

## **Implications of benthic ecological quality in structuring macrobenthos community in a tropical monsoon influenced port, New Mangalore, India**

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### **Abstract**

Soft bottom macrobenthos are highly diverse benthic invertebrates, and their diversity depends mainly on the health of the benthic habitat. The impact of anthropogenic stress and port related activities on macrobenthos diversity was studied in New Mangalore port, a tropical monsoon influenced environment. A shift in the macrobenthos abundance and diversity was observed with seasons, along with shift in the dominance of opportunistic species. The ecological quality status (EcoQS) indicated 'poor' to 'moderate' and also 'bad' status of benthic habitat, and this changed with the seasons and regions within the port. Higher diversity of macrobenthos at stations located in the high circulation area (HCA) compared to low circulation area (LCA) and oil and fertilizer wharf (OFW) indicated pivotal role of local hydrodynamics and activities within the port in structuring macrobenthos diversity. The occurrence of opportunistic species within the port demonstrated the role of anthropogenic stress in structuring macrobenthos community.

**Keywords:** Macrobenthos; Polychaetes; Ecological Quality; New Mangalore Port; Opportunistic species

### **Highlights**

- Benthic Ecological quality status (EcoQS) was assessed at New Mangalore Port.
- Benthic EcoQS was 'bad'- 'high', and it changed with seasons and region within port.
- Seasonal shift in macrobenthos community changed with regions within port.
- Dominance of opportunistic species reflected anthropogenic stress within the port.
- Local hydrodynamics and port activities determine benthic habitat health.

## 1. Introduction

The tropics make for over 30% of the total area of the continental shelf of the earth (Alongi 1990). Along tropical coastlines, pollution, urbanisation, and population expansion are all rising alarmingly (Snelgrove, 1998). Ports are often contained environments with low hydrodynamism, low biodiversity, low concentrations of pollutants in the water and sediment, and low oxygen levels in the water column (Guerra-Garcia and Garcia-Gomez 2004; Mandal and Harkantra 2013). They are the sheltered water bodies and are subjected to various forms of anthropogenic activities such as sewage or municipal runoff, terrestrial runoff during the monsoon, port related activities such as dredging, oil spill, petroleum effluents, accidental out-fall of variety of cargo handled at the port etc. Though they are important from the country's economic development from the perspectives of trade and transport, the activities within the port damage the habitat and cause adverse impact on both pelagic and benthic environment (Button, 1999; Talley, 2003; Rilov and Crooks 2009; Ng and Song, 2010). The impact on the benthic habitat would be most likely be greater than on the pelagic compartment due to the settling of unwanted waste on benthic surface and low circulation owing to the enclosed or semi enclosed nature. Thus organisms living in the benthic realm of the ports have to be tolerant to the most stressful conditions. Studies carried out in some of the major ports of India indicated that the water inside the port is eutrophicated and has high chlorophyll biomass owing to low flushing rate with the outside seawater (Sawant et al. 2007; Rajaneesh et al. 2015). Various anthropogenic activities in the ports might result in an increase in the opportunistic species (Galil 2000). As port areas have empty niches, they are prone to marine bio-invasion especially due to ballast water discharge from the ships (Rilov and Crooks 2009; Mandal and Harakantra 2013).

Soft-bottom macrobenthos is an important ecological group (Zhang et al. 2012), and they play important role in the bioturbation process and indirectly promote oxygen flux and circulation through sediment to promote bacterial activities involved in organic matter recycling, sediment decomposition, and secondary production (Lind 1979; Snelgrove 1998; Woodward and Hildrew 2002; Covich et al. 2004). Combined with their relatively sedentary lifestyles such as long life-cycles, the macrobenthos respond to environmental changes via community-related variations including species composition, diversity, abundance, and biomass (Rakocinski et al. 1997; Koperski, 2010; Welianje et al. 2017). Thus, their abundance and distribution can be used as effective bio-indicators to assess the health of the benthic habitat (Tong et al. 2013; Keeley et al. 2014; Wang et al. 2021). Coastal ecosystems are complex environments known for their importance in terms of biodiversity, however, they are also extremely sensitive as they are exposed to several anthropogenic pressures (e.g. pollution, tourism, overfishing, sediment discharge, shipping, industrial and urban developments). They host a range of

benthic assemblages and are threatened by anthropogenic stressors and habitat degradation as a result of coastal developments (Parulekar,1973; Pawar and Al-Tawaha 2017).

Seshappa (1953) and Kurian (1953) conducted the first detailed investigations on the bottom fauna off Madras, Malabar, and Travancore in India in 1953. Several investigations have been conducted since then on both east and west coasts (Ganapati and Lakshmana Rao 1959; Radhakrishna and Ganapati 1969; Kurian 1971; Damodaran 1973; Ansari et al. 1977; Harkantra et al. 1980, 1982; Parulekar and Wagh 1975; Raman and Adishesasai 1989; Raut et al. 2005). Programs to monitor the effects of pollution now routinely employ the structure of the benthic community. Compared to higher latitudes, the tropics have seen less benthic investigations, and the theory relating to community structure is mostly based on research from temperate locations (Alongi 1990). Neyman (1969) investigated on the benthos along the shelf region of northwest India. Further studies were conducted by Parulekar and Wagh (1975), Parulekar et al. (1976), Harkantra et al. (1980), Joydas and Damodaran (2001), and Joydas (2002) along the northwest coast of India. In addition, the benthos of the Indian waters were examined by Parulekar et al. (1982). Varshney et al. (1988), did research on the macro-benthos of very-near-shore depths (5-20 m) off Versova, west coast of India. Kundu et al (2010) studied the diversity and seasonal variation of infaunal macro-benthic organisms in the inshore waters of Parangipettai Coast, south-east coast of India.

The New Mangalore Port is a modern all-weather (operative during all the seasons) port and is the largest liquefied petroleum gas handling port in the country. The total cargo handling capacity of the port is 38 million tones with 15 berths. The major imports of the port include Crude Oil and Petroleum, Oils, Lubricants, liquefied petroleum gas, wood pulp, timber logs, finished fertilizers, liquid ammonium, phosphoric acid, other liquid chemicals, containerized cargo, etc. (Naik and Kunte 2016). It is situated on the south-west coast of India, and, is influenced by the south-west monsoon and about 90% of the rainfall is received during the months of May to October, however, the active monsoon months are from June to September, with very low rainfall during May and October. Depending upon this the year is divided into monsoon (June to September), post-monsoon (October to January), and pre-monsoon (February to May). With the change in the season, the direction of currents also changes. During the southwest monsoon, due to the heavy rains, it has been observed that reversal of currents in the approach channel, which is the only opening for the ships to enter port area. During the northeast monsoon (November to February) the currents are towards North. The New Mangalore Port has a water spread area of ~1.29 sq. km. There are two break waters, the northern and southern breakwater which make up the approach channel which is about 245m wide. Near the edge of the breakwaters a strong drift has been reported, which is variable and in the approach channel it can be as high as 1.5

knots during the southwest monsoon (Port Risk Assessment Report 2012). Analysis of data collected in and around Mangalore revealed that 0.4% of the waves have a height of 4.9 m, and the wave height during the non-monsoon months is comparatively low (more than 1.5 m) (Ramteke and Deshbhratar 2014). Such a challenging condition play a major role in the biodiversity at the New Mangalore Port, therefore it is necessary to study about the distribution and abundance of macrobenthos. Unfortunately, there are no reports on the distribution and abundance of macrobenthos from the New Mangalore Port, however, few studies have reported their distribution and abundance off the Mangalore coast (Devassy et al. 1987; Gopalakrishnan and Nair 1998; Joydas 2002; Kumar et al. 2004; Musale and Desai 2011). The present study was carried out to assess the distribution of macrobenthic community at the New Mangalore Port, a tropical monsoon influenced environment. Based on the physical characteristics, mainly the circulation within the port and the port related activities, the area within the port was divided as low circulation area (LCA), high circulation area (HCA) and oil and fertilizer wharf (OFW) to (1) observe spatial and temporal variation in the environmental variables and the sediment characteristics (2) to evaluate the variation in macrobenthic species diversity over a spatial and temporal scale and to elucidate the relationship between macrobenthic community and environmental variables and sediment characteristics (3) assess the EcoQS (ecological quality status) within different areas of the New Mangalore Port by employing AZTI's indices.

## **2. Materials and methods**

In the present study, 19 stations were selected for the collection of samples (Fig. 1). The port area has been divided into three areas depending upon the port-related activities at different berths, and the hydrographic conditions such as tides and currents which govern the exchange of seawater with the Arabian sea. They were (1) Low Circulation Area (LCA) which is comparatively a semi enclosed area (stations 1-8) (2) Oil and Fertilizer Wharf (OFW) which handles the liquid cargo mainly oil and fertilizers (stations 10-14), (3) High Circulation Area (HCA) stations 9 and 15-19 which are located in the main channel connecting the port (Fig. 1). The sampling was carried out during the month of November 2011 (Post-monsoon - abbreviated as PM I), May 2012 (Pre-monsoon – PreM), September 2012 (Monsoon – MON) and December 2012 (Post monsoon – PM II) representing different seasons.

The surface and near-bottom seawater samples were collected at all the stations (19 stations) during all the seasons in triplicate using a Niskin water sampler. The seawater samples at the surface were collected from 2m below the surface and the near bottom seawater samples were collected 1m above the bottom. The water column depth at different stations ranged between 8.5 m to 16.6 m. The salinity and dissolved oxygen (DO) of the samples was analysed as described by Parsons et al. (1984). Nutrients from seawater (nitrite, nitrate, phosphate, and silicate) were analysed by auto-analyzer

(SKALAR SAN<sup>plus</sup> ANALYZER). Temperature and water column depth were measured by a multiparameter Sonde DS5X (Hydrolab). The near bottom seawater samples were collected for chlorophyll-*a* and analysed spectrofluorometrically (Turner Trilogy; Parsons et al. 1984). The sediment samples were collected in triplicate using a Van Veen grab (sampling area of 0.04 m<sup>2</sup>) from different depths and it ranged between 8.5 m to 16.6 m at different stations. Sediment samples were sieved using a 500 µm mesh sieve, initially preserved in 10% buffered formaldehyde in seawater containing rose bengal stain, and later transferred to 5% formalin (Castelli et al. 2004). Sediment samples were also collected for the analysis of sediment texture, organic carbon, chlorophyll-*a*, and pore water nutrients. Organic carbon (OC) and sediment texture in terms of percentage of sand (1.41-0.088 mm), silt (0.0625-0.002 mm), and clay (<0.002 mm)) were determined by standard titration method and pipette analysis method respectively (Buchanan 1984; Wakeel-el and Riley 1956). Organic carbon is expressed as percentage of sediment dry weight. Estimation of sediment chlorophyll-*a* was carried out using spectrophotometric analysis (Carrere et al. 2004). Macrobenthos biomass was measured as wet weight and expressed as mg. m<sup>-2</sup> following methods by Mason et al. (1985).

### 2.1 Identification of macrobenthos

The taxa were identified to the lowest possible identification level (genus, species or family).. The Marine Species Identification Portal (<http://species-identification.org>) and taxonomic keys of Day (1967); Fauchald (1977); Light 1978 for polychaetes, Mookherjee (1985) for molluscs, Lincoln (1979); Barnard (1935); Rabindranath (1972) for crustaceans were used. Scientific names and identification of other macrobenthic taxa were supported by World Register of Marine Species (WoRMs) website (<http://www.marinespecies.org>).

### 2.2 Data analyses

The data on the taxonomic abundance of macrobenthos was logarithmically transformed [ $\log(x+1)$ ] before carrying out the statistical analysis. The univariate measures of macrobenthic diversity (Shannon–Wiener diversity index ( $H'$ ), Margalef's species richness index ( $d$ ), and Pielou's evenness index ( $J'$ )) were calculated for every station (Clarke and Gorley 2001). Bray–Curtis similarity for diversity of macrobenthos was determined using PRIMER-v5 (Clarke and Gorley 2006). The percentage distribution of different sediment types obtained for each station was plotted in a ternary diagram (Shephard 1954). The stations were clustered depending upon the abundance of macrobenthic species in different regions within the port. . Principal Coordinates analysis (PCO) was performed show the relationship between environmental parameters and macrobenthos taxa on Bray -Curtis similarity of macrobenthic species and Euclidean distance of environmental variables using PRIMER

v6 (Anderson 2008 ; Anderson et al, 2008). The data on the abundance of macrobenthos, environmental parameters and the sediment parameters were tested for normality test using Kolmogorov-Smirnov test and homogeneity (Levene test) before performing the ANOVA. The tests indicated that the variations in the abundance of macrobenthos and sediment characteristics were not equal (Table 1) and the significance was  $p < 0.05$ . Two-way ANOVA was performed to evaluate the variation in the abundance and biomass of macrobenthic organisms, chlorophyll-*a*, organic carbon, sand, silt, and clay as the dependent variables with respect to stations and seasons which are the considered as independent variables. In addition, factors detected to be significant by ANOVA were further analysed by Tukey HSD test. The log-transformed data was used for the analysis of variance. The differences in the abundance of macrofauna during different stations and seasons were tested by PERMANOVA analysis using primer software in a 2-factor such as stations (St- 1 to 19) and seasons (PM I, PreM, MON and PM II). With 999 permutations of the residuals and a simplified model, main and pairwise PERMANOVAs were run. P-values obtained by DO Monte Carlo testing were derived as a result of the limited set of permutations. In order to investigate statistically significant variations in macrofaunal abundance, pair-wise comparisons of samples (different areas within the port) were conducted using the Tukey HSD multiple comparisons test.

### 2.3 Benthic health evaluation – AMBI and M-AMBI indices

Multivariate AZTI's (AZTI- Ciencia tecnología marina alimentaria, Spain) marine biotic index (M-AMBI) (Muxika et al., 2007) and AZTI's marine biotic index (AMBI) (Borja et al. 2000) were used to evaluate the health of the benthic habitat at the New Mangalore Port. The AMBI and M-AMBI values were measured by the AMBI software (Version 5.0). All macrobenthic species data were analysed based on the AMBI guidelines (Borja and Muxika, 2005), and five ecological groups (EG I: disturbance-sensitive species; EG II: disturbance- indifferent species; EG III: disturbance-tolerant species; EG IV: the second-order opportunistic species; EG V: the first-order opportunistic species) were assigned in accordance to the macrobenthic species list as per AZTI. The benthic habitat status were classified as high, good, moderate, poor and bad (European Commission, 2003). The optimum conditions considered for 'high' ecological status were M-AMBI values nearing one and AMBI values nearing zero, and for the 'bad' ecological status the values of M-AMBI nearing zero and AMBI values towards 6 and more.

### 3. Results

#### 3.1 Variations in the hydrological parameters at different stations during different seasons.

The seawater temperature at the surface and near-bottom during different seasons (PM I, PreM, MON and PM II) is illustrated in Table 2, and it indicated a seasonal variation. The difference in the average surface seawater temperature was 3.5 °C and at the bottom it was 4.4 °C during different seasons. The seawater salinity at surface ranged between 34.4±0.3 and 35.9±0.1 and at near-bottom it ranged between 34.7±0.2 and 36±0.4, and also varied with the seasons (Table 2). The dissolved oxygen concentration varied with the seasons and between surface and bottom water (Table 2). The concentration of DO in bottom water was low during all the seasons, and such a trend was more prominent during the monsoon season (average DO was 1.1±1.2 mg. L<sup>-1</sup>), indicating hypoxic conditions at most of the stations. During PM II, at OFW stations, the DO concentration of the near-bottom seawater was higher than the surface seawater (Table 2).

#### 3.2 Variations in the sediment texture at different stations during different seasons.

The sediment texture was dominated by sand followed by clay and silt (Fig. 2) and their composition varied with the seasons. A comparison between the PM I (2011) and PM II (2012) indicated that PM I had higher percentage of sand when compared to PM II (Fig. 2A-D) indicating an inter-annual variation in the sediment texture. Different areas within the port showed variation in the sediment texture with the seasons, as stations 14 and 17, had lower percentage of sand (47 and 62% respectively) during PM I, and during PM II the percentage of sand was 92 and 83% respectively at these stations. In PreM, stations 3, 9, and 18 were dominated by sand (nearly 80%), however, at other stations the sediment was dominated by clay and silt. During MON, the percentage of sand was nearly 45% followed by clay and silt (Fig. 2A-D). Sediment texture significantly varied between the stations and seasons (Two-way ANOVA; P<0.001) (Table 3A).

The ternary diagram depicted ten classes of mixed sediment: clay, silty-clay, clayey-silt, silt, sandy-silt, silty-sand, sand, clayey-sand, sandy-clay, and combination of sand-silt-clay respectively (Fig. 2E). During PM I, the sediment was dominated by combination of sand-silt-clay and clayey-silt. During PreM season sand-silt-clay content was dominant along with clayey-sand, sandy-clay, sandy-silt, clayey-silt, silty-clay and silty sediment at different stations (Fig. 2E). The combination of sand-silt-clay was dominant along with silty-clay and clayey-silt during MON. During PM II, the sediment was dominated by sand-silt-clay at most of the stations and a few stations sediment was characterized by silt and sandy-silt.

### *3.3 Variations in the organic carbon at different stations during different seasons.*

A significant variation in the organic carbon (OC) content (0.13 to 4.14%) was observed with stations and seasons (Fig. 2A-D) (Two-way ANOVA;  $P < 0.001$ ) (Table 3A). The OC was minimum during PreM (ranged from 1.43 to 2.77%) (Fig. 2B), and during PM I it ranged from 1.7 to 2.78% (Fig. 2A). The maximum variation in the OC was observed during MON (0.4 to 4.12%) and PM II (0.13 to 4.14%) (Fig. 2D).

### *3.4 Variations in the chlorophyll-a at different stations during different seasons.*

A significant variation in the sediment chlorophyll-*a* was observed with the seasons and stations (Two-way ANOVA;  $P < 0.001$ ) (Table 3A). The average chlorophyll-*a* of near-bottom seawater during PM I was  $1.3 \pm 1 \text{ mg.m}^{-3}$  and it was lower than sediment chlorophyll-*a* (Table 2). A wide variation in the near-bottom seawater and sediment chlorophyll-*a* was observed with the seasons. During PreM, the average sediment chlorophyll-*a* was  $7.7 \pm 2.5 \text{ mg. m}^{-2}$ , and the stations located in the vicinity of the channel showed higher chlorophyll-*a* in the near-bottom seawater. During monsoon the variation in the chlorophyll-*a* content in near-bottom seawater and sediment was maximum (Table 2). The stations located in the LCA and OFW had higher chlorophyll-*a* content in the near-bottom seawater when compared to stations located in the HCA (Table 2). During this season average sediment chlorophyll-*a* was  $8.2 \pm 3.9 \text{ mg. m}^{-2}$ , and higher concentration of chlorophyll-*a* was observed at stations located in HCA. During PM II, the average chlorophyll-*a* of near-bottom seawater was  $8.2 \pm 3.9 \text{ mg.m}^{-3}$  and in the sediment the chlorophyll-*a* was  $7.3 \pm 2.7 \text{ mg. m}^{-2}$  (Table 2).

### *3.5 Variations in the near-bottom seawater and sediment pore water nutrients at different stations during different seasons.*

Seasonal variation in the nutrient concentration in near-bottom seawater and sediment pore water was observed (Supplementary Fig. 1). During PM I, the concentration of ammonium and silicate from the sediment (pore water) showed large variation with respect to the stations. However, during other seasons the nutrient concentrations did not show variation in both near-bottom seawater and sediment (pore water), except ammonium.

### *3.6 Variations in the macrobenthic community structure at different stations during different seasons.*

61 macrobenthos taxa belonging to 8 phyla were recorded during the study, and the number of taxa varied with the seasons (9, 32, 21 and 47 during PM I, PreM, MON, and PM II respectively). The abundance of macrobenthos also varied significantly (Two-way ANOVA;  $P < 0.001$ , Table 3A) between the stations and seasons and different areas within the port (Fig. 3; Table 3B&C; Supplementary Table 1). The abundance was  $1063 \text{ no.m}^{-2}$ ,  $9440 \text{ no.m}^{-2}$ ,  $3835 \text{ no.m}^{-2}$ , and  $16139 \text{ no.m}^{-2}$



<sup>2</sup> during PM I, PreM, MON and PM II respectively (Fig. 3A-D; Table 3B; Supplementary Table 1). The biomass of macrobenthic organisms also varied significantly with the seasons (Two-way ANOVA;  $P < 0.001$ ) (Table 3). The macrobenthos taxa comprised of polychaetes, crustaceans, molluscs, oligochaetes, sipunculans and nemerteans. Polychaetes were the most abundant organism's during PM I, MON and PM II, however, during PreM season the amphipod, *Ampelisca* sp. was abundant (Supplementary Table 1). The difference in the abundance of polychaetes was high between PM I ( $1001 \text{ no.m}^{-2}$ ) and PM II ( $15277 \text{ no.m}^{-2}$ ). At st-18 (located in the channel) maximum abundance of macrobenthos was observed during all the seasons (Fig. 3 A-D; Supplementary Table 1).

During PM I, *Prionospio* sp., *Cossura* sp. and *Polydora* sp. were dominant and they contributed ~75% to the total macrobenthic community (Fig. 4; Supplementary Table 1 (A)). Macrobenthos belonging to the family *Cirratulidae* and Chaetognatha, *Serratosagitta* sp., ( $31 \text{ no.m}^{-2}$  in both LCA and HCA areas) also contributed to the total abundance (Supplementary Table 1 (A)). The *Prionospio* sp. was dominant in HCA (34%) and OFW (100%), however, in LCA, *Cossura* sp. was dominant (48% to the total abundance) followed by *Prionospio* sp., indicating *Prionospio* sp. was distributed in all three areas of the port. The abundance of macrobenthos was minimum in the OFW area in PM I season (Fig. 3; Supplementary Table 1 (A)). During PreM, the amphipod, *Ampelisca* sp., was dominant followed by *Magelona capensis*, Pelecypod, and *Cossura* sp. along with isopoda and *Tharyx filibranchia* (Supplementary Table 1 (B)). During this season  $7192 \text{ no. m}^{-2}$  macrobenthic organisms were reported from the HCA area, and *Ampelisca* sp. alone contributed 62% to the total macrobenthos, whereas, in LCA ( $1987 \text{ no.m}^{-2}$ ) and OFW ( $262 \text{ no.m}^{-2}$ ) the total abundance was comparatively low (Fig. 3B; Supplementary Table 1 (B)). In LCA, *Cossura* sp. and Pelecypod were dominant, whereas, in OFW, *Cossura* sp. was dominant followed by Gastropod. Pelecypods were reported in all the three areas of the port. In the MON season, the abundance of polychaetes was  $3835 \text{ no. m}^{-2}$ , and *Prionospio* sp. was dominant (47%) followed by *Cossura* sp., *Tharyx filibranchia*, and Pelecypod (Supplementary Table 1 (C)). During this season also the abundance of macrobenthos was high in the HCA ( $2772 \text{ no.m}^{-2}$ ) and *Prionospio* sp. was dominant (63% contribution) along with Pelecypods and polychaete, *Magelona capensis*. Whereas, the abundance was comparatively low in LCA ( $755 \text{ no.m}^{-2}$ ) and OFW ( $308 \text{ no.m}^{-2}$ ), and in both these areas *Cossura* sp. was dominant (Supplementary Table 1 (C)).

During PM II the abundance of macrobenthos was maximum ( $16139 \text{ no. m}^{-2}$ ) compared to all the seasons (Supplementary Table 1 (D); Fig. 3D). The polychaetes, *Mediomastus capensis* ( $6545 \text{ no. m}^{-2}$ ), *Magelona capensis* ( $2264 \text{ no. m}^{-2}$ ) and *Tharyx filibranchia* ( $1925 \text{ no.m}^{-2}$ ) were dominant along with *Prionospio pinnata* and *Cossura* sp. (Fig. 4; Supplementary Table 1 (D)). The abundance of macrobenthos was higher in HCA ( $9024 \text{ no.m}^{-2}$ ) compared to LCA ( $6191 \text{ no.m}^{-2}$ ) and OFW ( $924 \text{ no.m}^{-2}$ ).

<sup>2</sup>) area (Supplementary Table 1 (D)). *Mediomastus capensis* was dominant in the LCA and HCA and contributed 41% and 43% respectively to the total abundance, whereas in OFW area, *Tharyx filibranchia* was dominant (Supplementary Table 1 (D)). The macrobenthic diversity index values were maximum during PM II and PreM season (Table 4A). The Shannon–Weiner index ( $H'$ ) was also high during these seasons (4.9 and 4.5 during PM II and PreM respectively). Species diversity was maximum during PM II followed by PreM, PM I and MON (Table 4A) indicating significant seasonal variation in the community structure of macrobenthos. The maximum number of species were encountered in HCA during PreM and PM II season (Table 4B). As per AMBI and M-AMBI output, the best benthic quality (good–high status) was observed during PMI, in LCA and HCA and benthic quality was moderate in the OFW regions at stations 13 and 14, whereas in other stations of OFW macrobenthos were not reported during this season indicating poor benthic health in this region. Also during pre monsoon, though macrobenthos were recorded in four stations (except st-10) of OFW, and the indices indicated poor benthic status. In the monsoon season, in OFW only at st-14 macrobenthos were reported, and at stations 10-13, macrobenthos were not reported, indicating poor benthic status. During the entire study, at most of the stations macrobenthic organisms were not reported (Table 5A-D).

### 3.7 Analyses of Cluster to indicate the grouping of stations in different areas of the port based on the abundance of macrobenthos taxa.

Cluster analysis indicated stations clustering in different groups based on the abundance of macrobenthic organisms (Fig. 5A-D) in different regions of the port. During PM I, stations 15, 17, and 18 (located in HCA) indicated differences in the community structure between the stations (Fig. 5A). The st-15 had higher abundance of *Nereis* sp., whereas, at st-17, the higher abundance of *Ancistrosyllis* sp.. At st-18 higher abundance of *Cossura* sp. and lower abundance of *Magelona capensis* was observed. In this season, OFW stations (st-13 and 14) formed group I, and these stations had higher abundance of *Prionospio* sp. Group II had st-2 and st-8 located in LCA (Fig. 5A) and *Cossura* sp. was dominant while in group III stations (3, 4, 5 and 6) higher abundance of *Cossura* sp., *Prionospio* sp., *Cirratudiae*, *Tharyx filibranchia* was observed. During PreM, four clusters were observed and few stations did not group to form clusters (Fig. 5B). In the OFW, st-14 higher abundance of *Tharyx filibranchia*. The st-11 and st-12 from this area in group I (Fig. 5B) dominated by *Cossura* sp. followed by Gastropods (Fig. 5B). In HCA, every station had different dominant macrobenthic organism (*Mediomastus capensis* at st-9, *Cossura* sp. at st-17, and amphipod at st-18). In LCA, at st-2 had higher abundance of *Tharyx filibranchia*. Station 1 in LCA had higher abundance of Pelecypods. However, in group II, at st-3 and st-7 (Fig. 5B), Pelecypoda was dominant. Group II stations (st-4 and st-8)

dominated by *Cossura* sp. followed by Nemertea and Gastropods. During MON, st-18 (HCA) had higher abundance of *Prionospio* sp. followed by Pelecypoda, *Magelona capensis*, macrobenthos belonging to Class Insecta (Fig. 5C). In LCA, st-6 had higher abundance of *Tharyx filibranchia* (Fig. 5C). In group II stations (stations 2, 3, 4, 5, and 8), dominant organism was *Cossura* sp. (Fig. 5C). At st-14 in OFW, *Prionospio* sp. was abundant followed by *Polydora* sp. and *Tharyx filibranchia*. During PM II, st-4, 11 and 17 did not cluster with other stations from their respective areas, however, st-4 (LCA) grouped with st-17 (HCA) to form group I (Fig. 5D). St-4 and st-17 had higher abundance of *Mediomastus capensis* and *Magelona capensis*. During this season, among the non-clustered stations, at st-18 (HCA) had higher abundance of *Mediomastus capensis*. In group II, stations from LCA (stations 1, 2, 5, 6 and 8) were grouped, and polychaetes *Cossura* sp. and *Tharyx filibranchia* were dominant (Fig. 5D).

### 3.8 Relationship between environmental variables and macrobenthos community during different seasons.

The results of the PCO analyses indicated correlation between the abundance of different taxa of macrobenthos with near bottom seawater parameters, and sediment characteristics (Fig. 6 A-D). During PMI, the high concentration of bottom water ammonium and low silicate influenced abundance of *Nereis* sp. (Fig. 6A). The parameters such as high PW nitrate and clay was positively influenced *Serratosagitta* sp. The polychaetes, *Ancistrosyllis* sp. was influenced by environmental variables such as high bottom water nitrate, low sediment chlorophyll-*a*, high temperature and DO concentration. During PreM season, the abundance of Chaetognatha was positively influenced by the concentration of high clay and low PW nitrite. The dominant non-polychaete, *Ampelisca* sp. and moderate abundance of Isopoda was positively correlated to the concentration of high silt and OC percentage (Fig. 6B). The concentration of bottom water nitrate and phosphate positively influenced the *Mediomastus capensis*, *Glycera* sp., *Nephtys* sp., followed by non-polychaete Amphipod, *Ampithoe* sp. and the bottom water temperature negatively influenced them. The concentration of bottom water silicate influenced the abundance of *Prionospio* sp. During MON, PW silicate, low sediment chlorophyll-*a*, low bottom water temperature and bottom water ammonium influenced the abundance of *Sternaspis scutata*. At the same time, *Cossura* sp. was supported by the concentration of bottom water silicate, phosphate and percentage of sand. The abundance of non-polychaete Nemertea was influenced by low DO concentration, low salinity and percentage of clay (Fig. 6C). During PM II, the dominant polychaete was *Mediomastus capensis* which was supported by bottom water salinity and bottom water nitrite and ammonium and these parameters also influenced the abundance of *Phyllochaetopterus* sp. The non-polychaete Pelecypoda and Ophiuroidea generally preferred habitat with fine sediment and were

correlated with the percentage silt and clay (Fig. 6D). Almost at all the stations *Tharyx filibranchia* and *Prionospio pinnata* were abundant and this was positively correlated with the concentration of PW nitrate, high OC, bottom water nitrate and bottom water temperature, indicating their preference to diverse habitats (Fig. 6D).

### 3.9 Seasonal variation in benthic habitat quality assessed through AMBI and M-AMBI indices.

An interesting observation was the seasonal changes in the benthic ecological quality status within different regions of the port (Table 5 A-D).

#### **Post-monsoon I**

During PM I, the AMBI values varied between 3.9 to 4.5 and the M-AMBI values ranged between 0.402 to 0.999 (Table 5A). Majority of the stations, located in the LCA and HCA region indicated high, good and moderate benthic status indicating low anthropogenic impact, however, stations in the OFW region showed moderate benthic status indicating moderately disturbed benthic conditions. The AMBI value was minimum at St.18 (3.96), and higher number of macrobenthic species were of second-order opportunistic species (Group IV: 72.2%), however, at stations 2-14 the AMBI values was 4.5 and dominant macrobenthos were second-order opportunistic species (Group IV: 100%). The minimum M-AMBI value (0.402) at st- 2 and 8-14, and indicated least species number (one species) at all these stations. The high macrobenthos diversity index was observed at st-18, and at this station the species belonging to EG I and EG III were also recorded indicating the healthiest benthic status at this station (Table 4A). In this season, the macrobenthic organisms did not observe in some of the stations (st-1,7,10,11,12,16 and 19) indicating those stations were highly disturbed station compared to the other stations.

#### **Pre-monsoon**

During PreM, the AMBI values varied between 0.127 to 7 and the M-AMBI values ranged between 0.043 to 0.935 (Table 5B). The station located in the LCA region indicated poor to good benthic status, except, st-3 which indicated bad benthic status and 100% macrobenthic organisms were belonging to second-order opportunistic species (Group IV: 100%) (Table IVB). Whereas, all station located in the OFW region indicated poor benthic status and maximum percentage of organism belonging to EG IV, the second-order opportunistic species, and in the HCA region st-9 and st-15 which are the innermost stations in the HCA indicated poor and bad benthic status whereas other stations indicated good (st-17) and high (st-18) benthic status with majority of organism belonging to EG I (Table 5B). It can be noted that only st-18 was classified at undisturbed station. The disturbance classification status indicated that the benthic habitat during this season was extremely disturbed to undisturbed, and it

varied with the stations. The least number stations (st-10,16 and 19) macrobenthic organisms were absent during this season. However, st-10 macrobenthos was absent may be due to influence of the oil because it is oil berth.

### **Monsoon**

During MON season low AMBI and high M-AMBI values were reported at st-17 and st-18, with higher diversity and most of the macrobenthic species belonging to EG IV along with EG I, II and III, whereas at st-15 and st-19, the low diversity ( $H_0 = 0$ ) resulted in the poor status of the benthic habitat in the HCA region (Table 5C). In the LCA region the benthic status was moderate to poor and all the macrobenthos species belonged to EG IV. The st-14 (located in the OFW) indicated good status of benthic habitat with high diversity of macrobenthos. Some of the stations (st-1,7,9,10,11,12,13 and 16) did not have macrobenthic organisms during this season. The higher number of stations absence in macrobenthic organisms was found in OFW region indicating oil impact may have influenced during this season.

### **Post-monsoon II**

During this season most of the stations were moderately disturbed and the benthic habitat quality status varied from poor to high (Table 5D). During this season higher percentage of macrobenthos belonged to second-order opportunistic species (EG IV), followed by disturbance-indifferent species (EG II), disturbance-sensitive species (EG I), disturbance-tolerant species (EG III) and also the first-order opportunistic species (EG V). Macrobenthos belonging to EG I (disturbance sensitive species) were higher at stations located in the HCA (st-17, 18 and 19), whereas at stations located in the other regions of the port (LCA and OFW) higher percentage of macrobenthos belonged to EG IV. The disturbance classification status indicated that the benthic habitat is slightly to moderately disturbed (Table 5D). Some of the stations (st-3,7,12,13,15 and 16) in this season did not have macrobenthic organisms to be seen.

PERMANOVA analysis conducted for species abundance dataset, main effects were significant (Pseudo  $F = 4.2$ ,  $P = 0.004$ ) during PM I (Supplementary Table 2A). Further analysis using pair-wise tests indicated significant differences between LCA and HCA ( $P = 0.001$ ) during PM I. This would suggest that the numerically dominating species in the macrobenthic communities experienced substantial change between port area, and that these changes varied depending on the regions being sampled. Beside this, none of the areas differed along the gradient, so the macrobenthic community showed no significant change during PreM, MON and PM II (Supplementary Table 2 B-D).

#### 4. Discussion

The macrobenthic community of the New Mangalore Port exhibited significant spatio-temporal variation in their distribution. The scenario during different seasons with respect to macrobenthos abundance, biomass and community structure along with sediment characteristics and environmental parameters varied with the seasons, thus scenario during each season is discussed in the following sections, and at the end a comparative account of all the seasons is provided.

##### Scenario during Post-monsoon I (PM I)

During PM I, the total abundance of macrobenthos was lower when compared to other seasons. The polychaete, *Prionospio* sp. was the most abundant species during this season, specifically at st-15 where the habitat was hypoxic ( $0.9 \text{ mg.L}^{-1}$ ), indicating their tolerance to low oxygen conditions. The occurrence of this species in high abundance along with few other macrobenthos in low oxygen concentration ( $0.1 \text{ mg.L}^{-1}$ ) has also been reported by Levin et al. (2009). As per the AMBI indices, at st-15 the second order opportunity species (group IV with 71.4%) were dominant, and the benthic quality index indicated moderately disturbed benthic habitat (Table 5A). The dominant polychaetes, *Prionospio* sp. followed by *Cossura* sp. and *Polydora* sp. are deposit feeders and primarily feed on the sediment organic carbon. Studies have indicated that the higher organic carbon possibly caused by depletion in oxygen can lead to decline in the species diversity, abundance and biomass (Jørgensen 1977; Revsbech and Jørgensen 1986; Snelgrove and Butman 1994; Hyland et al. 2005; Musale and Desai 2011). The sediment organic carbon during this season was moderate ranging between 2-3% and the abundance of detritivores was higher which are able to feed and proliferate on moderate to high organic carbon. The detritivorous macrobenthic organisms have an ability to survive in sediments with moderate organic carbon (Ansari et al. 2014). The higher abundance of macrobenthos was in HCA followed by LCA and OFW indicated distinct spatial distribution in different areas within the port. The exchange of seawater between the port and the open sea is maximum in HCA, and this will result in healthy bottom water condition owing to higher exchange of seawater and could be attributed to higher abundance and biomass of macrobenthos in this area. The AMBI indices also showed high benthic quality status indicating healthy benthic habitat in HCA area. The deposit feeders, *Prionospio* sp. was dominant followed by *Polydora* sp. and *Cossura* sp. were dominant, and in HCA the percentage of clay was higher than LCA and OFW, and the average OC was 2.2% and such conditions are preferred by deposit feeding polychaetes indicating preference of *Prionospio* sp. to sandy-silt habitat with OC ranging between 2-3%. Musale et al. (2015) reported that in the Visakhapatnam port, *Prionospio* sp. was abundant in the outer port region which is a semi-polluted environment with moderate OC and high percentage of sand and these conditions were similar to that in the HCA.

*Prionospio* sp. are capable of constructing tubes in which they hide from adverse conditions and also protect them from the predators (Moritz 2012), and such a habit can be attributed to their higher abundance in HCA. It is apparent that the distribution of this species is dependent on its ability to thrive in anthropogenically less polluted environment and can be a good indicator of quality of benthic habitat quality. In LCA the moderate abundance of macrobenthic organisms was observed with five dominant macrobenthic forms and the polychaete, *Cossura* sp. contributed ~50% to the total abundance, however, the biomass was minimum. In this area, the sediment was dominated by silt, and had moderate organic carbon. Considering the properties of sediment dynamics, it has been suggested that high silt-clay fraction in the sediment contains more food particles (Sanders 1960; Dzulyński and Sanders 1962; Jayaraj et al. 2008; Musale et al. 2015) which are commonly comprised of decomposable organic constituents and this sustains higher benthic organisms. The benthic quality indices also indicated moderate to high status in most of the stations of LCA and the all the macrobenthos belonged to EG IV (100%) at all the stations, however, higher M-AMBI values were observed in HCA area indicating that exchange of seawater from the Arabian sea improves the quality of the benthic habitat, when compared to other regions.

#### **Scenario during Pre-monsoon (PreM)**

During PreM season the benthic quality index at most of the station was poor to moderate including bad at couple of stations indicating disturbed benthic habitat. The percentage macrobenthos belonging to EG I was maximum during this season. The abundance was dominated by the benthic amphipod, *Ampelisca* sp. (48% to the total), a surface deposit feeder which were only observed at st-18 (HCA) followed by polychaete, *Magelona capensis* and the Pelecypods (10%), and their abundance was higher in HCA (st-18) followed by LCA area. *Ampelisca* sp. is a tube building amphipod, and increase in tube building amphipods favor sedimentation of fine particles (Mills 1967) and this also stimulates the recruitment of other benthic species (Glemarec 1986; Dauvin and Bellan-Santini 1990). However, amphipod tubes may make it difficult for larvae of other benthic organisms to settle, recruit and burrow due to the reduced flow velocity amongst the tubes (Hunt 2005) and such a condition might have led to higher abundance of *Ampelisca* sp. (amphipod) during this season at st-18. Also, the presence of fine particles as indicated by higher percentage of silt and clay would facilitate tube building in amphipods. The occurrence of bivalve beds has a significant negative influence on the hydro- and sediment dynamics (Levinton 1991; Alferink 2016). It can be noted that the Pelecypods were observed in all areas of the port and their abundance was comparatively higher. The bivalves are often found dominant in terms of biomass and/or abundance in coastal soft-sediment (Kautsky and Evans 1987; Norkko et al. 2001; Giles et al. 2006; Norkko and Shumway 2011) and they provide suitable habitats

for other species (McGrorty et al. 1993). During this season the concentration of chlorophyll-*a* in the near bottom seawater was also high, which can serve as food for the bivalves.

The polychaete, *Magelona capensis* also contributed significantly to the total macrobenthic abundance during this season, and indicated its preference to silty-clay sediment and moderate OC, however, their inhabitation was restricted to LCA region and at st-18 in the HCA. This species is capable of living as benthic filter feeder and deposit feeder, indicating its preference to fine sand to muddy sediments with moderate organic carbon. Further, this dominant species (*Ampelisca* sp.) has been grouped in EG I (disturbance sensitive species). The amphipod, *Ampelisca* sp. has been termed as an opportunistic species, and reported in high abundance in hydrodynamically unstable areas of the Brazilian shelf (Santos and Pires-Vanin 2004) and behaves both as filter-feeding and deposit feeding organism (Paganelli et al. 2012). The HCA is physically more unstable compared to the other two areas (LCA and OFW) and at station 18 highly diverse groups of macrobenthos (polychaete and non-polychaetes) were reported during this season. It is possible that at this port the east-west split restricts the tidal flow to a relatively small amount of water moving swiftly through the entrance, creating hydrodynamically unstable environment which may be suitable for *Ampelisca* sp. It is also evidenced that this station has been classified as undisturbed station as per AMBI analysis. A method was developed by Grifoll et al. (2010) to assess the water degradation risk owing to port activities considering the characteristics and nature of pollutants along with the hydrography, and they suggested that regions with low replenishment are accompanied by higher water quality degradation risk. They also indicated that this is associated with tides and currents which depends on the geography and structure of the port on which the flow of water between the port and the open sea is depended which will determine the dilution of water within the port. Barnard (1970), reported that the sediments in the channel are highly diverse and strongly affect the benthic population. A study carried out at Visakhapatnam port also reported dominance of crustaceans in the outer harbour region which is less polluted when compared to inner harbor during PreM season in the silty habitats (Musale et al. 2015). The stress-tolerant macrobenthic organism, *Cossura* sp. (EG IV - Second order opportunistic species) was abundant in OFW area. This species might have survived in this area over a long duration and may have enhanced their growth in anthropogenically disturbed area and can be thus termed as an indicator species. All the stations in the OFW (11-14) showed poor benthic habitat status which may be responsible for occurrence of second order opportunistic species (*Cossura* sp.). In OFW, the silt and sediment chlorophyll-*a* were considerably higher with low OC and such conditions favor suspension feeders (pelecypods and gastropods). In general, higher abundance of suspension feeders may reduce the concentration of suspended particles which will enhance the growth of benthic algae (Wall et al. 2008),



which could be useful as food for the pelecypods and gastropods. High densities of bivalves were reported in stable marine salinities but their abundance reduced considerably with lowering of salinity (Pillay and Perissinotto 2008) and this can be attributed to occurrence of pelecypods in the high saline bottom water during PreM and decrease in their abundance during monsoon.

### **Scenario during Monsoon**

During monsoon, the abundance of macrobenthic organisms significantly varied within different areas of the port (Table 3AC; Two-way ANOVA;  $P < 0.001$ ). As observed in other seasons, during monsoon also higher abundance of macrobenthic organisms was reported in HCA, and during this season only st-18 indicated 'high' benthic habitat status and the abundance was lower in OFW and in this region of the port most of the stations showed poor to moderate state of benthic habitat. The M-AMBI index was 0.94 and the diversity was also high compared to other stations indicating the significance of flushing of seawater in maintaining a healthy benthic habitat which can sustain a wide variety of macrobenthic organisms. During MON the near-bottom seawater DO concentration indicated hypoxic conditions, and most of the organisms reported were deposit feeders and had an ability to inhabit polluted hypoxic conditions. It has been reported that the severity of hypoxia affects the benthic organisms (Diaz and Rosenberg 1995) and as hypoxia increases towards anoxia, sensitive species die-off decreasing the macrobenthic diversity of the affected area (Sturdivant 2011) which can be attributed to low abundance and diversity of macrobenthic organisms during MON season. The OC was maximum during the MON, and this season has been characterized by collapse and sinking of phytoplankton bloom (Sivadas et al. 2013) which contribute to higher OC in the sediment. Though OC is an important food source for most of the macrobenthic organisms, higher organic carbon causes decline in species diversity, abundance, and biomass, possibly by depleting the oxygen concentration (Jørgensen 1977; Revsbech and Jørgensen 1986; Snelgrove and Butman 1994; Hyland et al. 2005). Such conditions may not impact certain macrobenthic polychaetes such as *Prionospio* sp. and *Cossura* sp. which can survive hypoxic conditions (Levin et al. 2009) which are generally found in low numbers and are called opportunistic species. These species are grouped as Second order opportunistic species (EG IV) as indicated by AMBI analysis. The abundance of macrobenthic organisms was higher in HCA contributed by *Prionospio* sp., pelecypod and *Magelona capensis*. The *Prionospio* sp. has been considered as an indicator of organic enrichment in subtidal areas (Elias et al. 2005), and it was dominant at stations which had high chlorophyll-*a* content, moderate OC and high silt and clay. This species has been reported off the southwest coast of India in high abundance in high OC (3%) condition and has been termed as indicator of organically enriched sediment (Musale and Desai 2011). In HCA, the effect of major environmental parameters was moderate and OC was also low (1.9%) and such

conditions can benefit the opportunistic species (*Cossura* sp., *Prionospio* sp. *Polydora* sp.). Among these, *Cossura* sp. is a well-known opportunistic species (Sivadas et al. 2010) and this is the only species reported in all the areas of the port irrespective of bad, poor and moderate status of benthic habitat truly defining its opportunistic behavior.

### **Scenario during Post-monsoon II (PM II)**

During PM II, the diversity and abundance of macrobenthos was higher compared to other seasons, and specifically both these were higher in the HCA region of the port. The polychaetes, *Mediomastus capensis*, *Magelona capensis*, *Tharyx filibranchia*, *Prionospio pinnata* and *Cossura* sp. contributed nearly 60% to the total abundance, however, the first two dominant species were reported in only four stations within the port. Whereas, the other dominant species were distributed in all regions of the port indicating their tolerance to wide range of benthic habitat. According to the benthic evaluation indices, most of the stations had moderate levels of disturbance, which may have contributed to the higher richness and variety of macrobenthos, which were grouped in all of the ecological groups (EG I to EG V). About 50% of the sediment was silty-clay and OC was ~3% and such conditions contributed to their higher abundance and diversity. The *M. capensis* and the species belonging to Genus *Mediomastus* are subsurface deposit feeders and predominantly found in silty and clayey sediments (Stewart et al. 2002). The New Mangalore Port basin was developed on a sandy beach, however, the major portion of the channel is located on the silty bed (Dattatri and Kamath 1997; Parvathy et al. 2014). Even though the littoral drift from the adjacent beaches is negligible, considerable amount of siltation occurs in the approach channel and port basin during southwest monsoon season as a result of deposition of suspended sediment due to coastal and tidal currents, and nearly 80% siltation has been observed during monsoon when the wave activity is at its maximum (Parvathy et al. 2014). This structural pattern is ideal for most of the macrobenthic organisms. The *Mediomastus* sp., an opportunistic species capable of inhabiting turbulent environment with moderate organic carbon, and *Mediomastus capensis* was dominant at st-18 (station located at the port mouth) which has been considered as a disturbed location owing to its location in the HCA and the average OC was low (1.9%). Rivero et al. (2005) reported that, the mouth of the Mar del Plata Harbor (Argentina) is characterized by high environmental energy and *Mediomastus* sp. was dominant and these species can flourish in habitat with moderate amount of OC (Pearson and Rosenberg 1978). Basically, some surface deposit feeder's (*Tharyx filibranchia*) and sub-surface deposit feeder's (*Mediomastus* sp.) are not capable of thriving in low oxygen conditions, however they appeared to be tolerating stressful conditions (low DO concentrations) during MON. The abundance of *Mediomastus capensis* and *Tharyx filibranchia* during PM II indicate the return of normoxic conditions in the benthic environment

at New Mangalore port, which indicates towards the seasonal variation in the macrobenthic community.

The higher abundance in HCA contributed by *Mediomastus capensis*, *Magelona capensis* and *Sternaspis scutata*, which are subsurface deposit feeders and burrowers and their feeding activity usually occurs below the surface (Jumars et al. 2015). Surface deposit feeders and burrowers are commonly observed in high abundance when the sediment has fine grains and high organic matter (Mendez 2013) as observed in HCA. The low OC in HCA compared to LCA can be attributed to its utilization by the deposit feeders. Souza et al. (2013), emphasized that Magelonids are mainly non-selective surface deposit feeders, but some species exhibit alternate feeding mode (suspension feeding) (Fauchald and Jumars 1979), and such alteration in feeding strategies may support Magelonids to inhabit both muddy and sandy sediments (Rouse and Pleijel 2001).

It was observed that at oil berth (st-10) in OFW, the macrobenthic organisms were not reported or absent during all the seasons except during PM II. This station was dominated by EG IV (64.5%) group of species (Second order opportunistic species). It has been reported that in where the industrial growth focuses on the segment of oil refining, aluminum and petrochemical industries they generate effluents which contain hydrocarbons (Sridhar 2015), and these effluents can cause the issues of macrobenthic groupings which involve altering the community structure, greater numbers of species, and decrease in the normal biodiversity. This can be attributed to lower abundance of opportunistic polychaetes in OFW compared to LCA and HCA.

### **A comparative account of macrobenthos during different seasons**

As discussed in the previous sections, the community composition and abundance of macrobenthos varied with the seasons, and indicated a seasonal shift in the community structure and also the dominance of macrobenthic species within the port area. Such a shift in the community may be attributed to the significant variations in the sediment characteristics mainly the texture, organic carbon and the sediment chlorophyll-*a*. The higher bottom water chlorophyll-*a* will contribute to higher chlorophyll-*a* in the surficial sediments. Jenness and Duineveld (1985) indicated that tidal currents strongly affect the distribution of the algae (phytoplankton) at the sediment-water interface, including other suspended organic material and detritus which also follows similar pattern, and the algae are deposited on the sediment surface during periods of slack tidal currents, providing food source for epibenthic fauna and other surface deposit feeders. They also pointed out that this high level of chlorophyll-*a* was alternatively buried in the sediment to a depth of 5 cm and then re-suspended. The port construction also determines the current pattern which influences the water stagnation and

flushing in the regions of breakwater or landfills (Grancharova and Grancharov 2013). If wastewater enters port area with poor circulation or flushing, it can worsen the habitat owing to an increase in phytoplankton due to eutrophication (Champ 2003). This could be the reason for the seasonal variations in the total abundance of macrobenthos. *Amplexica* sp. predominated during pre-monsoon, followed by *Magelona capensis* and Pelecypoda, however, *Amplexica* sp. was not found over the subsequent seasons (Monsoon and Post-monsoon II). The elimination of *Amplexica* sp. during other seasons may also be explained by the competing interference of organisms that are typically dispersed over a wide area but are now gathered on the sediment surface due to their rising abundance. A relatively large area is required as a living space by the macrofauna indicate that the competition for space may be the biological factor in determining the temporal and spatial abundance pattern (Peterson, 1977; Dayton and Oliver, 1980), as observed in this study. Interactions between species that live in different spaces in the sediment are possible and probably do happen because surface area is ultimately limited. Animals may be limited by syphons from the surface, and vice versa. However, interference between organisms that have identical spatial requirements, or between animals that reside in the same sedimentary location, should be most severe. Our predictions concerning faunal replacements occurring on the sediment surface are based on this hypothesis, which seems to be confirmed by the absence of *Amplexica* sp. abundance in the succeeding seasons. Higher bottom water chlorophyll-*a* during PreM supported higher abundance of suspension feeders and also surface deposit feeders, and similar pattern was also observed during MON season. Several studies have indicated poor water quality due to anthropogenic activities in major ports of India and attributed this to the weak flushing (Sawant et al. 2007; Musale et al. 2015; Rajaneesh et al. 2015). The HCA area, which has been considered as hydrodynamically active had maximum abundance and diversity of macrobenthos and this was contributed by both deposit feeders and suspension feeders in PreM and MON. During PM II, the maximum abundance of macrobenthos was observed specifically in the HCA followed by LCA as result of high sediment chlorophyll-*a* and similar trend was also observed for the near-bottom seawater chlorophyll-*a* and all the dominant organisms reported were deposit feeders. Thus it can be stated that the influx of food from the water column into the sediment may be sustaining the higher abundance of benthic epifauna. The CCA also showed a positive correlation between the abundance of macrobenthic species and environmental variables and sediment texture, suggesting optimum or favorable conditions for the macrobenthic organisms to survive and proliferate during PM II. The low percentage of organic carbon can be attributed to its utilization by deposit feeders in this area owing to their higher abundance.

## 5. Conclusion

This is the first study to evaluate the implications of benthic ecological quality on the distribution of macrobenthic organisms in the New Mangalore Port, a tropical monsoon-influenced environment. Seasonal variation in the abundance and biomass of macrobenthic organisms was reported, along with significant shift in the community of macrobenthos which varied with different areas within the port indicating the impact of variations in the sediment characteristics, environmental variables and perturbations in the region on benthic community. The assessment of EcoQS (ecological quality status) indicated anthropogenically disturbed benthic habitat conditions. The variation in the local hydrodynamic conditions with the seasons influenced the abundance, distribution and community composition of macrobenthos, and this also played an important role to ameliorate the effect caused by anthropogenic pollution. The occurrence of pollution indicator species such as *Prionospio* sp., *Cossura* sp. and *Tharyx filibranchia* in the port area pointed that the area is anthropogenically disturbed. The dominance of amphipod, *Ampelisca* sp. in the channel connecting the port to the open sea can be attributed to its dual mode of feeding and preference to hydrodynamically unstable conditions and can be an indicator organism. The baseline information on the macrobenthos diversity generated in this study will be helpful for future research and to compare the potential impact on the port environment located in a tropical monsoon influenced region.

## Acknowledgment

We thank the Director, CSIR-National Institute of Oceanography, Goa for support and encouragement. This work was carried out as a part of the Ballast Water Management Programme, India, funded by the Directorate General of Shipping, Government of India. This is a NIO contribution #####.

**Funding:** This study was funded by the Directorate General of Shipping, Government of India, and award no. GAP2429.

## Authors Contribution:

AP: Formal analysis, Investigation, Methodology, Writing-original draft

DD: Conceptualization, Data curation, Supervision, Resources, Writing – review & editing

ACA: Conceptualization, Funding acquisition, Project administration, Review & editing

**Conflict of Interest:** The authors declare that they have no conflict of interest.

**Consent to Participate:** Not applicable

**Consent to Publish:** Not applicable

**Ethical approval:** No animal testing was performed during this study.

**Data Availability:** All data generated or analysed during this study are included in this manuscript and data is also provided as supplementary data file.

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### Captions for Tables

**Table 1.** Results of the normality test using Kolmogorov-Smirnov test and homogeneity (Levene test) for the data on abundance of macrobenthos, environmental parameters and the sediment parameters.

**Table 2.** Seasonal variation in environmental parameters in surface (S), bottom (B) water, and sediment (Se) at different sampling stations. PM I - Post monsoon I; PreM – Pre-monsoon; MON – Monsoon; and PM II- Post monsoon II.

**Table 3A-C.** Results of the Two-way ANOVA of seasonal variation in the abundance and biomass of macrobenthic organisms, and sediment parameters at different stations.

**Table 4A:** Number of species (*S*), Number of specimens (*N*), Margalef species richness (*d*), Pielou's evenness (*J'*), Shannon index (*H*), of microbenthic species during (A) Post-monsoon I (B) Pre-monsoon (C) Monsoon and (D) Post- monsoon II in New Mangalore Port.

**Table 4B:** Number of species (*S*), Number of specimens (*N*), Margalef species richness (*d*), Pielou's evenness (*J'*), Shannon index (*H*), of macrobenthic species during Post-monsoon I, Pre-monsoon, Monsoon, and Post-monsoon II in three regions (LCA, OFW and HCA) in New Mangalore Port.

**Table 5A.** Results of M-AMBI and AMBI indices during PMI at different sampling stations at New Mangalore Port. The colors indicate different regions within the port.

**Table 5B.** Results of M-AMBI and AMBI indices during PreM at different sampling stations at New Mangalore Port.

**Table 5C.** Results of M-AMBI and AMBI indices during MON at different sampling stations at New Mangalore Port.

**Table 5D.** Results of M-AMBI and AMBI indices during PM II at different sampling stations at New Mangalore Port.

**Supplementary Table I.** Variation the abundance of macrobenthic community at different stations during (A) Post-monsoon I (B) Pre-monsoon (C) Monsoon, and (D) Post-monsoon II. The stations have been highlighted as per the area within the port

**Supplementary Table II.** Results of the differences in the abundance of macrofauna during different stations and seasons (St- 1 to 19) tested by PERMANOVA analysis.

### Captions for Figures

**Fig. 1.** Map of the study area and sampling stations at New Mangalore Port. Low Circulation Area (LCA) stations - st-1 (Berth No.1), st-2 (Berth No.2), st-3 (Berth No.3), st-4 (Berth No.4), st-5 (Northern Return), st-6 (Berth No.5), st-7 (Berth No.6), st-8 (Berth No.7); Oil and Fertilizer Warf (OFW) stations – st-10 (Berth No.9), st-11 (Berth No.10), st-12 (Berth No.11), st-13 (Berth No.12), st-14 (Berth No.13); High Circulation Area (HCA) stations – st-9 (Berth No.8), st-15 (Berth No.14), st-16 (Berth No.15), st-17 (Channel Marker Buoy-1), st-18 (Channel Marker Buoy-2), st-19 (Turning Circle).

**Fig. 2.** Seasonal variation in the sediment texture and organic carbon (percentage) in New Mangalore port (A) post-monsoon I (B) pre-monsoon (C) monsoon (D) post-monsoon II (E) ternary triangle..

**Fig. 3.** Seasonal variation in the abundance (no. m<sup>-2</sup>) of macrobenthos at different stations in New Mangalore port (A) Post monsoon I (B) Pre monsoon (C) Monsoon and (D) Post monsoon II.

**Fig. 4.** Seasonal variation in the abundance (no. m<sup>-2</sup>) of polychaete taxa in New Mangalore port.

**Fig. 5.** Cluster analyses on the abundance of macrobenthos at different stations in different areas of the port during different seasons (A-D)

**Fig. 6.** PCO plots of different seasons (A) Post-monsoon I (B) Pre-monsoon (C) Monsoon (D) Post monsoon II at New Mangalore Port to indicate the relationship between the near bottom environmental parameters, sediment characteristics on macrobenthos taxa. (Serra: *Serratosagitta* sp., Cirra: Cirratulidae, TharF: *Tharyx filibranchia*, Coss: *Cossura* sp., MageC: *Magelona capensis*, Nere: *Nereis* sp., Anci: *Ancistrosyllis* sp., Prio: *Prionospio* sp., Poly: *Polydora* sp., Chae: Chaetognatha, Gast: Gastropoda, Pele: Pelecypoda, Neme: Nemertea, Sipu: Sipunculida, Amph: Ampharetidae, Meli: *Melinna* sp., Chae: Chaetopteridae, MediC: *Mediomastus capensis*, Onup: *Onuphinae* sp., Hesi: *Hesione* sp., Glyc: *Glycera* sp., Neph: *Nephtys* sp., AricC: *Aricidea capensis*, Eteo: *Eteone* sp., Sabe: Sabellidae, Syll: *Syllis* sp., Amph: Amphipoda, Ampe: *Ampelisca* sp., Amp: *Ampithoe* sp., Isop: *Isolda* sp., Ostr: Ostrocooda, Tana: Tanaidacea, Deca: Decapod, Ophi: Ophiuroidea, Fish: Fishlarvae, Pleo: Pleosporales, Anth: Anthozoa, Lumb: *Lumbrineris* sp., ProtoE: *Protodorvillia egena*, SterS: *Sternaspis scutata*, Olig: Oligochaete, Cuma: Cumacea, Pycn: Pycnogonida, Inse: Insecta, Hydr: Hydrozoa, Phyl: *Phyllochaetopterus* sp., CapiC: *Capitella capitata*, Hyal: *Hyalinoceia* sp., LumbM: *Lumbrineris metorana*, GlycP: *Glycera papillosa*, GlycL: *Glycera longipinnis*, MaldC: *Maldanella capensis*, NephL: *Nephtys lyrochaeta*, NereF: Family Nereidae, DendA: *Dendronereis arborifera*, NainL: *Naineris laevigata*, AricL: *Aricidae longobranchiata*, AnciP: *Ancistrosyllis parva*, Mega: *Megalomma* sp., Lygd: *Lygdamis gilchristi*, PrioPy: *Prionospio pygmaea*, PrioP: *Prionospio pinnata*, PrioC: *Prionospio cirrifera*, PrioS: *Prionospio steenstrupi*, PolyS: *Polydora socialis*, PhylM: *Phyllodoce malmgreni*, Inve: Invertebrate egg mass, Mala: Malacostraca.

**Supplementary Fig. 1.** Seasonal variation in the nutrient concentration of bottom water and sediment pore water at different sampling stations in New Mangalore port, (A) Post monsoon I (B) Pre monsoon (C) Monsoon and (D) Post monsoon II.



Table 1. The result of the normality tests, Kolmogorov-Smirnov and Shapiro-Wilk and homogeneity test, Levene test for the data on abundance of macrobenthos and sediment characteristics.

Test of Normality	Kolmogorov-Smirnov <sup>a</sup>			Shapiro-Wilk			Levene's Test			
	Statistic	df	Sig.	Statistic	df	Sig.	Levene Statistic	df1	df2	Sig.
Organic C	0.128	100	0.000	0.933	100	0.000	3.331	16	83	0.000
Sand	0.158	100	0.000	0.900	100	0.000	3.323	16	83	0.000
Silt	0.181	100	0.000	0.793	100	0.000	14.764	16	83	0.000
Clay	0.210	100	0.000	0.850	100	0.000	8.930	16	83	0.000
Abundance	0.090	100	0.043	0.942	100	0.000	2.933	16	83	0.001
Biomass	0.102	100	0.013	0.935	100	0.000	4.136	16	83	0.000
Sed. Chlorophyll a	0.163	100	0.000	0.777	100	0.000	6.118	16	83	0.000

a. Lilliefors Significance Correction

**Table 2:** Seasonal variation in temperature, salinity, dissolved oxygen, and chlorophyll-*a* in surface (S), near-bottom (B) seawater, and sediment (Sed.) at different sampling stations. PM I - Post monsoon I; PreM – Pre monsoon; MON – Monsoon; and PM II- Post monsoon II.

St. no.	Temperature (°C)								Salinity								Dissolved oxygen (mg. L <sup>-1</sup> )								Chlorophyll- <i>a</i> (seawater- mg.m <sup>-3</sup> ; Sed. - mg.m <sup>-2</sup> )								
	PM I		PreM		MON		PM II		PM I		PreM		MON		PM II		PM I		PreM		MON		PM II		PM I		PreM		Mon		PM II		
	S	B	S	B	S	B	S	B	S	B	S	B	S	B	S	B	S	B	S	B	S	B	S	B	S	B	S	B	S	B	S	B	S
1	29.5	29.6	28.9	28.1	26.6	24.9	29.0	29.1	35.9	36.0	35.8	36.4	34.0	34.7	34.7	34.8	4.6	4.3	4.3	5.1	3.8	0.8	5.1	3.8	1.11	9.4	8.9	6.5	26.3	9.6	7.4	7.9	
2	29.6	29.6	29.3	28.1	26.2	25.1	29.2	29.1	36.0	36.0	35.7	36.4	34.1	34.3	34.7	34.7	4.5	2.7	2.6	3.0	3.7	0.8	4.7	4.3	1.44	3.8	12.5	5.2	4.3	6.2	8.4	14.3	
3	29.7	29.6	29.5	28.3	26.3	24.8	29.3	29.2	35.8	36.0	35.6	36.0	34.8	34.9	34.7	34.3	4.3	3.8	4.2	3.4	5.9	0.8	3.4	3.6	1.19	7.2	2.12	8.3	6.8	5.8	-	-	
4	29.7	29.6	29.5	28.3	26.1	25.0	29.2	29.2	35.9	36.0	36.5	36.5	33.9	34.7	34.7	34.7	4.1	3.9	4.7	2.3	6.0	1.5	3.7	3.6	1.01	5.2	11.4	6.5	6.8	3.7	6.4	6.3	
5	29.6	29.6	29.6	28.4	26.5	25.0	29.2	29.2	35.9	35.9	36.4	35.7	34.1	34.4	34.7	34.7	3.5	3.5	3.3	3.1	6.0	1.2	3.8	3.1	1.00	3.1	9.2	4.2	3.4	6.4	7.9	5.5	
6	29.7	29.6	29.3	28.4	26.9	25.0	29.3	29.2	35.9	35.9	35.8	35.9	34.8	34.9	34.9	34.9	3.2	2.5	2.7	2.6	6.2	1.9	3.4	3.9	1.29	4.5	21.9	8.8	-	-	5.1	6.0	
7	29.9	29.6	29.1	28.0	25.4	25.0	29.3	29.2	35.8	35.8	35.6	35.9	34.8	34.0	34.8	34.8	4.1	3.8	4.6	2.3	1.7	0.5	4.0	3.6	-	-	-	5.2	26.3	5.3	6.0	7.5	
8	29.7	29.5	29.8	27.8	25.4	25.1	29.4	29.3	35.8	36.0	35.5	35.8	34.2	34.8	34.7	34.8	4.1	2.4	6.0	2.2	2.7	0.2	5.3	5.5	0.89	3.3	4.2	6.2	4.7	15.2	6.9	7.1	
9	29.7	29.5	29.0	28.0	25.6	25.0	29.1	29.0	35.8	35.5	35.7	36.2	34.6	34.7	34.8	34.8	4.6	2.1	4.6	3.0	3.5	0.4	5.3	4.0	0.83	7.2	1.3	5.4	9.4	13.8	6.1	9.0	
10	29.2	29.2	29.3	27.8	25.4	25.0	29.0	29.0	36.0	36.0	35.6	35.8	34.9	34.8	34.9	34.9	2.3	2.6	7.0	1.9	5.2	0.5	3.9	3.8	0.71	7.5	0.8	9.5	4.2	6.3	8.8	6.5	
11	29.4	29.3	29.4	27.8	25.6	24.9	29.4	29.1	36.1	36.0	35.7	36.3	34.4	34.9	34.8	34.8	2.1	1.2	3.0	2.5	3.4	0.4	5.6	6.2	-	-	1.1	11.3	6.9	11.3	8.4	6.1	
12	29.5	29.3	29.5	27.8	25.5	24.9	29.4	29.2	36.1	36.0	35.7	35.9	33.8	34.8	34.7	34.8	2.4	2.0	6.9	2.6	1.8	0.5	3.7	5.6	1.30	3.8	5.3	9.2	2.5	9.8	-	-	
13	29.5	29.3	30.0	28.0	25.8	25.0	29.4	29.2	36.1	36.0	35.7	35.8	34.2	34.8	34.8	34.9	2.1	2.0	7.7	2.2	2.5	0.6	4.8	3.4	4.47	6.2	30.1	12.7	0.8	0.2	21.9	5.6	
14	29.5	29.2	29.9	27.9	26.2	25.2	29.4	29.1	36.0	35.0	35.7	36.0	34.5	34.7	34.8	34.8	2.9	2.7	7.8	2.2	4.6	0.6	4.5	4.9	0.93	3.8	37.7	11.6	10.8	6.2	5.9	1.9	
15	29.7	29.5	29.9	27.6	26.6	25.1	29.0	29.0	35.8	36.0	35.7	35.7	34.4	34.8	34.8	34.8	3.4	0.9	6.6	2.2	4.3	0.6	4.7	4.6	0.34	3.5	33.1	8.7	11.2	5.1	-	-	
16	29.6	29.5	29.7	27.8	26.6	25.3	29.0	28.9	35.8	35.9	35.2	35.9	34.4	34.9	34.4	34.5	1.7	0.6	7.6	2.4	4.3	0.6	4.9	3.9	-	-	5.2	5.9	21.2	13.4	7.8	8.5	
17	29.6	29.5	29.6	27.6	26.3	25.3	-	-	35.8	35.8	34.5	34.8	34.8	34.9	34.4	34.6	5.0	2.3	4.2	1.2	3.7	4.0	3.7	4.0	0.47	4.9	27.1	7.2	11.4	10.3	7.8	5.6	
18	29.6	29.5	29.7	28.3	26.6	25.4	29.2	28.8	35.8	36.1	35.7	36.7	34.3	34.9	34.8	34.7	4.8	3.1	5.8	1.3	4.1	0.9	3.8	4.2	0.39	3.5	0.0	4.8	6.7	10.0	11.2	10.0	
19	29.8	29.5	29.3	27.8	25.8	25.3	29.6	28.9	35.7	36.0	35.7	35.8	34.2	35.0	34.8	34.9	-	-	4.2	0.6	4.2	4.6	0.6	4.6	2.93	4.5	17.3	8.7	26.3	9.6	5.8	8.5	
<b>AVG±</b>	29.6±	29.5±	29.5	28±0	26.1	25.1	29.2	29.1	35.9±	35.9±	35.7	36±0.	34.4	34.7	34.7	34.7±	3.5±1.	2.6±1	5.1±1.7	2.4±0.9	4.1±1.	1.1±1.	4.2±1.	4.2±0.	1.3±1	5.1±1.9	12.1±	7.7±	10.6	8.2±	8.2±3.9	7.3±	
<b>STD</b>	0.2	0.1	±0.3	.3	±0.5	±0.2	±0.2	±0.1	0.1	0.3	±0.4	4	±0.3	±0.2	±0.1	0.2	1	2	1	4	2	1	8	1	12.3	2.5	±8.5	3.9				2.7	

**Table 3A:** Results of the Two-way ANOVA of seasonal variation in the abundance and biomass of macrobenthic organisms, and sediment parameters at different stations.

Source	Dependent Variable	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Stations	Abundance	24.292	16	1.518	408.330	.001	0.992
	Biomass	19.296	16	1.206	521.332	.001	0.994
	Chlorophyll- <i>a</i>	2.391	16	0.149	1.482E3	.001	0.998
	Organic carbon	0.363	16	0.023	11.388	.001	0.785
	Sand	1.043	16	0.065	15.314	.001	0.831
	Silt	1.850	16	0.116	32.445	.001	0.912
	Clay	5.448	16	0.341	140.456	.001	0.978
Seasons	Abundance	11.127	3	3.709	997.490	.001	0.984
	Biomass	11.840	3	3.947	1.706E3	.001	0.990
	Chlorophyll- <i>a</i>	0.462	3	0.154	1.528E3	.001	0.989
	Organic carbon	0.609	3	0.203	101.883	.001	0.859
	Sand	0.604	3	0.201	47.310	.001	0.739
	Silt	0.184	3	0.061	17.182	.001	0.508
	Clay	0.307	3	0.102	42.170	.001	0.717
Stations * Seasons	Abundance	8.955	30	.299	80.285	.001	0.980
	Biomass	40.452	30	1.348	582.882	.001	0.997
	Chlorophyll- <i>a</i>	3.873	30	.129	1.280	.001	0.999
	Organic carbon	0.862	30	.029	14.430	.001	0.896
	Sand	2.513	30	.084	19.685	.001	0.922
	Silt	4.830	30	.161	45.183	.001	0.964
	Clay	6.845	30	.228	94.114	.001	0.983

**Table 3B.** Results of Two-way ANOVA to indicate the variation in the abundance of macrobenthos between stations and seasons.

Source	Sum of Squares	df	Mean Square	F	Sig.
Stations	24.292	16	1.518	408.330	0.000
Seasons	11.127	3	3.709	997.490	0.000
Stations * Seasons	8.955	30	.299	80.285	0.000
Error	.186	50	.004		
Total	495.402	100			
Corrected Total	45.327	99			

**Table 3C.** Results of the ANOVA to indicate the variation in the abundance of macrobenthos within different areas (LCA, HCA, OFW) of the New Mangalore port.

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	2.113	2	1.056	2.371	0.099
Within Groups	43.215	97	.446		
Total	45.327	99			

**Table 4A:** Number of species (*S*), Number of specimens (*N*), Margalef species richness (*d*), Pielou's evenness (*J'*), Shannon index (*H*), of microbenthic species during (A) Post-monsoon I (B) Pre-monsoon (C) Monsoon and (D) Post-monsoon II in New Mangalore Port.

**(A) PM I**

Stations	<i>S</i>	<i>N</i>	<i>d</i>	<i>J'</i>	<i>H'(log2)</i>
1	0	0	-	-	0
2	1	3	0	-	0
3	2	7	0.517	1	1
4	3	12	0.8031	0.9984	1.582
5	2	6	0.5454	0.9919	0.9919
6	4	13	1.156	0.9873	1.975
7	0	0	-	-	0
8	1	3	0	-	0
9	1	3	0	-	0
10	0	0	-	-	0
11	0	0	-	-	0
12	0	0	-	-	0
13	1	3	0	-	0
14	1	4	0	-	0
15	3	11	0.8407	0.9821	1.557
16	0	0	-	-	0
17	3	11	0.8316	0.9767	1.548
18	4	15	1.104	0.9873	1.975
19	0	0	-	-	0

**(B) PreM**

Stations	<i>S</i>	<i>N</i>	<i>d</i>	<i>J'</i>	<i>H'(log2)</i>
1	6	18	1.719	0.9909	2.561
2	4	12	1.198	0.9923	1.985
3	2	9	0.4589	0.9657	0.9657
4	5	18	1.396	0.984	2.285
5	7	26	1.851	0.9873	2.772
6	9	33	2.279	0.9878	3.131
7	1	3	0	-	0
8	7	24	1.876	0.9912	2.783
9	4	12	1.213	0.9967	1.993
10	0	0	-	-	0
11	3	8	0.9402	1	1.585
12	3	9	0.9078	0.9952	1.577
13	3	9	0.8905	0.989	1.567
14	4	12	1.213	0.9967	1.993
15	1	3	0	-	0
16	0	0	-	-	0
17	2	6	0.5454	0.9919	0.9919
18	24	95	5.051	0.9781	4.485
19	0	0	-	-	0

**(C) MON**

Stations	<i>S</i>	<i>N</i>	<i>d</i>	<i>J'</i>	<i>H'(log2)</i>
1	0	0	-	-	0
2	2	6	0.5454	0.9919	0.9919
3	2	7	0.5082	0.9654	0.9654
4	1	5	0	-	0
5	1	3	0	-	0
6	2	11	0.4185	0.9987	0.9987
7	0	0	-	-	0
8	1	3	0	-	0
9	0	0	-	-	0
10	0	0	-	-	0
11	0	0	-	-	0
12	0	0	-	-	0
13	1	5	0	-	0
14	5	18	1.385	0.9891	2.297
15	1	4	0	-	0
16	0	0	-	-	0
17	2	6	0.5808	1	1
18	16	62	3.631	0.9818	3.927
19	1	3	0	-	0

**(D) PM II**

Stations	<i>S</i>	<i>N</i>	<i>d</i>	<i>J'</i>	<i>H'(log2)</i>
1	5	19	1.369	0.9824	2.311
2	3	10	0.8644	0.9922	1.581
3	0	0	-	-	0
4	14	60	3.17	0.9751	3.786
5	5	16	1.452	0.9941	2.318
6	3	16	0.721	0.9757	1.577
7	0	0	-	-	0
8	3	9	0.9078	0.9952	1.583
9	8	30	2.063	0.9742	2.983
10	12	42	2.941	0.9888	3.575
11	6	18	1.735	0.9954	2.582
12	0	0	-	-	0
13	0	0	-	-	0
14	5	16	1.435	0.9787	2.31
15	0	0	-	-	0
16	0	0	-	-	0
17	10	38	2.475	0.98	3.307
18	31	121	6.253	0.9843	4.937
19	3	11	0.8467	0.9852	1.579

**Table 4B:** Number of species (*S*), Number of specimens (*N*), Margalef species richness (*d*), Pielou's evenness (*J'*), Shannon index (*H*), of macrobenthos species during Post-monsoon I, Pre-monsoon, Monsoon, and Post-monsoon II with respect different areas (LCA, OFW and HCA) within the New Mangalore Port.

Post-monsoon I						Pre-monsoon					Monsoon					Post-monsoon II				
LCA						LCA					LCA					LCA				
St.	<i>S</i>	<i>N</i>	<i>d</i>	<i>J'</i>	<i>H' (log2)</i>	<i>S</i>	<i>N</i>	<i>d</i>	<i>J'</i>	<i>H' (log2)</i>	<i>S</i>	<i>N</i>	<i>d</i>	<i>J'</i>	<i>H' (log2)</i>	<i>S</i>	<i>N</i>	<i>d</i>	<i>J'</i>	<i>H' (log2)</i>
1	0	0	-	-	0	6	18	1.719	0.991	2.561	0	0	-	-	0	5	19	1.369	0.982	2.281
2	1	3	0	0	0	4	12	1.198	0.992	1.985	2	6	0.545	0.992	0.9919	3	10	0.864	0.992	1.573
3	2	7	0.517	1	1	2	9	0.459	0.966	0.9657	2	7	0.508	0.965	0.9654	0	0	0	0	0
4	3	12	0.803	0.998	1.582	5	18	1.396	0.984	2.285	1	5	0	0	0	14	60	3.17	0.975	3.712
5	2	6	0.545	0.992	0.9919	7	26	1.851	0.987	2.772	1	3	0	0	0	5	16	1.452	0.994	2.308
6	4	13	1.156	0.987	1.975	9	33	2.279	0.988	3.131	2	11	0.418	0.999	0.9987	3	16	0.721	0.976	1.546
7	0	0	-	-	0	1	3	0	0	0	0	0	0	-	0	0	0	0	-	0
8	1	3	0	0	0	7	24	1.876	0.991	2.783	1	3	0	0	0	3	9	0.908	0.995	1.577
OFW						OFW					OFW					OFW				
10	0	0	-	-	0	0	0	-	-	0	0	0	-	-	0	12	42	2.941	0.988	3.545
11	0	0	-	-	0	3	8	0.940	1	1.585	0	0	-	-	0	6	18	1.735	0.995	2.573
12	0	0	-	-	0	3	9	0.908	0.995	1.577	0	0	-	-	0	0	0	0	-	0
13	1	3	0	0	0	3	9	0.890	0.989	1.567	1	5	0	0	0	0	0	0	-	0
14	1	4	0	0	0	4	12	1.213	0.997	1.993	5	18	1.38	0.989	2.297	5	16	1.435	0.979	2.273
HCA						HCA					HCA					HCA				
9	1	3	0	0	0	4	12	1.213	0.997	1.993	1	5	0	-	0	8	30	2.063	0.974	2.923
15	3	11	0.841	0.982	1.557	1	3	0	0	0	1	4	0	0	0	0	0	0	-	0
16	0	0	-	-	0	0	0	0	-	0	0	0	0	-	0	0	0	0	-	0
17	3	11	0.832	0.977	1.548	2	6	0.545	0.992	0.9919	2	6	0.581	1	1	10	38	2.475	0.98	3.256
18	4	15	1.104	0.987	1.975	23	90	4.89	0.977	4.42	16	62	3.631	0.9818	3.927	31	121	6.253	0.984	4.877
19	0	0	-	-	0	0	0	-	-	0	1	3	0	0	0	3	11	0.847	0.985	1.561

Table 5A. Results of M-AMBI and AMBI indices during PMI at different sampling stations at New Mangalore Port. The colors indicate different regions within the port ( ■ - LCA; ■ - HCA; ■ - OFW)

Stations	AMBI	M-AMBI	I(%)	II(%)	III(%)	IV(%)	V(%)	DC	NA (%)	Status	Diversity
2	4.5	0.40253	0	0	0	100	0	MD	0	Moderate	0
3	4.5	0.77481	0	0	0	100	0	MD	0	High	1.585
4	4.5	0.77481	0	0	0	100	0	MD	0	High	1.585
5	4.5	0.60485	0	0	0	100	0	MD	0	Good	0.9183
6	4.5	0.71873	0	0	0	100	0	MD	0	Good	1.1488
8	4.5	0.40253	0	0	0	100	0	MD	0	Moderate	0
9	4.5	0.40253	0	0	0	100	0	MD	0	Moderate	0
13	4.5	0.40253	0	0	0	100	0	MD	0	Moderate	0
14	4.5	0.40253	0	0	0	100	0	MD	0	Moderate	0
15	4.25	0.80135	0	0	28.6	71.4	0	MD	0	High	1.3788
17	4.4	0.74508	0	0	8.3	91.7	0	MD	0	Good	1.1887
18	3.9643	0.99908	9.1	0	18.2	72.7	0	MD	0	High	1.7899

Table 5B. Results of M-AMBI and AMBI indices during PreM at different sampling stations at New Mangalore Port.

Stations	AMBI	M-AMBI	I(%)	II(%)	III(%)	IV(%)	V(%)	DC	NA (%)	Status	Diversity
1	1.5	0.594	25	50	25	0	0	SD	33.3	Good	2.2516
2	3.6	0.406	16.7	16.7	16.7	50	0	MD	0	Moderate	1.7925
3	5.75	0.107	0	0	0	100	0	HD	87.5	Bad	0.54356
4	3.9286	0.384	10	0	10	80	0	MD	16.7	Poor	1.6432
5	4.0455	0.441	13.6	0	4.5	81.8	0	MD	15.4	Moderate	2.0647
6	3.6429	0.584	21.1	10.5	0	68.4	0	MD	26.9	Good	2.7203
7	4.625	0.308	50	0	0	50	0	MD	33.3	Poor	1.585
8	2.4625	0.603	29.4	5.9	17.6	47.1	0	SD	5.6	Good	2.5522
9	4.5	0.369	0	0	0	100	0	MD	60	Poor	1.9219
11	4.5	0.315	0	0	0	100	0	MD	66.7	Poor	1.585
12	4	0.334	0	0	33.3	66.7	0	MD	25	Poor	1.5
13	4.5	0.290	0	0	0	100	0	MD	40	Poor	1.371
14	4.5	0.369	0	0	0	100	0	MD	60	Poor	1.9219
15	7	0.043	0	0	0	0	0	ED	100	Bad	0
17	2.375	0.593	92.4	0	0	7.6	0	SD	16.4	Good	2.1797
18	0.12671	0.935	94.3	2.2	0.9	2.5	0	UD	10	High	2.1633

Table 5C. Results of M-AMBI and AMBI indices during MON at different sampling stations at New Mangalore Port.

Stations	AMBI	M-AMBI	I(%)	II(%)	III(%)	IV(%)	V(%)	DC	NA (%)	Status	Diversity
2	4	0.47658	0	0	33.3	66.7	0	MD	0	Moderate	0.9183
3	4.5	0.35116	0	0	0	100	0	MD	12.5	Poor	0.54356
4	4.5	0.26791	0	0	0	100	0	MD	0	Poor	0
5	4.5	0.26791	0	0	0	100	0	MD	0	Poor	0
6	4.5	0.39933	0	0	0	100	0	MD	0	Moderate	0.9629
8	4.5	0.39421	0	0	0	100	0	MD	0	Moderate	0.9183
14	4.275	0.63241	8.3	0	0	91.7	0	MD	0	Good	2.1258
15	4.5	0.26791	0	0	0	100	0	MD	0	Poor	0
17	3.4688	0.71514	12.3	0	1.4	86.3	0	MD	8.8	Good	1.3276
18	3.8243	0.94118	12.7	6.3	7.6	72.2	1.3	MD	11.2	High	2.3559
19	4.5	0.26791	0	0	0	100	0	MD	0	Poor	0

Table 5D. Results of M-AMBI and AMBI indices during PM II at different sampling stations at New Mangalore Port.

Stations	AMBI	M-AMBI	I(%)	II(%)	III(%)	IV(%)	V(%)	DC	NA (%)	Status	Diversity
1	4.125	0.46344	12.5	0	0	87.5	0	MD	0	Moderate	1.875
2	4.3782	0.45665	6	2.4	0	91.7	0	MD	0	Moderate	1.9973
4	3.963	0.59693	10.2	2.4	1.5	85.9	0	MD	2.4	Good	2.0648
5	4.2143	0.42031	0	7.7	0	92.3	0	MD	0	Moderate	1.553
6	4.5	0.2889	0	0	0	100	0	MD	0	Poor	0.7969
8	4.1667	0.36305	0	3.4	0	96.6	0	MD	0	Poor	1.0374
9	4.1176	0.52872	0	14.6	2.4	82.9	0	MD	2.4	Moderate	2.093
10	3.8571	0.6981	9.7	16.1	3.2	64.5	6.5	MD	0	Good	3.1486
11	4.3929	0.46021	0	10	0	80	10	MD	9.1	Moderate	2.0495
14	4	0.46326	3.7	3.7	0	92.6	0	MD	3.6	Moderate	1.6238
17	2.824	0.68724	23	4.6	1.1	69	2.3	SD	0	Good	1.9477
18	3.5004	0.8703	31	4.7	11.3	50.6	2.5	MD	1.2	High	2.6598
19	3	0.51615	33.3	0	0	66.7	0	SD	62.5	Moderate	1.2988

**Footnote:** Absence macrobenthos stations during PMI (st-1,7,10,11,12,16 and 19), PreM (st-10,16 and 19), MON (st-1,7,9,10,11,12,13 and 16) and PM II (st-3,7,12,13,15 and 16).

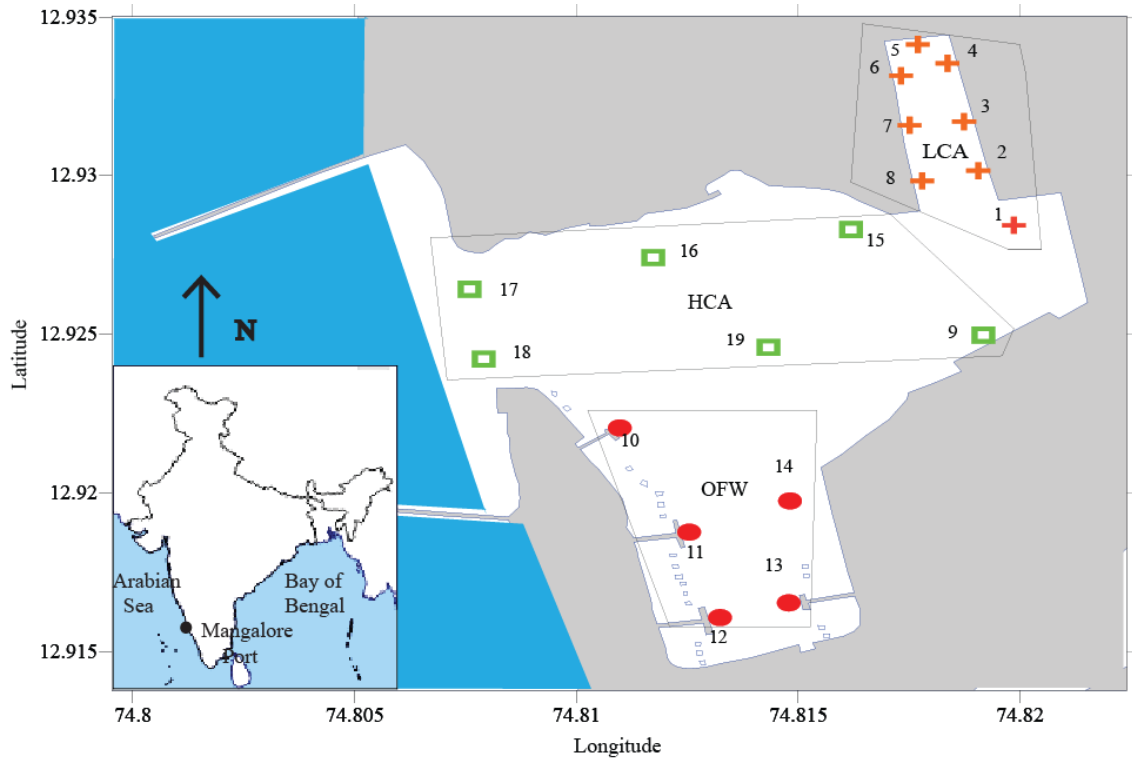


Fig. 1. Map of the study area and sampling stations at New Mangalore Port. Low Circulation Area (LCA) stations - st-1 (Berth No.1), st-2 (Berth No.2), st-3 (Berth No.3), st-4 (Berth No.4), st-5 (Northern Return), st-6 (Berth No.5), st-7 (Berth No.6), st-8 (Berth No.7); Oil and Fertilizer Warf (OFW) stations – st-10 (Berth No.9), st-11 (Berth No.10), st-12 (Berth No.11), st-13 (Berth No.12), st-14 (Berth No.13); High Circulation Area (HCA) stations – st-9 (Berth No.8), st-15 (Berth No.14), st-16 (Berth No.15), st-17 (Channel Marker Buoy-1), st-18 (Channel Marker Buoy-2), st-19 (Turning Circle).

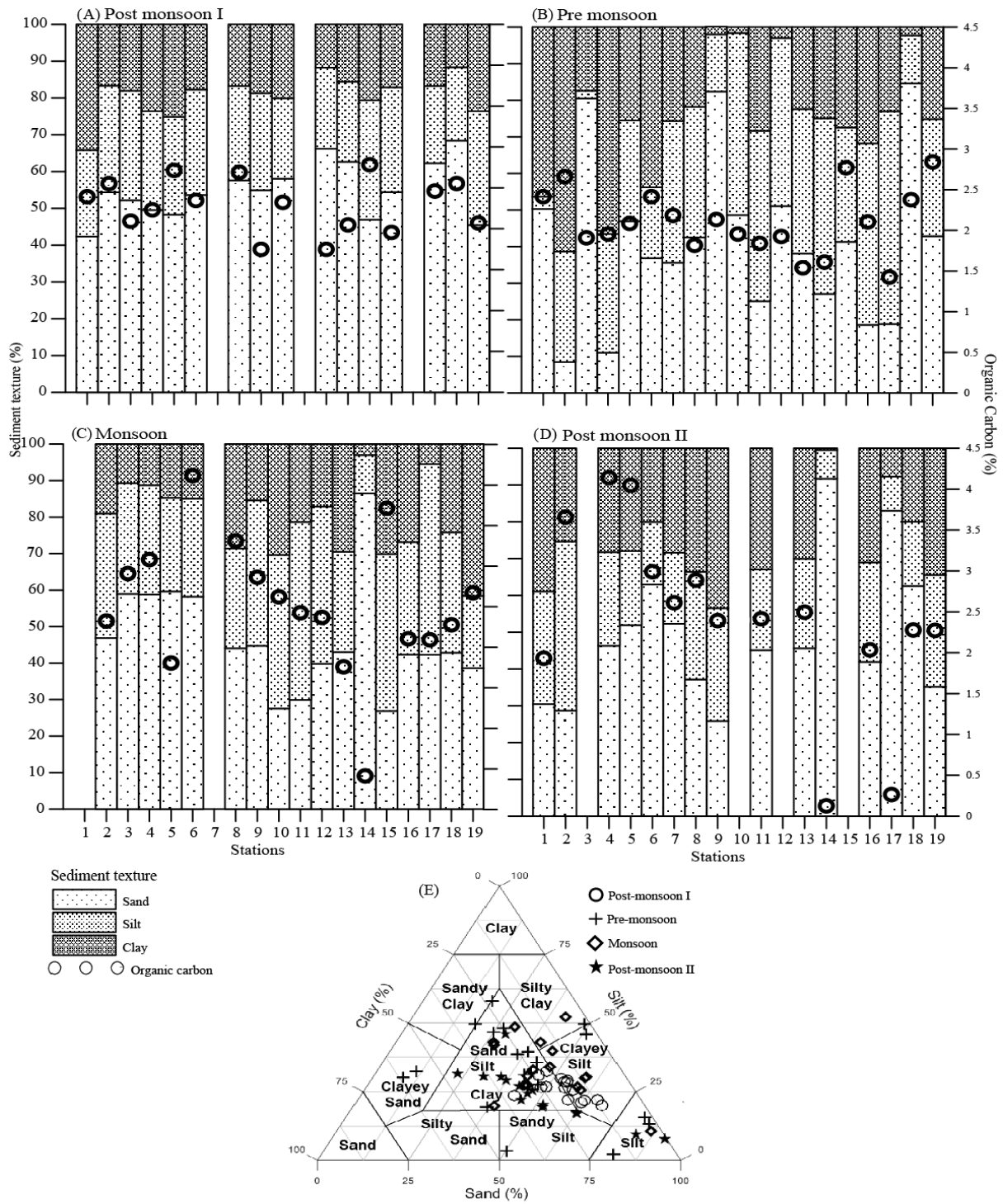


Fig. 2. Seasonal variation in the sediment texture and organic carbon (percentage) in New Mangalore port (A) post-monsoon I (B) pre-monsoon (C) monsoon (D) post-monsoon II (E) ternary triangle.



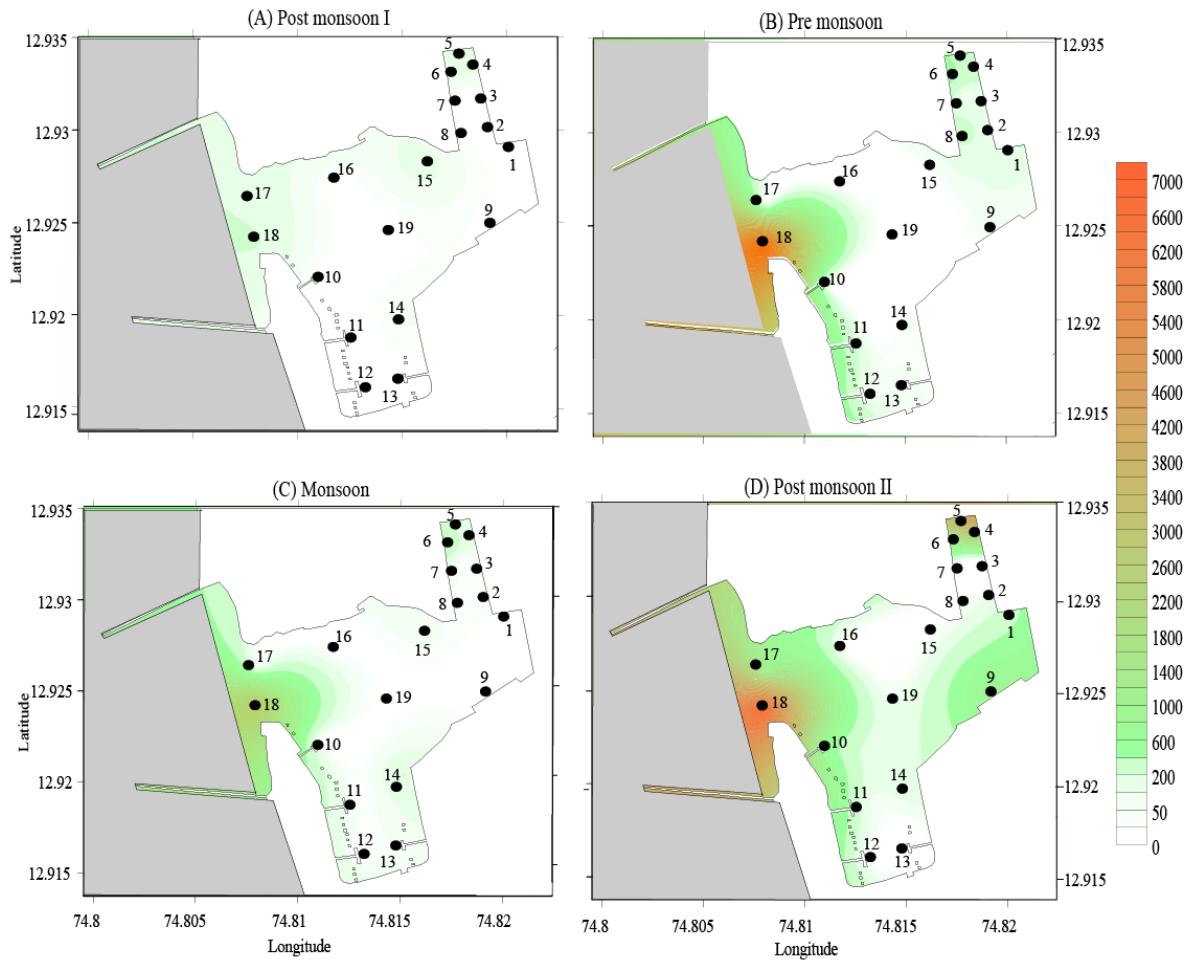


Fig. 3. Seasonal variation in the abundance of macrobenthos at different stations in New Mangalore port (A) Post monsoon I (B) Pre monsoon (C) Monsoon and (D) Post monsoon II.

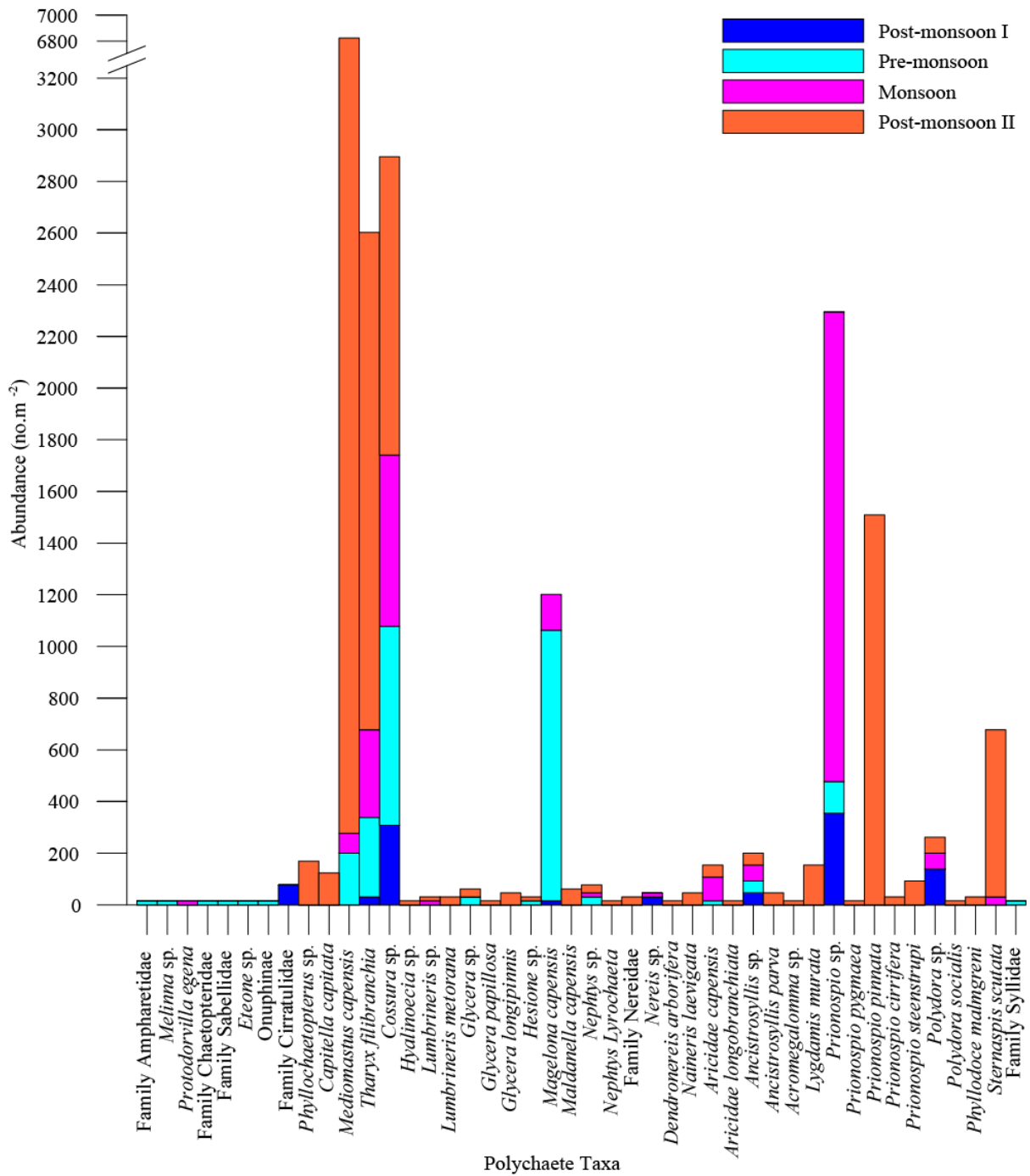


Fig. 4. Seasonal variation in the abundance (no. m<sup>-2</sup>) of polychaete taxa in New Mangalore port.

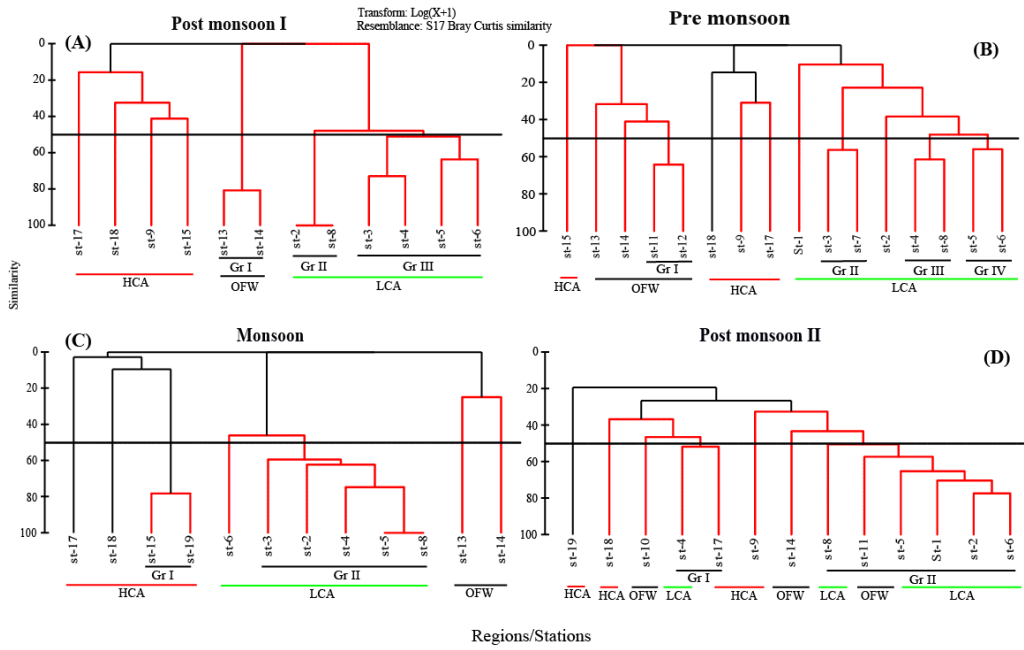


Fig. 5. Cluster analyses on the abundance of macrobenthos at different stations in different regions (HCA, OFW and LCA) of the port during different seasons (A-D).

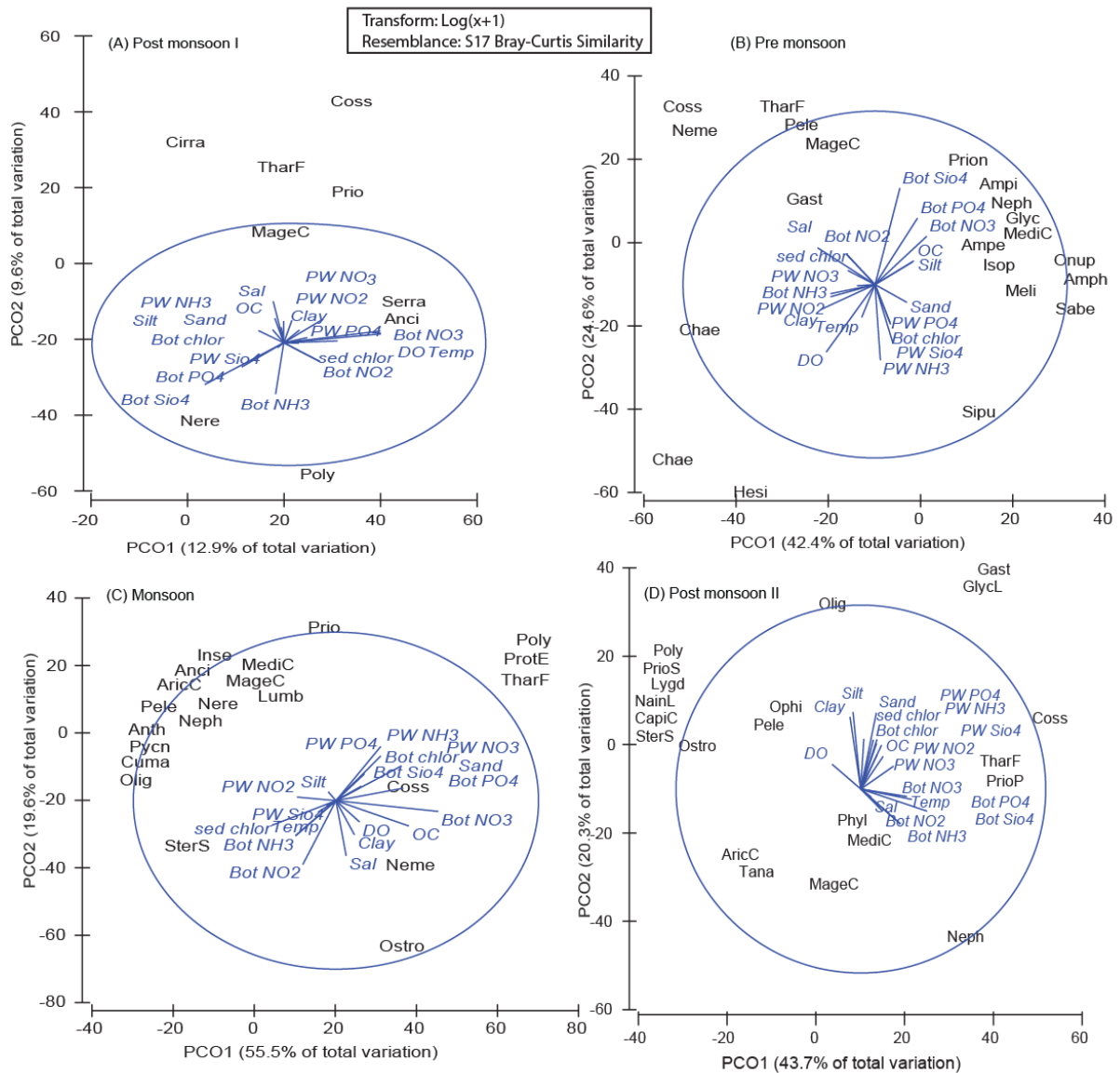


Figure 6. PCO plots of different seasons (A) Post-monsoon I (B) Pre-monsoon (C) Monsoon (D) Post monsoon II at New Mangalore Port to indicate the relationship between the near bottom environmental parameters, sediment characteristics on macrobenthos taxa.

(Serra: *Serratosagitta* sp., Cirra: Cirratulidae, TharF: *Tharyx filibranchia*, Coss: *Cossura* sp., MageC: *Magelona capensis*, Nere: *Nereis* sp., Ancic: *Ancistrosyllis* sp., Prio: *Prionospio* sp., Poly: *Polydora* sp., Chae: Chaetognatha, Gast: Gastropoda, Pele: Pelecypoda, Neme: Nemertea, Sipu: Sipunculida, Amph: Ampharetidae, Meli: *Melinna* sp., Chae: Chaetopteridae, MediC: *Mediomastus capensis*, Onup: *Onuphinae* sp., Hesi: *Hesione* sp., Glyc: *Glycera* sp., Neph: *Nephtys* sp., AricC: *Aricidea capensis*, Eteo: *Eteone* sp., Sabe: Sabellidae, Syll: *Syllis* sp., Amph: Amphipoda, Ampe: *Ampelisca* sp., Ampic: *Ampithoe* sp., Isop: *Isolda* sp., Ostr: Ostracoda, Tana: Tanaidacea, Deca: Decapod, Ophi: Ophiuroidea, Fish: Fishlarvae, Pleo: Pleosporales, Anth: Anthozoa, Lumb: *Lumbrineris* sp., ProtoE: *Protodorvilia egea*, SterS: *Sternaspis scutata*, Olig: Oligochaete, Cuma: Cumacea, Pycn: Pycnogonida, Inse: Insecta, Hydr: Hydrozoa, Phyl: *Phyllochaetopterus* sp., CapiC: *Capitella capitata*, Hyal: *Hyalinoecia* sp., LumbM: *Lumbrineris metorana*, GlycP: *Glycera papillosa*, GlycL: *Glycera longipinnis*, MaldC: *Maldanella capensis*, NephL: *Nephtys lyrochaeta*, NereF: Family Nereidae, DendA: *Dendronereis arborifera*, NainL: *Naineris laevigata*, AricL: *Aricidae longobranchiata*, AncicP: *Ancistrosyllis parva*, Mega: *Megalomma* sp., Lygd: *Lygdamis gilchristi*, PrioPy: *Prionospio pygmaea*, PrioP: *Prionospio pinnata*, PrioC: *Prionospio cirrifera*, PrioS: *Prionospio steenstrupi*, PolyS: *Polydora socialis*, PhylIM: *Phyllodoce malmgreni*, Inve: Invertebrate egg mass, Mala: Malacostraca.

**Supplementary Table 1.** Variation the abundance of macrobenthic community at different stations during (A) Post-monsoon I (B) Pre-monsoon (C) Monsoon, and (D) Post-monsoon II. The stations have been highlighted as per the regions within the port (LCA - ■ ; OFW - ■ ; HCA - □ )

(A) Post-monsoon I

Macrofauna	st-1	st-2	st-3	st-4	st-5	st-6	st-7	st-8	st-9	st-10	st-11	st-12	st-13	st-14	st-15	st-16	st-17	st-18	st-19	Total
<i>Prionospio</i> sp.			31	46		15			15				15	62	92			77		354
<i>Cossura</i> sp.		15	31	46	31	77		15										92		308
<i>Polydora</i> sp.															15		123			139
Family Cirratulidae				77																77
<i>Serratosagitta</i> sp.						31											31			62
<i>Ancistrosyllis</i> sp.																	15	31		46
<i>Tharyx filibranchia</i>					15	15														31
<i>Nereis</i> sp.															31					31
<i>Magelona capensis</i>																		15		15
Total (no.m <sup>2</sup> )		15	62	169	46	139		15	15				15	62	139			169	216	1063
Biomass (mg.m <sup>-2</sup> )		0.002	0.005	0.023	0.011	0.035		0.011	0.002				0.01	0.063	0.042			0.063	0.055	0.32

(B) Pre-monsoon

Macrofauna	st-1	st-2	st-3	st-4	st-5	st-6	st-7	st-8	st-9	st-10	st-11	st-12	st-13	st-14	st-15	st-16	st-17	st-18	st-19	Total
<i>Ampelisca</i> sp.																		4297		4297
<i>Magelona capensis</i>		15			62	31		92										847		1047
Pelecypoda			216	31	46	77	31		15		15			15		15		508		970
<i>Cossura</i> sp.			31	154	154	262		46			15	31	46			31				770
Isopoda																		539		539
<i>Tharyx filibranchia</i>		46		15	62	77		46						31				31		308
Gastropoda	77			15				15	15		15	15		15				123		293
<i>Mediomastus capensis</i>									31									169		200
<i>Ampithoe</i> sp.					31													154		185
<i>Prionospio</i> sp.					46			15				15						46		123
Nemertea		15		31				46				15								108

Order Pleosporales													0				92		92	
Fish Larvae						15							15	15	15				62	
Decapoda	15	15															31		62	
Sipunculida	15																31		46	
<i>Ancistrosyllis</i> sp.	15				15												15		46	
Chaetognatha	15				15														31	
<i>Glycera</i> sp.					15												15		31	
<i>Nephtys</i> sp.					15												15		31	
Family Ampharetidae																	15		15	
<i>Melinna</i> sp.																	15		15	
Family Chaetopteridae					15														15	
<i>Onuphinae</i> sp.																	15		15	
<i>Hesione</i> sp.	15																		15	
<i>Aricidae capensis</i>																	15		15	
<i>Eteone</i> sp.																	15		15	
Family Sabellidae																	15		15	
Family Syllidae								15											15	
Order Amphipoda								15											15	
Class Ostrocooda																	15		15	
Family Tanaidacea																	15		15	
Class Ophiuroidea																	15		15	
Total (no.m <sup>-2</sup> )	154	92	246	246	370	570	31	277	77				46	62	77	77	15	46	7054	9441
Biomass (mg.m <sup>-2</sup> )	0.14	0.05	35.2	2.03	0.48	1.01	0.81	0.33	1.43				0.08	0.23	0.002	1.181	0.36	0.015	4.95	48.25

(C) Monsoon

Macrofauna	st-1	st-2	st-3	st-4	st-5	st-6	st-7	st-8	st-9	st-10	st-11	st-12	st-13	st-14	st-15	st-16	st-17	st-18	st-19	Total
<i>Prionospio</i> sp.														77				1740		1817
<i>Cossura</i> sp.		31	77	108	15	185		15					92	15	77			31	15	662
<i>Tharyx filibranchia</i>						293								46						339
Pelecypoda																		246		246
<i>Magelona capensis</i>																		139		139
Class Insecta																		123		123
<i>Aricidae capensis</i>																		92		92
<i>Mediomastus capensis</i>																		77		77

<i>Ancistrosyllis</i> sp.																	62		62
<i>Polydora</i> sp.													62						62
<i>Sternaspis scutata</i>																15	15		31
Class Ostrocooda		15														15			31
Class Pycnogonida																		31	31
Oligochaete																		15	15
Class Anthozoa																		15	15
Nemertea	15																		15
<i>Lumbrineris</i> sp.																		15	15
<i>Protodorvillia egena</i>													15						15
<i>Nephtys</i> sp.																		15	15
<i>Nereis</i> sp.																		15	15
Class Cumacea																		15	15
Total (no.m <sup>-2</sup> )		46	92	108	15	477		15				92	216	77		31	2649	15	3835
Biomass (mg.m <sup>-2</sup> )		0.21	0.01	0.012	0.001	0.46		0.001				0.021	0.09	0.001		0.02	1.005	1.31	3.131

(D) Post-monsoon II

Macrofauna	st-1	st-2	st-3	st-4	st-5	st-6	st-7	st-8	st-9	st-10	st-11	st-12	st-13	st-14	st-15	st-16	st-17	st-18	st-19	Total
<i>Mediomastus capensis</i>				2526						108							570	3342		6545
<i>Magelona capensis</i>	15			385													246	1617		2264
<i>Tharyx filibranchia</i>	123	46		154	31	955			185	123	46			154			15	92		1925
<i>Prionospio pinnata</i>	108	15		370	15	46		15	616	154	15			15			92	46		1509
<i>Cossura</i> sp.	31	31		739	46	200		31		31	15								31	1155
<i>Sternaspis scutata</i>																		647		647
Class Ophiuroidea				46						31								123		200
Family Tanaidacea				31													31	108		169
<i>Phyllochaetopterus</i> sp.	15			15						46							31	62		169
<i>Lygdamis muratus</i>																		154		154
<i>Capitella capitata</i>																		123		123
Gastropoda											15			15					77	108
Pelecypoda				46					15									46		108
<i>Prionospio steenstrupi</i>																		92		92
<i>Maldanella capensis</i>										15								46		62
<i>Polydora</i> sp.																		62		62

Decapoda								31	15									46	
<i>Glycera longipinnis</i>								31	15									46	
<i>Naineris laevigata</i>																46		46	
<i>Aricidae capensis</i>															31	15		46	
<i>Ancistrosyllis</i> sp.			46															46	
<i>Ancistrosyllis parva</i>																46		46	
Oligochaete									15	15							15	46	
Class Ostrocooda			15							0							31	46	
<i>Lumbrineris metorana</i>								15		15								31	
<i>Glycera</i> sp.				15												15		31	
<i>Nephtys</i> sp.				15												15		31	
<i>Prionospio cirrifera</i>																31		31	
<i>Phyllodoce malmgreni</i>									15					15				31	
Family Nereidae								15									15	31	
Nemertea									15							15		31	
Sipunculida																15	15	31	
Class Hydrozoa													15					15	
Chaetognatha																	15	15	
<i>Hyalinoceia</i> sp.																	15	15	
<i>Lumbrineris</i> sp.																	15	15	
<i>Glycera papillosa</i>																	15	15	
<i>Hesione</i> sp.																	15	15	
<i>Nephtys Lyrochaeta</i>								15										15	
<i>Dendronereis arborifera</i>																	15	15	
<i>Aricidae longobranchiata</i>																	15	15	
<i>Megalomma</i> sp.			15															15	
<i>Prionospio pygmaea</i>							15											15	
<i>Polydora Socialis</i>			15															15	
Order Amphipoda																	15	15	
Invertebrate Egg mass																	15	15	
Class Malacostraca			15															15	
Total (no.m <sup>-2</sup> )	293	92	4420	123	1201		62	924	585	123						1063	6915	123	16139
Biomass (mg.m <sup>-2</sup> )	0.2	0.02	0.74	0.03	0.2		0.1	0.6	1.99	0.1						0.91	1.09	0.05	6.22



**Supplementary Table 2A.** Result of PERMANOVA using Bray-Curis similarity matrices to test differences in the abundance of macrobenthos and test for pairwise comparison between the areas on the abundance of macrobenthos during PMI.

						Pairwise comparison between areas		
Source	df	SS	MS	Pseudo-F	P(perm)	Regions	t	P(perm)
Regions	2	13848	6924.2	4.2759	<b>0.004</b>	LCA, OFW	2.8755	<b>0.035</b>
Res	9	14574	1619.4			LCA, HCA	2.1642	<b>0.005</b>
Total	11	28423				OFW, HCA	1.0995	<b>0.343</b>

**Supplementary Table 2B.** Result of PERMANOVA using Bray-Curis similarity matrices to test differences in the abundance of macrobenthos and test for pairwise comparison between the areas on the abundance of macrobenthos during PreM

						Pairwise comparison between areas		
Source	df	SS	MS	Pseudo-F	P(perm)	Regions	t	P(perm)
Regions	2	6400.6	3200.3	1.1252	<b>0.362</b>	LCA, OFW	1.2503	<b>0.213</b>
Res	13	36974	2844.2			LCA, HCA	1.0611	<b>0.326</b>
Total	15	43375				OFW, HCA	0.76235	<b>0.816</b>

**Supplementary Table 2C.** Result of PERMANOVA using Bray-Curis similarity matrices to test differences in the abundance of macrobenthos and test for pairwise comparison between the areas on the abundance of macrobenthos during MON

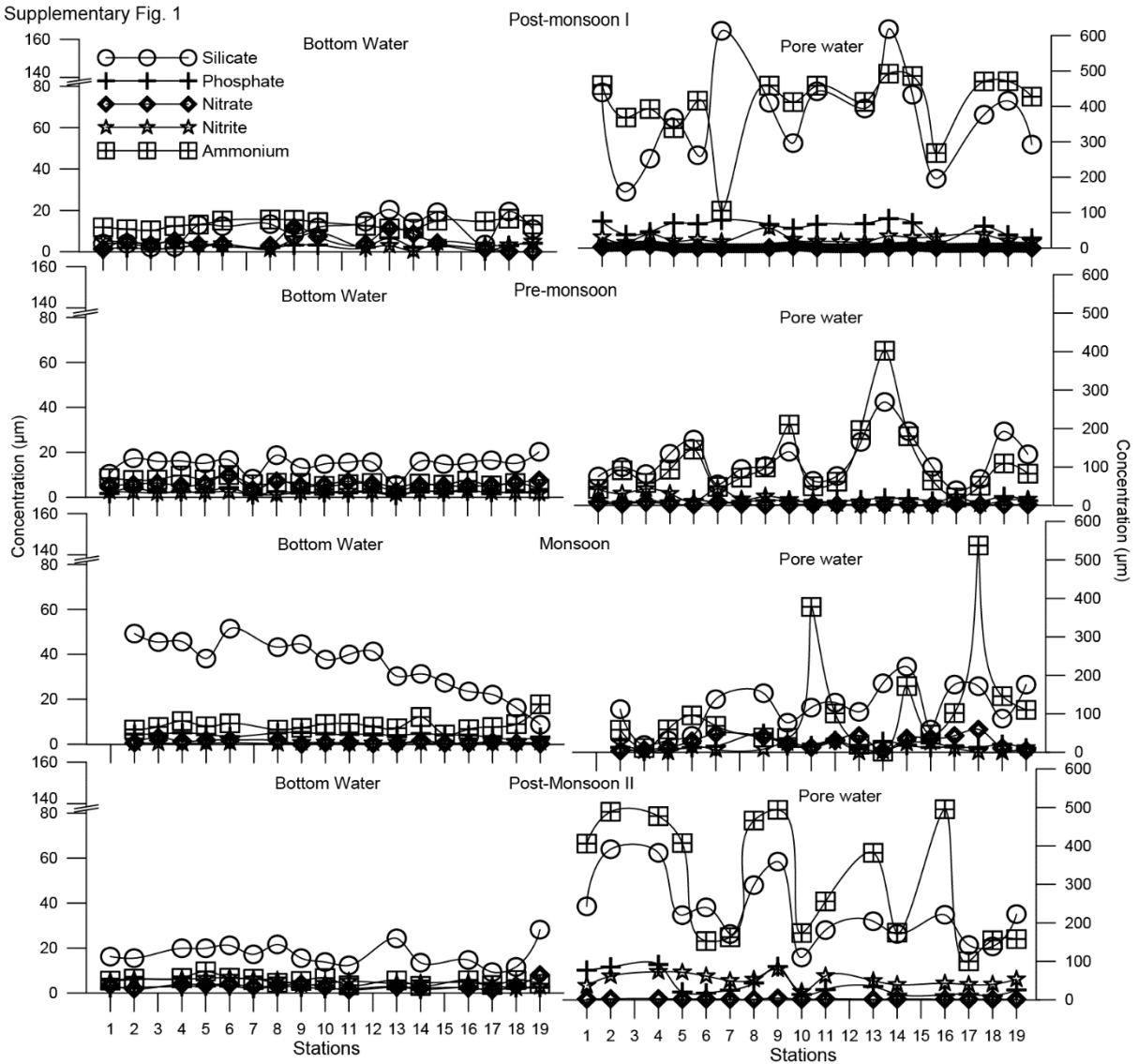
						Pairwise comparison between areas		
Source	df	SS	MS	Pseudo-F	P(perm)	Regions	t	P(perm)
Regions	2	4219.2	2109.6	1.0162	<b>0.387</b>	LCA, OFW	1.0061	<b>0.367</b>
Res	9	18684	2076			LCA, HCA	1.195	<b>0.224</b>
Total	11	22903				OFW, HCA	0.76379	<b>0.72</b>

**Supplementary Table 2D.** Result of PERMANOVA using Bray-Curis similarity matrices to test differences in the abundance of macrobenthos and test for pairwise comparison between the areas on the abundance of macrobenthos during PM II

						Pairwise comparison between areas		
Source	df	SS	MS	Pseudo-F	P(perm)	Regions	t	P(perm)
Regions	2	5825.8	2912.9	1.1087	<b>0.341</b>	LCA, OFW	1.1423	<b>0.263</b>
Res	11	28900	2627.3			LCA, HCA	1.0732	<b>0.334</b>
Total	13	34726				OFW, HCA	0.90933	<b>0.601</b>

**Footnote:** 999—permutations, SS sum of squares, MS mean square, Monte Carlo test, Pseudo-F = statistics, P (perm) = p-values calculated by permutations

Supplementary Fig. 1



Supplementary Fig. 1, Seasonal variation in the nutrient concentration of bottom water and sediment pore water at different sampling stations in New Mangalore Port, (A) Post monsoon I (B) Pre monsoon (C) Monsoon (D) Post monsoon II.