

**Temporal variability of macrofauna from a disturbed habitat in Zuari estuary,  
west coast of India**

S. Sivadas, \*B. Ingole and M. Nanajkar  
Biological Oceanography Division,  
National Institute of Oceanography, Dona Paula, Goa-403004, India.  
\*email: baban@nio.org  
Tel No. 91-(0)0832-2450242; Fax No. 91-(0)0832-2450606

**Abstract**

Natural disturbances along with human interference make the tropical estuaries among the most disturbed areas globally. In spite of this, information on the seasonal variability of macrofauna from tropical estuaries is few. Temporal variability of macrofaunal community from Mormugao Bay, Zuari estuary, on the west coast of India was examined from 2003 - 2004 at seven stations. Environmental variability was assessed through physico-chemical parameters of water and sediment. The changes in macrobenthic community were assessed using abundance, biomass and species diversity indices. The environmental parameters showed a significant seasonal variation influenced by monsoonal changes. The changes in the environmental conditions brought about variation in the macrobenthic community. Macrofaunal abundance, biomass and species diversity was highest during post-monsoon (Values for each parameter) influenced by recruitment. In monsoon, the macrobenthic community was dominated by polychaetes (92.17%), whereas bivalves dominated during the post-monsoon (57.7%). The macrofauna showed drastic decline during the stable pre-monsoon season, a period when highest abundance of fauna is observed in the tropical estuary. Therefore, the macrobenthic community in the area did not follow the seasonal trend generally observed in a tropical estuary. Further, the community during pre-monsoon season were dominated by the opportunistic polychaete species indicating a possible influence of harbour activities in structuring the benthic community of the area.

**Key Words:** Seasonality; macrobenthos; *Timoclea scabra*; tropical estuary; India.

## **Introduction**

Tropical estuaries are recognized as important and complex habitats that play a critical role in the global ocean processing (Smith et al., 2003). The system is also amongst the most exploited by human due to their abundant natural resources. In the tropics, the annual monsoons bring about significant influence on the physico-chemical and biological characteristics of the estuaries. Therefore this ecosystem is under considerable stress from natural and anthropogenic disturbances.

The Zuari estuary on the west coast of India is a dynamic tropical estuary. The estuary harbours one of the finest deep water ports in the Indian subcontinent. The Mormugao port accounts for  $\approx 40\%$  of the country's iron ore exports and ranks within the ten leading iron ore exporting ports of the world. Along the estuary there are small fishing jetties, wharfs and small workshops. Mangrove vegetation is seen all along the river which makes the region biologically productive. The estuary sustains a rich fisheries and organism such as prawns, fishes and clams are exploited from the region.

In spite of the importance of maritime activity in the Mormugao harbour and the resulting potential environmental impacts, research conducted on this estuary is mainly focused on physico-chemical properties (Shetye et al., 2007; Bhosle et al., 2004), phytoplankton variability (Patil and Anil, 2008). Studies on macrobenthic fauna of the Zuari estuary are restricted to large scale studies covering the entire estuary (Parulekar et al., 1980, Ansari et al., 1986, 1995, 2007; Harkantra and Rodrigues 2003) which usually overlook the smaller patterns caused by anthropogenic influences. The few studies carried out on the macrofauna of the harbour area (Ingole et al. 2009; Ansari et al. 1994) were based on single sampling which does not consider the temporal variability. Further, ports are vulnerable to invasion as they are naturally and anthropogenically disturbed habitats. It is estimated that 10,000 different species are being transported between biogeographic regions in ballast tanks alone (Carlton, 1999). The lack of knowledge about the temporal variability makes it difficult to distinguish between natural and anthropogenic disturbance (Hewitt and Thrush 2007; Clarke and Warwick 1994).

The present study aimed at understanding the temporal variability of macrofauna and whether the harbour activities influences seasonal pattern of macrofaunal community. As the coastal process in tropical regions is fundamentally different from those of higher latitudes an understanding of this dynamic system is important for their management.

## **Materials and Methods**

### ***Study Area***

Mormugao harbour (Lat.15°25' N and Long.73° 47'E) is located on the southern bank of the Zuari river mouth (Fig 1). The 10 km stretch upstream from the mouth of the Zuari estuary, known as the Mormugao Bay, is approximately 5 km wide. There exists three quay berth, one deep-drafted oil berth, one specialised mechanical ore berth and two multipurpose general cargo berths. A breakwater of 522.40 meters long protects the harbour from the SW monsoon. The harbour is dominated by periodic tidal exchange of oceanic and estuarine water (Cherian et al., 1974; Shetye et al., 2007) with strong bottom currents ( $1.5 \text{ m s}^{-1}$ ).

### ***Sampling and Analysis***

Sediment and water column study was carried out at seven predetermined locations during monsoon (June - September), post- monsoon (October-January) and pre- monsoon (February-May). Sampling was restricted to the harbour region and reference station was not taken as the sediment outside the harbour was dominated by sand. Sampling during August was not possible due to the inclement weather. Macrofaunal samples were collected in triplicates with a van Veen grab ( $0.04 \text{ m}^2$ ) at each station. Sediment samples were sieved on  $500 \mu\text{m}$  mesh sieve and fixed in 5% formalin-rose Bengal solution. In the laboratory, the samples were again washed, sorted, identified and counted. Biomass was determined by the wet weight method.

At each station, sediment was taken for analysis of chlorophyll-*a* (Chl-*a*), phaeopigment (Phaeo) and organic carbon (OC). Chl-*a* was analysed by acetone extraction method (Holm-Hansen, 1978) and OC was analyzed by wet oxidation method (El Wakeel and Riley 1957). Water parameters, sediment texture, petroleum hydrocarbons (PHC) and metals (Cd, Pb and Hg) were analysed following standard methods (Anon 2004).

## ***Data Analysis***

The statistical analysis was carried out using Statistica 6 and Primer E. ANOVA and Tukey's (HSD) post hoc analysis was carried out to find out the significance of spatial and temporal variation on environmental and biological parameters. Margalef's species richness (d), Shannon-Wiener diversity (H') and Peilou's evenness (J') was calculated. Non-Multi Dimensional Scaling (nMDS) and Bray-Curtis cluster was constructed based on macrofaunal abundance after square root transformation. Following division into groups from clusters and nMDS analysis, the species having the greatest contribution to this division was determined using SIMPER. In order to investigate relationships between biotic and abiotic variables, the BIO-ENV procedure was used. Principal Component Analysis (PCA) of the environmental parameters was performed.

## **Results**

### ***Environmental characteristics***

Salinity, temperature, pH and nutrients showed significant differences only between the seasons. Dissolved oxygen (DO) in the overlying waters varied significantly and ranged from 4.6 - 5.9 mg l<sup>-1</sup> during pre-monsoon and post-monsoon respectively (p<0.05). BOD was highest during the pre-monsoon season and lowest during post-monsoon.

The chl-*a* content in surface and bottom water showed a decreasing trend from monsoon to pre-monsoon. Seasonally, the chl-*a* value differed significantly (p<0.05) and post hoc test detected significantly high value of chl-*a* for monsoon. There was significant variation of bottom water chl-*a* among season (p<0.001) and station (p<0.01). Post hoc test showed a significant high value of chl-*a* at stn 7 during monsoon. Phaeopigment content had similar temporal pattern to that of chl-*a*. OC showed significant differences among the stations (p<0.05) and season (p<0.001). Tukey's post hoc test for multiple comparisons shows that stn 2 had significantly low mean value during monsoon and stn 5 in had highest OC value in post monsoon. Sediment texture was heterogeneous with stns 1, 5, 6 and 7 dominated by silt (70-90%), whereas stns 2 and 4 were dominated by sand (45-60%).

Principal Component Analysis (PCA) was carried in order to find out the environmental parameters, which accounted for the variation in the study area. A scree plot for the eigen values showed a pronounced change of slope after fourth eigen values. Therefore, the first four PC were retained, as they explained 68.9% of the variance in the data (Table 1). The first principal component (PC1) explained 35.5% of variance and was negatively loaded by salinity, NO<sub>2</sub>, water Pb and Hg. Surface and bottom water chl-a and bottom water PO<sub>4</sub> showed a positive loading on this axis. Highest score on the first PC1 was for monsoon season suggesting strong influence of temporal variability brought by the monsoonal changes. PC2 explained 18.9% of the variability and was negatively contributed by surface water DO, sediment chl-a and sand. Bottom water BOD and silt was positively loaded on this axis. PC3 and PC4 explained 7.8% and 6.7% of the variability respectively and related to the increased harbour activities. This is indicated by positive loading of Pb, Hg (sediment and water) and BOD on PC3. Stn 5, 6, 7, during pre monsoon, had the highest scoring on this axis. PC4 were positively loaded by water Cd, chl-a (sediment), organic carbon and silt. Stn 5 during post monsoon had highest score on PC4.

### ***Macrobenthic community***

The macrofaunal community in the Mormugao harbour comprised of 139 taxa belonging to 10 phyla (Table 2). Polychaetes (49%) and bivalves (45%) dominated the faunal abundance (Fig.2a). Crustaceans and other groups (Coelenterate, Nematoda, Nemertinea, Oligochaeta, Sipuncula, Phoronida, Gastropoda, Insecta and Ophiuroidea) comprised the remaining 6% of the faunal abundance. The dominance of polychaetes and bivalves fluctuated with marked seasonal variation (Fig 2a). Polychaetes dominated during the monsoon (92.17%) and pre-monsoon (82.8%) whereas bivalves predominated in post-monsoon (57.7%). Spatially, polychaetes dominated at all the stations except stn 4 and 7, which were occupied by bivalves.

The macrofaunal abundance was highest at stn. 4 during post monsoon (18474 ind m<sup>-2</sup>) whereas lowest value was at stn. 5 during pre monsoon (176 ind m<sup>-2</sup>). Overall, macrofaunal abundance was significantly higher during post-monsoon (8923 ind m<sup>-2</sup>) but decreased drastically in pre-monsoon (to 887 ind m<sup>-2</sup>; Fig. 2b). Spatially, average macrofaunal abundance ranged from 878 - 7840 ind m<sup>-2</sup> (4116 ± 2829 SD). High values were recorded at stn 6, and low

at stn 5 (located in the channel area). Two-way ANOVA detected significant seasonal differences in macrobenthic abundance ( $p < 0.001$ ). Tukey's post hoc test confirmed significantly high abundance during post-monsoon.

*Timoclea (Chioneryx) scabra* dominated the macrofauna in terms of abundance (43%) with highest abundance at stn. 4 (14603 ind  $m^{-2}$ ) during post-monsoon. However, the values decreased abruptly from post-monsoon to pre-monsoon.

Among the polychaetes, *Prionospio pinnata* (7.7%), *Magelona* sp. (6.0%), *Mediomastus* sp. (5.57%), *Cossura* sp. (5.0 %) and *Tharyx* sp. (4.5%) dominated. The abundance of *P. pinnata* was higher during the monsoon (533 ind  $m^{-2}$ ) but reduced to 322 ind  $m^{-2}$  during post-monsoon with a further decrease to 15 ind  $m^{-2}$  during pre-monsoon. On contrary, the mean abundance of *Magelona* sp. increased from monsoon (58 ind  $m^{-2}$ ) to post-monsoon (591 ind  $m^{-2}$ ) but decreased sharply during pre-monsoon (36 ind  $m^{-2}$ ). Similar to *Magelona* sp, the abundance of *Mediomastus* sp was highest during post-monsoon (383 ind  $m^{-2}$ ) but decreased in pre-monsoon (127 ind  $m^{-2}$ ). Compared to other polychaete species, the abundance of *Cossura* sp. was stable with high values in monsoon (210 ind  $m^{-2}$ ), which decreased marginally in post-monsoon (180 ind  $m^{-2}$ ) and pre-monsoon (187 ind  $m^{-2}$ ). Abundance of *Tharyx* sp. was high during monsoon with low values in pre-monsoon season.

Bray-Curtis cluster analysis performed on the faunal abundance data grouped the sampling months into three groups (Fig. 3a). The post-monsoon months (Oct-Jan) formed the major group with a similarity value of 49.56% (Group 1). February, March and April clustered at 62% similarity (Group 2). The month of May clustered with June and July forming the third group at 53% similarity. nMDS showed a similar pattern of clustering of the months (Fig. 3b). The result of SIMPER analysis revealed that group1 differed from the other two groups due to the complete dominance of *T. scabra* and accounted for >40% of the dissimilarity observed (Fig. 3c). The low abundance of macrofauna during pre-monsoon with the dominance of *Cossura* sp. was responsible for the clustering of the pre-monsoon months and its dissimilarity with other groups (Fig. 3d). September did not cluster with any group mainly due to the dominance of *P. pinnata* (1448 ind  $m^{-2}$ ; Fig. 3e).

Macrofaunal biomass showed a similar pattern to that of abundance with highest values during post-monsoon ( $72.07 \text{ g m}^{-2}$ ) and lowest in monsoon ( $4.27 \text{ g m}^{-2}$ ) at all stations (Fig. 4). Bivalvia made up 84.4% of the total macrofaunal biomass. Values ranged from  $63.27 - 5.45 \text{ g m}^{-2}$  (mean:  $26.7 \pm 31.80 \text{ g m}^{-2}$ ) observed during post-monsoon and monsoon, respectively. Average polychaete biomass was highest during post-monsoon ( $2.90 \text{ g m}^{-2}$ ) with very low value in pre-monsoon ( $0.96 \text{ g m}^{-2}$ ). The biomass of other groups showed a similar trend with high values of  $5.08 \text{ g m}^{-2}$  during post-monsoon and low values in monsoon ( $0.09 \text{ g m}^{-2}$ ). The biomass showed significant seasonal variation ( $p < 0.001$ ). The post hoc test indicated significantly low biomass during monsoon. Similarly, the highest faunal biomass of  $78.78 \text{ gm}^{-2}$  was recorded at stn 4 (Fig. 4) and low value of  $4.47 \text{ gm}^{-2}$  at stn 5. The high value at stn 4 was contributed by bivalves. The biomass of all other taxa was generally high at stn 7 ( $14.7$ ) and low value was at stn 4 ( $0.07 \text{ g m}^{-2}$ ). The values showed significant variation between stations ( $p < 0.001$ ).

### ***Macrofaunal Species Diversity***

In terms of species, Polychaeta again dominated with 70 species and accounted for 50% of the total identified taxa. In terms of number of species, the class Bivalvia was next in order of dominance with 15 species and the family Veneridae dominated the group with 8 species. Amphipoda (13 species), Gastropoda (9 species), Isopoda (4 species), Cumacea (3 species) and Decapoda (5 species) were the other dominant groups.

Species richness was higher during post- monsoon (9.4) and low during monsoon (4.9; Fig. 5a). Tukey's test showed that all three seasons differed significantly in term of species richness. Species evenness was higher during pre-monsoon at all stations except stns 1 and 5 (Fig. 5b) and showed significant temporal variation ( $p < 0.001$ ). Shannon-Wiener diversity was higher during pre-monsoon at stns 3, 4, 6 and 7 (2.72). Stns 1, 2 and 5 had higher diversity during post-monsoon and the values dropped during pre-monsoon (Fig. 5c). Diversity showed a significant spatio-temporal difference ( $p < 0.01$ ).

Overall, the BIOENV analyses reveal a weak correlation between environmental parameters and benthic data ( $\rho = 0.37$ ). Of all the parameters, silt content showed highest correlation ( $\rho = 0.37$ ). Sediment chl-*a*, DO, sand content, BOD and NO<sub>3</sub> provided the best overall correlations ( $\rho = 0.47$ ).

## **DISCUSSION**

### ***Environmental Parameters***

The PCA analysis of the physico-chemical parameters of water and sediment showed a strong seasonal influence, largely dictated by monsoonal precipitation. On an average 3000 mm rain is recorded annually for Goa region with maximum precipitation of 906 mm being recorded in July 2004 (Fig. 6). In general, water temperature, salinity and pH showed a similar seasonal pattern for all stations. Salinity was similar during post- and pre-monsoon except during monsoon, indicating that the area is well mixed. The freshwater influx in the area is at the rate of >10,000 ML day<sup>-1</sup> (Shetye et al., 1995). The heavy runoff occurring during the summer monsoon every year completely flushes the Zuari estuary, turning the estuarine water fresh (Shetye et al., 2007).

The values for bottom water DO were low in monsoon, increased after the monsoon and decline during late pre-monsoon (May). The reduced DO in the monsoon was related to the coastal upwelling (Shenoy and Patil 2003) which increases the primary productivity of the area (Madhupratap et al. 1996). High biological production and subsequent sinking of organic matter lead to high demand of oxygen. Moreover, organic load associated with runoff can further reduce the oxygen during the monsoon in the Zuari estuary (Singbal 1985). The reduced DO in May was due to the increased water temperature during pre-monsoon, which is known to negatively affect the solubility of DO (Vega et al., 1998). It is interesting to note that at all stations BOD values attained a peak during the pre-monsoon. This may be due to summer evaporation and reduced freshwater flow resulting in increased BOD.

The granulometry of the area agrees with the typical distribution of sediment in the estuary i.e., higher sand content towards the mouth region and dominance of fine sediment towards the inner part of the estuary. Seasonally, sediment texture showed a slight variation in the inner



harbour. Outer harbour stations, however, showed an increase in sand content during the monsoon. The sediment texture in the area is related to the hydrodynamic conditions and the influence of river inputs. Chl-*a* was high during the monsoon, a phenomenon common in tropical estuaries (Shenoy and Patil 2003; Madhu et al., 2007). Organic carbon (OC) was higher at inner harbour compared to the other stations. Since domestic sewage from Vasco da Gama city, Mormugao municipal area is released and fishing activities carried out in the area (Ansari et al., 1994). Further, petroleum hydrocarbons from routine harbour activities add to the OC of an area (Kiyashko et al. 2001) indicating organic pollution to be a major environmental concern in the Mormugao harbour.

### ***Macrofaunal Community***

In tropical estuaries, the benthic fauna show marked seasonal pattern influenced by changes brought by monsoonal rains. Faunal abundance decreased during the monsoon followed by substantial increase in post -monsoon. Indicating faster recovery of bottom fauna with stabilized estuarine conditions (Pannikar, 1969; Parulekar et al., 1980; Harkantra and Rodrigues, 2003). Heavy rains cause defaunation of the benthic community either due to the mortality of adult and larval population or migration (Alongi, 1990). Decrease in salinity during monsoon can also trigger the gonadal release from the macrobenthic community (Kinne 1977). Further, under extreme condition the larval forms may undergo adaptive strategies like cyst formation, postponement of larval settlement (Richer and Sarthien, 1977; Kinne, 1977; Osman, 1977).

The macrofaunal abundance, biomass and diversity increased after monsoon through post-monsoon and fell drastically during pre-monsoon. In general, the macrofaunal community in the area was dominated by a few species (viz., *P.pinnata*; *T. scabra*). Even though most of them persisted throughout the study period their abundance showed marked temporal fluctuation and this was the main cause for observed significant variation in the faunal abundance. *P. pinnata* and *Tharyx* sp. which dominated during monsoon are known to increase in number after an environmental disturbance. Being surface deposit feeder, they can exploit the organic material very efficiently. Besides, their life cycle allows them to rapidly colonize disturbed areas (Hylleberg and Nateewathana, 1991; Blake and Arnofsky, 1999;

Rouse and Pleijel 2001). The high abundance of macrofauna during post-monsoon was predominantly due to the recruitment of *T. scabra*. However, their abundance decreased drastically during pre-monsoon. It was remarkable to note that despite extensive macrobenthic sampling conducted by previous workers (Parulekar et al. 1980; Ansari et al. 1986; Ansari et al. 1994; Harkantra and Rodrigues 2003), *T. scabra* has not been reported from this area in the past. The species was observed during pre-monsoon in the mouth region of Chapora estuary (0-2250 ind m<sup>-2</sup>) and Kalbadevi Bay (25-1150 ind m<sup>-2</sup>) (*per. obs.*). It is a suspension feeder, burrowing in soft sandy substrate (Naruchi 1980). The occurrence of *T. scabra* in large numbers in fine sandy sediment of Zuary estuary suggests that this species is typical of such habitat. It has also been reported from subtidal region of Formosa to south of China in quiet waters with little disturbance (Naruchi 1980). Filter (suspension) feeding bivalves favour habitat with sandy substrate. Sandy sediment is typical of high energy habitats as the action of currents and waves provide greater availability of particle in water than finer sediments habitats. Moreover, sandy substrates are often subjected to lesser resuspension. Therefore it is quite possible that the *T. scabra* observed in the Zuary estuary during post-monsoon may have been from the adult population established outside the harbour area and the larvae may have been transported upstream during the monsoon.

Our data suggest that fauna was poorly developed during pre-monsoon. Possible reason for the drastic decrease in the bivalve abundance in the harbour during pre monsoon could be the enhanced harbour activities (vessel movement and maintenance dredging) which peaks during the fair season (pre-monsoon). During the SW monsoon, the sea condition is usually rough. High tidal current coupled with strong waves during the monsoon will reduce the harbour activities. Subsequent increase in harbour activity augments the sediment load and contaminants during pre- monsoon that can make the condition unsuitable for the bivalve. Mass mortalities of *T. scabra* have been linked to oxygen depletion in Hong Kong waters (Nicholson and Morton 2000; Horikoshi and Thompson 1980; Shin 1985). Further, this species has been reported from the area with little anthropogenic disturbance (Horikoshi and Thompson 1980; Shin 1985). Therefore it is possible that *T. scabra* species is sensitive to the sediment disturbance. Similarly, the abundance of other macrofaunal species showed a similar trend. The abundance decreased and levelled at a value unrelated to the peak abundance

observed during post-monsoon and the community was dominated by opportunistic polychaete species. In disturbed areas, the dominant recolonizing factor is the supply of larvae, juveniles and/or adults, coming from farther locations (Chollett and Bone, 2007). In fact, the tide dominated Zuari River may facilitate wide dispersion of larvae. Most marine benthic invertebrates have planktonic larvae, which last for four to eight weeks (Shanks et al., 2003). The present study suggests that the faunal community of Mormugao harbour did not follow the general pattern of seasonal variation typical of tropical estuaries. Although macrofauna increased from monsoon to post monsoon season, it showed drastic decline during the stable pre monsoon period. The community during post-monsoon was dominated by juvenile populations suggesting recolonization of the area after cessation of the monsoon. However, during pre-monsoon season, the faunal abundance was low and was dominated by opportunistic polychaete species indicating a possible influence of increased harbour activities on the macrobenthic community. Increased harbour activities is evident from the enhanced level of contaminants (metal and PHC) during pre -monsoon (PCA). Further, increased vessel movement augment the organic enrichment and sediment stability causing considerable stress to the benthic organisms, and only species tolerant to this high stress survives.

### ***Macrofaunal Species Diversity***

Species richness and diversity was lowest during monsoonal. The low evenness during post-monsoon was expected, as faunal abundance was completely dominated by *T. scabra*, *Mediomastus* sp. and *Magelona* sp. Species belonging to the family Spionidae, Paranoidae, Capitellidae and Cirratulidae dominated in terms of diversity in the area. Species belonging to these families quickly respond to open or unexploited habitats by either a high reproduction rate and/or a high dispersal ability (Grassle and Grassle, 1974). Further, the adults and larvae of these species have remarkable tolerance to elevated hydrocarbon and other pollutants that are toxic to most other fauna (Levin et al., 1996; Chandler et al., 1997; Holmer et al., 1997). The elevated level of OC may have further contributed to the flourishing of opportunistic polychaete species in the Mormugao harbour. However, the negative impact of OC was indicated by low species diversity in the harbour stations. The present finding agrees very well with other studies where maximum diversity was observed in an area with moderate OC, and a decrease in diversity was observed with increased OC (Magni, 2003; Albayrak et al., 2006).

Out of the 71 polychaete species 62 are reported for the first time from the area. This may be due to extensive sampling carried during the present study. Since the Mormugao port is one of the busiest ports along the west coast of India and handles  $\approx 7\%$  of the total traffic of the country the possibility of invasive species entering in the area cannot be ruled out. However, in the absence of baseline data it is difficult to confirm, the invasive species in Mormugao harbour.

BIOENV analyses showed weak correlation between environmental parameters and biotic data ( $\rho = 0.37$ ). Of all the parameters, a relatively good combination was given with silt, chl-*a*, DO, sand, BOD and NO<sub>3</sub>. The results of the present study agrees with Snelgrove and Butman (1994) who concluded that with the exception of extreme habitats benthic community in the coastal zone is not controlled by one or a simple combination of parameters.

## **CONCLUSION**

The Zuari estuary becomes a freshwater regime during the SW monsoon occurring between June and September. This brings about critical changes on the physico-chemical and biological characteristics, and sedimentation processes of the estuary. In the present study, the macrofaunal community in the Mormugao did not follow the general pattern of seasonal variability typical of tropical estuaries. The community showed high abundance, biomass and species number during post monsoon, which was mainly due to the recruitment process. The pre-monsoon season is generally considered to be a stable period; however, the macrofaunal abundance was lowest during this period. Even though the possible reason for abrupt changes in population could not be ascertained from the present data, harbour activities which peak during pre-monsoon could undoubtedly reduce the established benthic population. Therefore, long term monitoring is required to understand the dynamics of macrofauna from tropical estuary.

## **Acknowledgment**

The authors are thankful to Dr Satish Shetye, Director, NIO, for his encouragement. We also wish to thank Dr XN Verlecar for coordinating the field studies and all the help rendered during

the study. The first and third author was supported by Council of Scientific & Industrial Research, (CSIR) Govt. of India fellowship. This is contribution number... of NIO, CSIR.

### References

Albayrak, S., Balkis, H., Zenetos, A., Kurun, A., & Kubanc, C. (2006). Ecological quality status of coastal benthic ecosystems in the Sea of Marmara. *Marine Pollution Bulletin*, 52, 790-799.

Alongi, D. (1990). The ecology of tropical soft-bottom benthic ecosystems. *Oceanography and Marine Biology an Annual Review*, 28,381-496.

Anon, (2004). Environmental monitoring for dredging and reclamation for berths 5A and 6A at Mormugao harbour. NIO/SP-32/2004.

Ansari, Z.A., Ingole, B.S., Banerjee, G., & Paruelkar, A.H. (1986). Spatial and temporal changes in benthic macrofauna from Mandovi and Zuari Estuaries of Goa, West Coast of India. *Indian Journal of Marine Science*, 15,223-229.

Ansari, Z.A., Ingole, B.S., & Parulekar, A.H. (1995). Reassessment of bottom communities of estuarine complex of Goa in relation to anthropogenic changes. In *Man and Environment*. Proceeding of the X Annual Congress of NESO, NIO, Goa, pp 29-32.

Ansari, Z.A., Sivadas, S., & Ingole, B.S. (2007). Benthic macrofauna. In Shetye, S.R, M. DileepKumar, D. Shankar, D (Eds) *The Mandovi and Zuari estuaries*. National Institute of Oceanography Goa, India, (pp.91-98).

Ansari, Z.A., Sreepada, R.A., & Kanti, A. (1994). Macrobenthic assemblages in the soft sediment of Mormugao harbour, Goa (central west coast of India). *Indian Journal of Marine Science*, 23, 225-231.

Bhosle, N.B., Garg, A., Jadhav, S., Harji, R., Sawant, S., Venket, K., & Anil, A.C. (2004). Butyltins in water, biofilm and sediments of the west coast of India. *Chemosphere*, 57, 897–907.

Blake, J.A., & Arnofsky, P.L. (1999). Reproduction and larval development of the spiniform polychaete with application to systematic and phylogeny. *Hydrobiologia*, 402, 57-106.

Carlton, J.T. (1999). The scale and ecological consequences of biological invasions in the world's ocean. In: O.T. Sandlund, P.J. Schei and A. Viken, Editors, *Invasive Species and Biodiversity Management*, Kluwer Academic Publishers, Dordrecht, (pp. 195–212).

Chandler, G.T., Shipp, M.R., & Donelan, T.L. (1997). Bioaccumulation, growth and larval settlement effects of sediment-associated polynuclear aromatic hydrocarbons on the estuarine polychaete, *Streblospio benedicti* (Webster). *Journal of Experimental Marine Biology Ecology*, 213, 95–110.

Cherian, T., Rao, G.L.V., & Varma, K.K. (1974). Hydrography and suspended sediment load of oceanic estuarine waters adjoining Mormugao harbour during early summer. *Indian Journal of Marine Science*, 3, 99-104.

Chollett, I., & Bone, D. (2007). Effects of heavy rainfall on polychaetes: Differential spatial patterns generated by a large scale disturbance. *Journal of Experimental Marine Biology Ecology*, 340, 113-125.

Clarke, K.R., & Warwick, R.M. (1994). Changes in marine communities: an approach to statistical analysis and interpretation. Tech Report Plymouth Marine Laboratory, Plymouth, England.

El Wakeel, S.K., & Riley, J.P. (1957). The organic carbon of marine mud. *Journal Du. Conseil International Exploration*, 22, 180-183.

Grassle, J.F., & Grassle, J.P. (1974). Opportunistic life histories and genetic system in marine benthic polychaetes. *Journal of Marine Research*, 32,253-284.

Harkantra, S.N., & Rodrigues, N.R. (2003). Pattern of species succession of soft-bottom macrofauna in the estuaries of Goa, west coast of India. *Current Science*, 85(10),1458-1474.

Hewitt, J.E., & Thrush, S.F., (2007). Effectice long-term ecological monitoring using spatially and temporally nested sampling. *Environmental Monitoring Assessment*, 133:295-307.

Holmer, M., Forbes, V.E., & Forbes, T.L. (1997). Impact of the polychaete *Capitella* sp 1 on microbial activity in organic-rich marine sediment contaminated with the polycyclic aromatic hydrocarbon fluoranthene. *Marine Biology*, 128, 679–688.

Holm-Hansen, O. (1978). Chlorophyll 'a' determination: Improvement in methodology *Oikos*, 30, 438-447.

Horikoshi, M., & Thompson, G. (1980). Distribution of subtidal mollusks collected by trawling in Tolo Harbour and Tolo channel. Hong Kong, with special reference to habitat segregation in two venerid bivalves. In B. Morton (Ed.), *The Malacofauna of Hong Kong and Southern China // Proceeding of the first International workshop on the Malacofauna of Hon Kong and Southern China*, Hong Kong 1977. Hong Kong University Press (pp.149-62).

Hylleberg, J., & Natewathana, A. (1991). Spatial and temporal distribution of spionid polcyahetes at Phuket Island, the Andaman Sea. *Bulletin of Marine Science*, 48, 346-357.

Ingole B.S., Sivadas, S., Nanajkar, M., Sautya, S., & Nag, A. (2009). A comparative study of macrobenthic community from harbours along the central west coast of India. *Environmental Monitoring and Assessment*, 154:135-146.

Kinne, O. (1977). Environmental Factors–Salinity: Animal–Invertebrates. In Kinne, O. (ed), *Marine Ecology*, John Wiley, New York, 1, 821–996.

Kiyashko, S.I., Fadeeva, N.P. & Fadeev, V.I. (2001). Petroleum hydrocarbons as a source of organic carbon for the benthic macrofauna of polluted marine habitats as assayed by the  $^{13}\text{C}/^{12}\text{C}$  ratio analysis. *Doklady Biological Sciences*, 381(2), 283-285.

Levin, L., Caswell, H., Bridges, T., Di Bacco, C., Cabrera, D., & Plaia, G. (1996). Demographic responses of estuarine polychaetes to pollutants: life table response experiments. *Ecological Applications*, 6, 1295–1313.

Madhu N.V., et al. (2007). Monsoonal impact on planktonic standing stock abundance in a tropical estuary (Cochin backwaters- India). *Estuarine Coastal Shelf Science*, 73, 54-64.

Madhupratap M., et al. (1996). Mechanism of the biological response to winter cooling in the northeastern Arabian Sea. *Nature*, 384, 549-551.

Magni, P. (2003). Biological benthic tools as indicators of coastal marine ecosystem health. *Chemistry and Ecology*, 19 (5), 363-372.

Nicholson, S., & Morton, B. (2000). The Hypoxia tolerances of subtidal marine bivalves from Hong Kong. In Morton B (ed) *The Marine flora and fauna of Hong Kong and Southern China V*, Proceeding of the Tenth International Marine Biological Workshop: The Marine Flora and fauna of Hong Kong and Southern China, Hong Kong, Hong Kong University Press, (pp. 229-239).

Naruchi, W. (1980). On the biology of *Veremolpa scabra* (Hanley 1845) (Bivalvia: Veneridae) from the South China Sea. In Morton B (ed) *The Marine flora and fauna of Hong Kong and Southern China V*. Proceeding of the first International Marine Biological Workshop: The Marine Flora and fauna of Hong Kong and Southern China, Hong Kong, Hong Kong University Press, (pp. 277-289).



Osman, R. W. (1977). The establishment and development of a marine epifauna community. *Ecological Monograph*, 1977, **47**, 37–63.

Patil, J.S., A.C. Anil, 2008. Temporal variation of diatom benthic propagules in a monsoon-influenced tropical estuary. *Continental Shelf Research*, 28, 2404–2416

Pannikar, N.K. (1969). New perspectives in estuarine biology. Proceeding of all India Symposium in Estuarine Biology, Madras, (pp.8).

Parulekar A.H., Dhargalkar, V.K., Singbal, S.Y.S. (1980). Benthic studies in Goa Estuaries: Part III- Annual cycle of Macrofaunal Distribution, Production and Trophic relations. *Indian Journal Marine Science*, 9,189-200.

Richer, W., & Sarnthein, M. (1977). Molluscan Colonization of Different Submerged Platforms in the Western Baltic Sea. In Keegen, B. F., Ceidigh, P.O., & Boaden, P.J.S. (eds) *Biology of Benthic Organisms*, Pergamon Press, New York: (pp. 465–477).

Rouse, G.W., & Pleijel, F. (2001). Polychaetes. Oxford University Press, Hon Kong.

Rubio, B., Nombela, M.A., & Vilas, F. (2000). Geochemistry of major and trace elements in sediments of the Ria de Vigo (NW Spain): an assessment of metal pollution. *Marine Pollution Bulletin*, 40, 968-980.

Singbal, S.Y.S. (1985). Environmental study of the waters of Mandovi - Zuari estuarine complex. Goa Seminar on Earth Resources for Goa's Development, 18-21 September 1981. Geological Survey of India (pp. 530-548).

Shanks A.L., Grantham, B.A., & Carr, M.H. (2003). Propagule dispersal distance and the size and spacing of marine reserves. *Ecological Applications*, 13,159–169

Shenoy, D.M., & Patil J.S. (2003). Temporal variations in dimethyl sulphonioacetate and dimethyl sulphide in the Zuari estuary, Goa (India). *Marine Environmental Research*, 56(3), 387– 402.

Shetye, S., (1995). Propagation of tides in the Mandovi-Zuari estuarine network. *Proceeding Indian Academy Science (Earth Planet Science)*,104:667-682.

Shetye, S.R., DileepKumar, M., & Shankar, D. (2007). The environment that conditions the Mandovi and Zuari estuaries. In Shetye, S.R, M. DileepKumar, D. Shankar, D (eds) *The Mandovi and Zuari estuaries*. National Institute of Oceanography Goa, India, (pp. 3-27).

Shin, P.K.S. (1985). A trawl survey of the subtidal mollusca of Tolo Harbour and Mirs Bat, Hong Kong. In Morton, B., & Dudgeon D. (ed) *The Malacofauna of Hong Kong and Southern China II*. Proceeding of the second International workshop on the malacofauna of Hon Kong and Southern China, Hong Kong. Hong Kong University Press: 439-47

Smith G.C., Covich, A.P., & Brasher, A.M.D. (2003) An Ecological Perspective On The Biodiversity Of Tropical Island Streams. *Bioscience*, 53(11), 1048- 1051.

Snelgrove, P.V.R., & Butman, C.A. (1994). Animal-sediment relationships revisited: cause versus effect. *Oceanography Marine Biology an Annual Review* , 32,111-177.

Vega M., Pardo, R., Barrado, E., & Deban, L. (1998). Assessment of seasonal and polluting effects on the quality of river water by exploratory data analysis, *Water Research*, 32, 3581– 3592.

**Table 1**

Principal component analysis (PCA) loading of water and sediment parameters.

<b>Variable</b>	<b>PC1</b>	<b>PC2</b>	<b>PC3</b>	<b>PC4</b>
SS	<b>-0.27</b>	-0.05	-0.01	0.07
BS	<b>-0.24</b>	-0.05	-0.19	0.05
ST	-0.22	0.12	0.1	0.03
BT	-0.22	0.12	0.10	0.03
S pH	-0.07	<b>-0.27</b>	0.21	0.09
B pH	-0.19	-0.10	0.16	-0.03
S NO <sub>2</sub>	<b>-0.25</b>	0.05	0.04	0.01
B NO <sub>2</sub>	-0.22	0.13	0.02	0.12
S NO <sub>3</sub>	-0.21	-0.11	-0.01	-0.04
B NO <sub>3</sub>	-0.21	-0.20	-0.03	-0.07
S PO <sub>4</sub>	0.21	0.15	-0.01	-0.01
B PO <sub>4</sub>	<b>0.25</b>	0.06	-0.001	0.14
S Phaeo	0.09	-0.21	0.08	0.05
B Phaeo	0.17	-0.13	0.10	-0.07
S Chl a	<b>0.24</b>	-0.17	0.09	0.01
B Chl a	<b>0.25</b>	-0.07	0.12	-0.01
S DO	-0.04	<b>-0.31</b>	-0.19	0.07
B DO	-0.12	-0.19	-0.19	-0.21
S BOD	-0.01	0.22	<b>0.37</b>	-0.11
B BOD	-0.13	<b>0.26</b>	-0.07	-0.05
S PHC	0.12	-0.07	-0.15	0.02
B PHC	-0.01	0.10	<b>-0.25</b>	0.03
S Cd	-0.01	-0.09	0.02	<b>0.43</b>
B Cd	0.06	-0.09	0.10	<b>0.33</b>
S Pb	<b>-0.25</b>	-0.17	-0.08	0.07
B Pb	-0.22	-0.19	-0.04	0.14
S Hg	<b>-0.25</b>	0.10	0.04	0.002
B Hg	-0.22	0.12	<b>0.29</b>	0.01
Sed Cd	0.02	0.08	-0.08	0.17
Sed Pb	-0.06	0.17	<b>0.42</b>	0.16
Sed Hg	0.12	-0.01	<b>0.37</b>	0.09
Sed Chl a	0.08	<b>-0.27</b>	0.06	<b>0.28</b>
OC	-0.05	-0.22	0.06	<b>0.35</b>
Sand	-0.03	<b>-0.25</b>	0.15	<b>-0.36</b>
Silt	0.04	<b>0.24</b>	-0.09	<b>0.36</b>
Clay	-0.02	0.22	<b>-0.33</b>	0.19
<b>Eigen values</b>	12.8	6.79	2.79	2.4
<b>%Variation</b>	35.5	18.9	7.8	6.7
<b>Cum.% Variation</b>	35.5	54.4	62.2	68.8

S surface; B bottom; SS surface salinity, BS bottom salinity; T; temperature

**Table 2** Seasonal variation of macrobenthic taxa in the study area, 2003-2004  
(+ : present; - : absent)

<b>Taxa</b>	<b>Monsoon</b>	<b>Post monsoon</b>	<b>Pre monsoon</b>
<i>Hydrozoa (Obelia colony #1)</i>	+	+	+
<i>Hydrozoa (Obelia colony #2)</i>	+	+	+
<i>Anthozoa</i>	-	+	-
<i>Nematoda</i>	+	+	+
<i>Nemertenia</i>	+	+	+
<b>Polychaeta</b>			
<i>Phyllodoce malmgreni</i>	-	+	+
<i>Phyllodoce madeirensis</i>	-	+	-
<i>Phyllodoce sp.</i>	-	+	-
<i>Eteone sp.</i>	-	+	-
<i>Podarke sp.</i>	-	+	+
<i>Syllis cornuta</i>	-	+	-
<i>Syllis krohnii</i>	+	+	+
<i>Syllis sp.</i>	-	+	-
<i>Sphaerosyllis sp.</i>	-	-	-
<i>Exogene sp.</i>	+	+	+
<i>Odontosyllis sp.</i>	+	-	-
<i>Sthenelais sp.</i>	-	+	-
<i>Harmothoe sp.</i>	+	+	+
<i>Hesion sp.</i>	+	-	-
<i>Ancistrasyllis constricta</i>	+	+	+
<i>A. groelandica</i>	+	+	+
<i>Nephtys polybranchia</i>	+	+	+
<i>Nereis sp.</i>	-	+	+
<i>Drilonereis macrocephala</i>	-	+	-
<i>Glycera alba.</i>	+	+	+
<i>Glycera longipinns</i>	+	+	+
<i>Glycinde oligodon</i>	-	+	+
<i>Gylcinde sp.</i>	+	+	+
<i>Goniadides sp.</i>	+	+	+
<i>Goniada hexadentes</i>	-	+	+
<i>Goniada sp.</i>	-	+	+
<i>Pisione oesterdii</i>	+	+	+
<i>Tharyx sp.</i>	+	+	+
<i>Chaetozone sp. 1</i>	+	+	+
<i>Chaetozone sp. 2</i>	+	+	+
<i>Capitilla sp.</i>	-	+	-
<i>Mediomastus sp.</i>	+	+	+
<i>Heteromastus sp.</i>	-	+	+
<i>Neomediomastus sp.</i>	-	+	-
<i>Notomastus sp.</i>	-	+	+
<i>Dasybranchus sp.</i>	-	+	-
<i>Capitellidae</i>	+	+	+
<i>Euclymene insecta</i>	+	+	+

Contd..

<b>Taxa</b>	<b>Monsoon</b>	<b>Post monsoon</b>	<b>Pre monsoon</b>
<i>Axiothella obockensis</i>	-	+	+
<i>Prionospio pinnata</i>	+	+	+
<i>P. krusadensis</i>	-	-	+
<i>Polydora sp.</i>	-	+	-
<i>Polydora ciliate</i>	+	+	+
<i>P. coeca</i>	+	+	+
<i>P. antennata</i>	-	+	+
<i>Pseudopolydora kempi</i>	-	+	+
<i>Minuspio cirrifera</i>	+	+	+
<i>Magelona sp.</i>	+	+	+
<i>Poecilochaetus serpens</i>	-	+	+
<i>Phyllochaetopterus sp.</i>	-	+	+
<i>Disoma orissae</i>	+	+	-
<i>Dorvillea manadapmae</i>	+	+	+
<i>Lumbriconereis laterelii</i>	+	+	+
<i>Lumbriconereis sp.</i>	+	+	-
<i>Eunice indica</i>	-	+	+
<i>Dioptra clapaderi</i>	-	+	-
<i>Onuphis eremite</i>	+	+	+
<i>O. dibranchiate</i>	-	+	-
<i>Onuphis sp.</i>	-	+	-
<i>Terebellides stroemi</i>	+	+	+
<i>Sabellaria cementaria</i>	-	+	-
<i>Jasimineira sp.</i>	-	+	+
<i>Saccocirrus sp.</i>	-	+	-
<i>Sternapsis scutata</i>	+	+	+
<i>Scoloplos sp.</i>	+	+	+
<i>Aricidea catherina</i>	+	+	+
<i>Aricidea multiantennata</i>	-	-	+
<i>Aricidea assimilis</i>	-	+	-
<i>Aricidea sp.</i>	+	-	-
<i>Paradoneis armata</i>	+	+	-
<i>Levinsenia sp.</i>	+	+	+
<i>Cossura sp.</i>	+	+	+
<i>Armandia lanceolata</i>	-	+	-
<i>Unidentified Polychaeta</i>	+	+	-
<b>Oligocheata</b>	+	+	+
<b>Sipuncula</b>	-	+	-
<b>Phoronida</b>	-	+	-
<b>Bivalvia</b>			
<i>Nuculana sp.</i>	-	-	+
<i>Modiolous sp.</i>	-	+	-
<i>Cardita bicolor</i>	+	+	+
<i>Venerupis sp.</i>	-	+	-
<i>Sunetta sp.</i>	-	+	-

**Contd..**

<b>Taxa</b>	<b>Monsoon</b>	<b>Post monsoon</b>	<b>Pre monsoon</b>
<i>Paphia textile</i>	+	+	+
<i>Sunetta</i> sp.	-	+	-
<i>Pitar erycina</i>	-	-	+
<i>Timoclea scabra</i>	+	+	+
<i>Venus</i> sp.	-	+	-
<i>Gafrarium</i> sp.	-	+	-
<i>Dosinia</i> sp.	-	+	+
<i>Mactra</i> sp.	-	+	-
<i>Tellina</i> sp.	-	+	+
Solenidae	-	+	-
<b>Gastropoda</b>			
<i>Monilea</i> sp.	-	+	-
<i>Marginella</i> sp.	-	+	-
<i>Calyptreaea</i> sp.	-	-	+
<i>Chelicera</i> sp.	-	+	-
<i>Olivia</i> sp.	-	+	+
<i>Muricidea</i> sp.	-	+	-
<i>Thais</i> sp.	-	+	+
<i>Surcula</i> sp.	-	-	+
Unidentified Gastropoda	+	-	-
<b>Amphipoda</b>			
<i>Ampelisca</i> sp.	+	+	+
<i>Hyale</i> sp.	-	+	-
<i>Cheirocratus</i> sp.	-	+	-
<i>Maera</i> sp.	-	+	-
<i>Monoculodes</i> sp.	-	+	+
<i>Westwoodilla</i> sp.	+	+	-
<i>Ampithoe</i> sp.	-	+	-
<i>Pallasia</i> sp.	-	+	-
<i>Photis</i> sp.	+	+	+
<i>Gammaropsis</i> sp.	-	+	-
<i>Corophium</i> sp.	+	+	-
<i>Podocerus</i> sp.	-	+	-
<i>Caprella</i> sp.	-	+	-
Unidentified Amphipoda	+	-	+
<b>Tanaidacea</b>	+	+	+
<b>Cumacea</b>			
<i>Cyclaspis</i> sp.	+	+	-
<i>Pseudocyclaspis</i> sp.	-	+	+
Unidentified Cumacea	+	+	+
<b>Isopoda</b>			
<i>Cyathura</i> sp.	+	+	+
<i>Accalthur</i> sp.	-	+	-

Contd..

<b>Taxa</b>	<b>Monsoon</b>	<b>Post monsoon</b>	<b>Pre monsoon</b>
Unidentified Isopoda #1	-	+	-
Unidentified Isopoda #2	-	-	+
<b>Ostracoda</b>	+	+	+
<b>Decapoda</b>			
Varuninae	+	-	-
Brachyuran	-	-	+
Thalassinidea	-	+	-
Caridea	-	-	+
<i>Eupagurus</i> sp.	+	-	-
Penaidae	+	-	+
<b>Harpacticoida</b>	-	-	+
<b>Pycnogonida</b>	+	-	-
<b>Insecta</b>	-	+	-
<b>Ophiuridae</b>	-	+	+

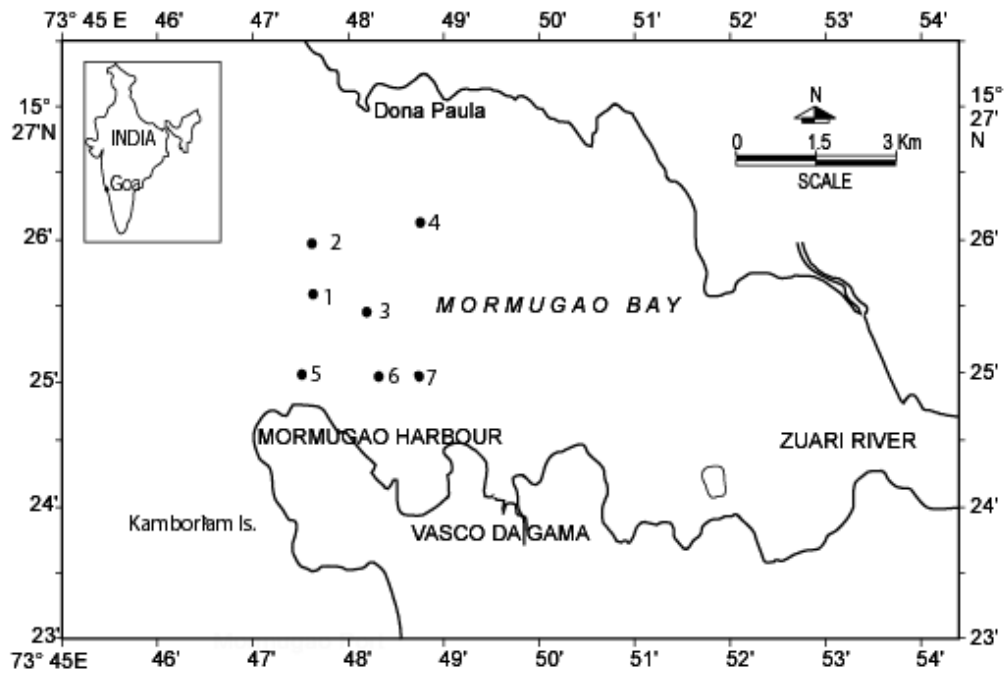


Fig 1 Location of the sampling stations- Mormugao harbour



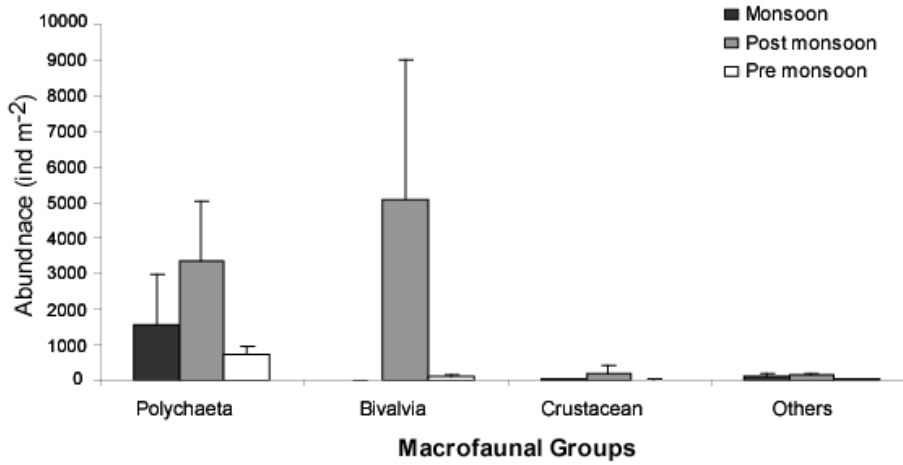


Fig 2a Seasonal variation of macrofaunal group in the study area

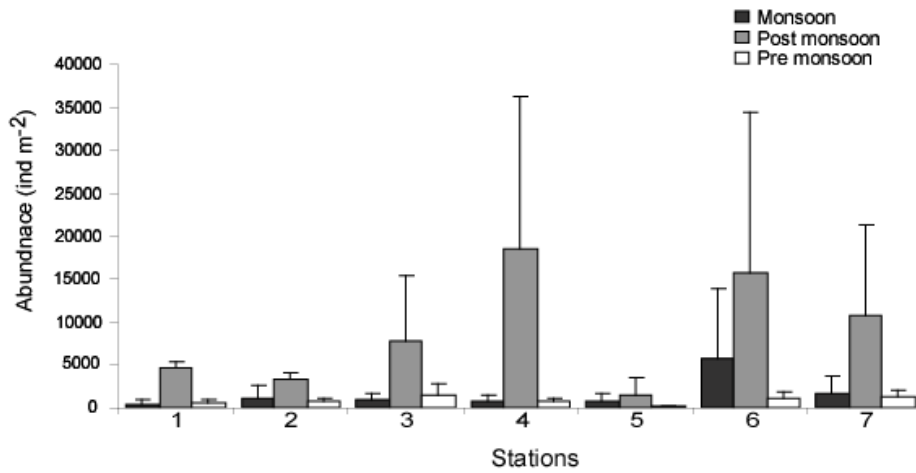


Fig 2b Seasonal variation in macrofaunal abundance in the study area

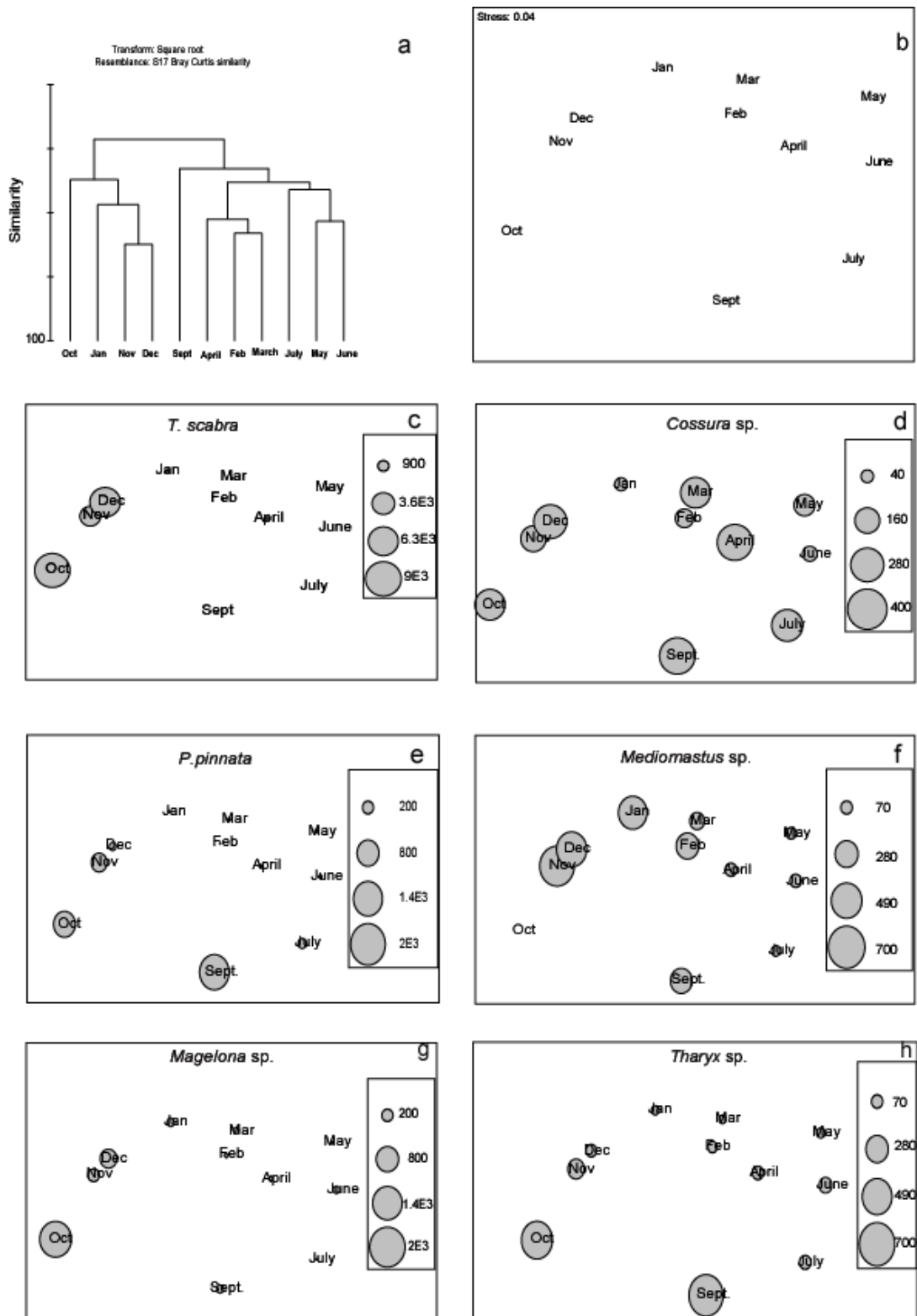


Fig 3. Bray-Curtis cluster (a) and MDS (b) based on the monthly species abundance. Bubble plot of abundance of dominant species (c-h).

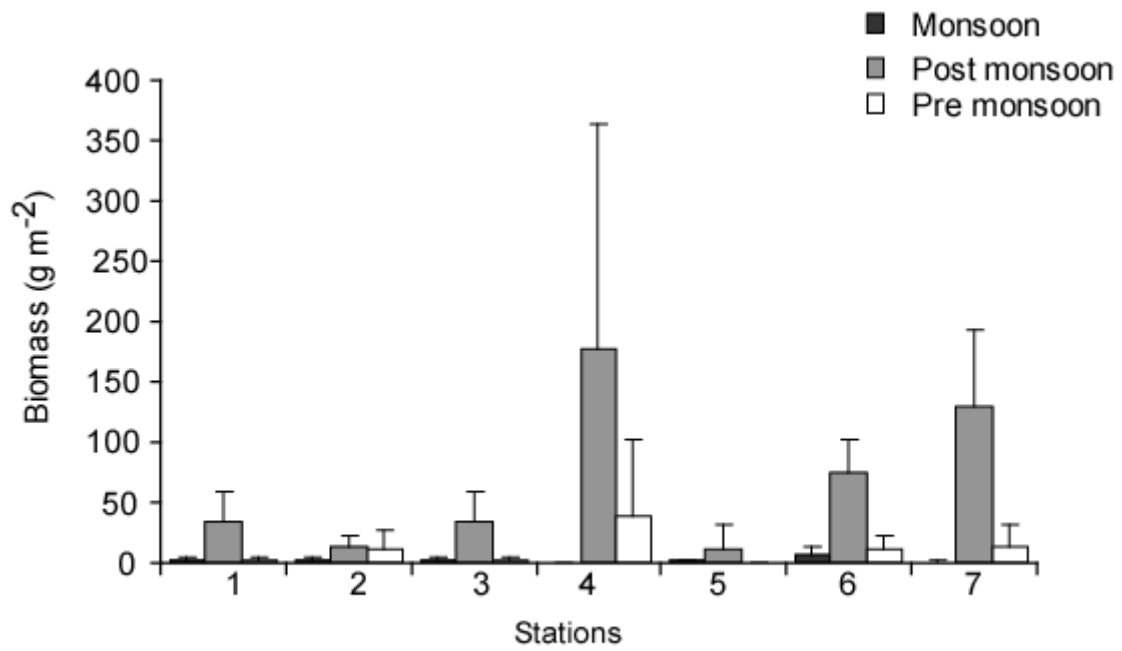


Fig 4 Seasonal variation in macrofaunal biomass

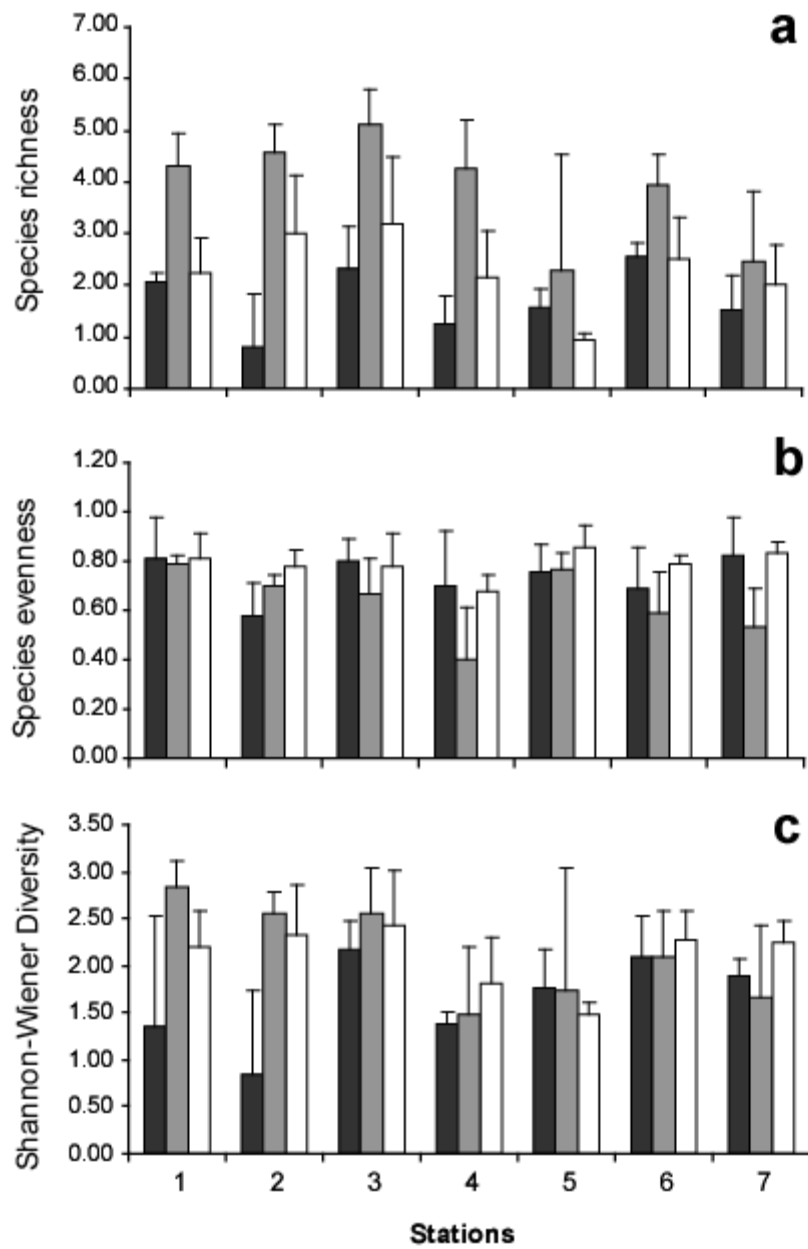


Fig 5 Seasonal variation in macrofaunal species richness(a)species evenness(b) and species diversity(c)

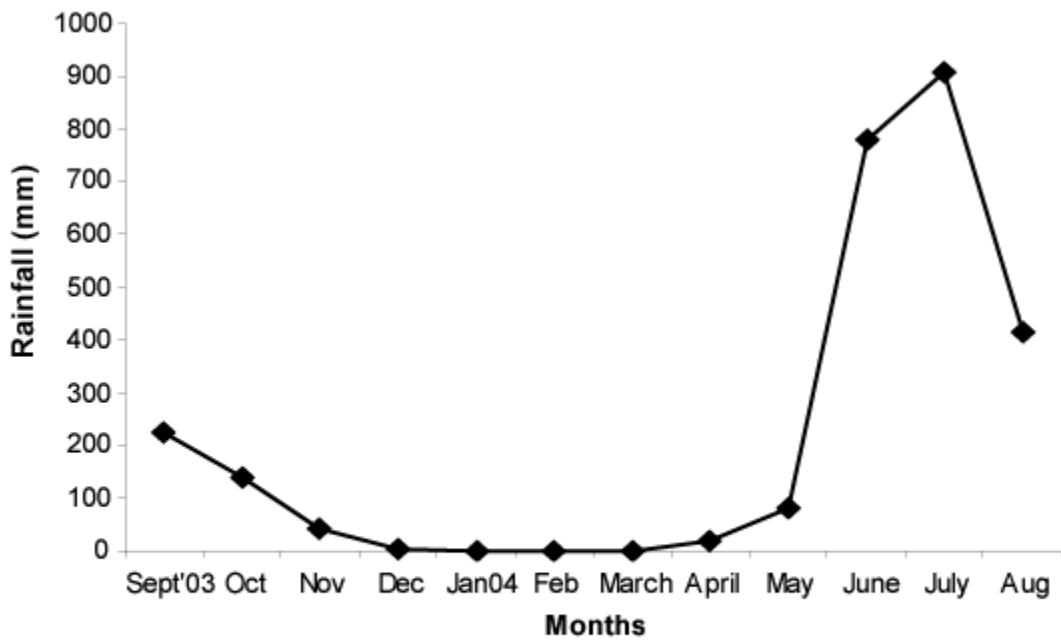


Fig 6 Monthly variation of rainfall in the study area