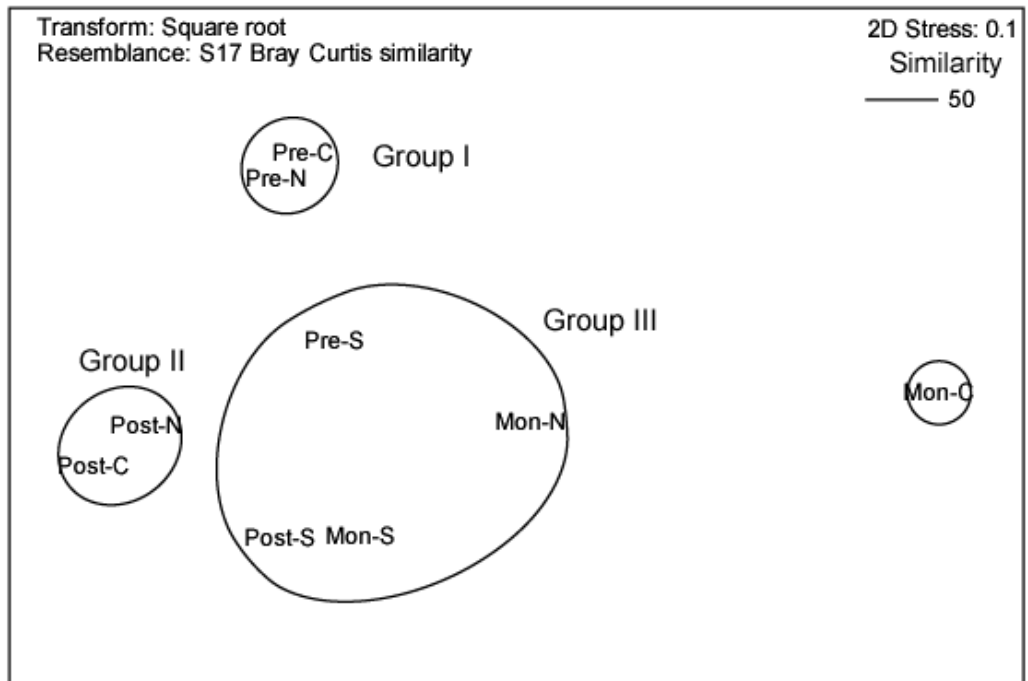


Fig. 2

a



b

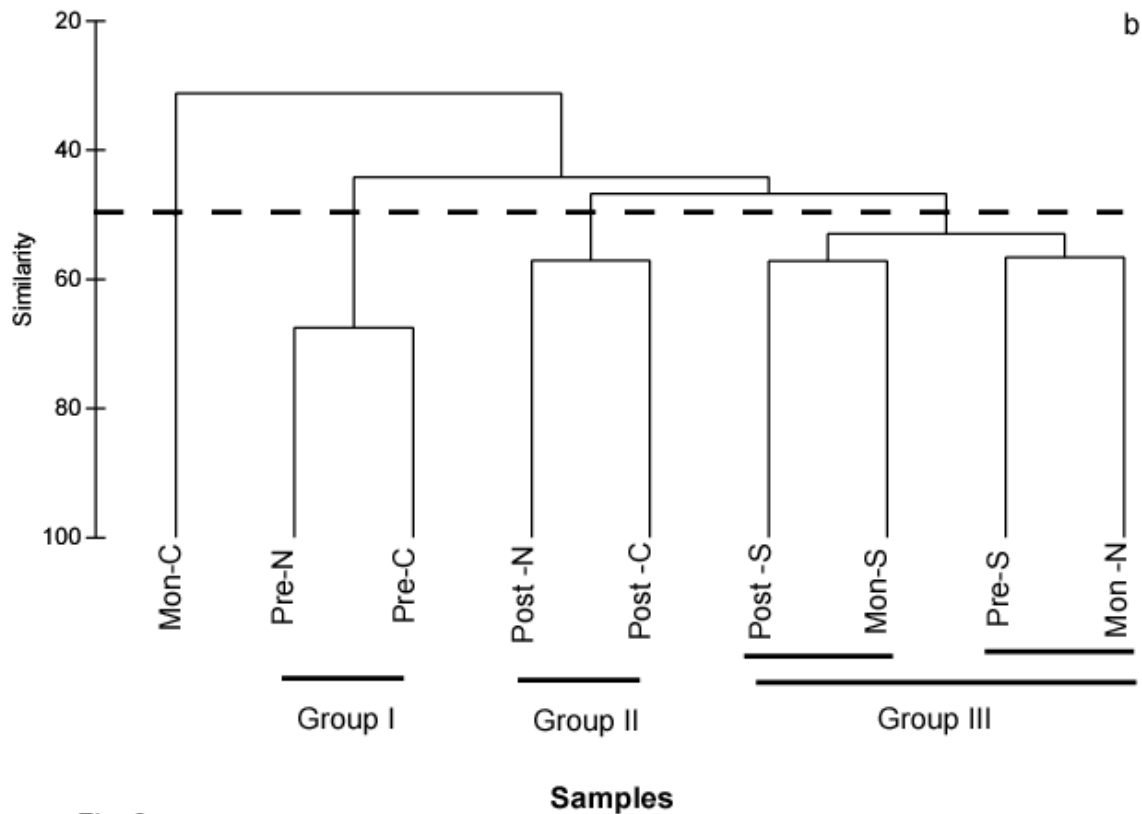


Fig. 3

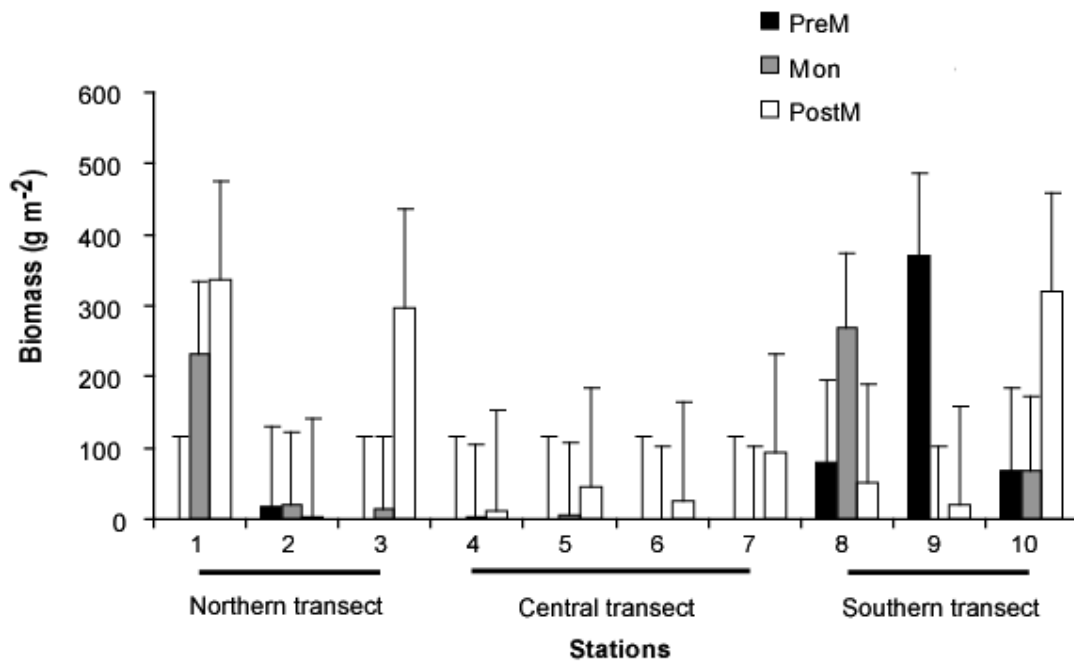


Fig. 4