Distribution Pattern of Macrobenthic Organisms In A Tropical Monsoon Influenced Port, New Mangalore, India

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Abstract

Study was carried out to understand the impact of natural and anthropogenic impacts on the macrobenthic organisms at the New Mangalore port, influenced by south-west monsoon located along the south-west coast of India. Soft bottom macrobenthos are the group of highly diverse benthic invertebrates in the coastal regions. The spatio-temporal variation in their abundance and diversity was observed along with the variations in the water column and sediment characteristics. Among the 61 taxa of macrobenthos reported, 41 belonged to the polychaetes. The organic carbon levels of >2% supported higher abundance of deposit feeders. A correlation in the abundance of polychaetes and sediment characteristics along with dissolved oxygen and pore water nutrients was observed. A shift in the community of macrobenthic species in response to environmental parameters was observed with the change in the season. During post-monsoon I, *Prionospio* sp., was dominant , whereas during pre-monsoon the amphipod, *Ampelisca* sp. was dominant. The abundance of opportunistic polychaetes, *Prionospio* sp., *Cossura* sp., and *Tharyx filibranchia* varied with the seasons indicating a change in the habitat characteristics during different seasons. The occurrence and dominance of macrobenthic speceis was influenced by the physical processes mainly governed by the exchange of seawater between the port and the Arabian sea. The stations located in the high circulation area showed higher seasonal variation in the macrobenthic community indicating pivotal role of local hydrodynamics on macrobenthic organisms. The occurrence of opportunistic species inside the port demonstrate the role of anthropogenic stress in structuring the macrobenthic community.

Highlights

- Elucidated spatio-temporal variation in macrobenthic taxa at New Mangalore port.
- 61 taxa of macrobenthos were reported, and polychaetes dominated with 41 taxa.
- Shift in the dominance of macrobenthic species was observed with change in seasons.
- Occurrence of opportunistic species validated anthropogenic stress within the port.
- Perturbations due to local hydrodynamics in port influenced macrobenthic community.

Introduction

Soft-bottom macrobenthos is an important ecological group (Zhang et al. 2012), and play an 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). Some macrobenthic organisms inhabit beneath the sediment surface where they interact with the marine environment through feeding, digging and building tubes (Zhang et al. 2012; Thilagavathi et al. 2013). They are abundant, easy to collect and highly diverse with representatives from different phyla (Snelgrove 1998), colonizing different habitats and adopt different types of foods (Rhoads 1974; Fauchald and Jumars 1979; Weisberg 1997; Little, 2000; Sarker et al. 2016). Combined with their relatively sedentary lifestyles such as long life-cycles, macrobenthos respond to environmental changes via community-related variations including species composition, diversity, abundance, and biomass (Koperski, 2010; Rakocinski et al. 1997; Weliange et al. 2017). Thus, their abundance and distribution can be used as effective ecological 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). These disturbances are directly or indirectly responsible for the deterioration of marine benthic habitats (Mosbahi et al. 2019). In addition, benthic assemblages mostly respond predictably to pollution (Pearson and Rosenberg 1978; Hart and Fuller 1979) and, inhabit the stressful enivornment over several months to years (Sarker et al. 2016).

Ports, which are the sheltred water bodies 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.. Studies carried out in the some of the major ports of India indicated that the 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). Occurrence of pollutants in the harbor due to various anthropogenic, industrial, and maritime discharges renders the harbor environment hostile for native species and opens a window for the proliferation of opportunistic native and exotic species (Galil 2000). As harbor 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). 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 observe the distribution of macrobenthic community at the New Mangalore Port. The results will provide inputs in elucidating the distribution and occurrence of macrobenthic speceis in a disturbed environment such as the ports from a tropical monsoon influenced environment and such ecosystems in other parts of the world. Based on the physical characteristics mainly the circulation within the port and the port related activites, 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 chanractersits (2) to evaluate the variation in macrobenthic speceis diversity over a spatial and temporal scale, and (3) to elucidate the relationship between macrobenthic community and environmental variables and sediment charactrisitcs.

Materials And Methods

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).

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 semienclosed 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 New Mangalore 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 change. 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 2011). 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 et al. 2015). 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 in triplicate using a Niskin water sampler for measuring salinity and dissolved oxygen (DO) as described by Parsons et al. (1984). Nutrients from seawater (nitrite, nitrate, phosphate, and silicate) were analysed by auto-analyser (SKALAR SAN^{plus} 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^2) from an average depth of 12 m. 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. 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 (percentage of sand, silt, and clay) 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^{-2} following methods by Mason et al. (1984).

Identification of macrobenthos

The macrobenthic taxa were identified microscopically (Olympus BX53) up to genus, species or family level. 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).

Data analyses

The data on the abundance of macrobenthos were transformed to 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. In order to evaluate the relationships between environmental variables and macrobenthic speceis, canonical correspondence analysis (CCA) using CANOCO (version 4.5) was performed (ter Braak 1986; ter Braak and Smilauer 2002). For CCA analysis environmental data was transformed to Square-root and the species abundance were calculated using log (x + 1). CCA axes 1 and 2 were framed by 0.1 and − 0.1 in order to show equal distance of the length of the arrow. Seasonal variation in the total macrobenthic community is presented using SURFER-6 (developed by Golden Software Inc., USA). 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. 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.

Results

Hydrological parameters

The seawater temperature at the surface and near-bottom ranged from 29.2 to 29.9 (avg. 29.6 ± 0.2) °C and 29.2 to 29.6 (avg. 29.5 ± 0.1) °C, 28.9 to 30 (avg. 29.5 ± 0.3) °C and 27.6 to 28.4 (avg. 28 ± 0.3) °C, 25.4 to 26.9 (avg. 26.1 ± 0.5) °C and 24.8 to 25.4 (avg. 25.1 ± 0.2) °C, 29.0 to 29.6 (avg. 29.2 ± 0.2) °C and

28.8 to 29.3 (avg. 29.1 ± 0.1) ºC during PM I, PreM, MON and PM II respectively (Table I). The difference in the average surface seawater temperature was 3.5 ºC and at the bottom it was 4.4 ºC 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 it varied with the seasons (Table I). The dissolved oxygen concentration varied with the seasons and between surface and bottom water (Table I). 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^{-1}), 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 I).

Sediment texture

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 II).

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 at few stations sediment was characterized by silt and sandy-silt.

Organic carbon

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 II). 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).

Chlorophyll-a

A significant variation in the sediment chlorophyll-*a* was observed with the seasons and stations (Two-way ANOVA; $P < 0.001$) (Table II). The average chlorophyll-*a* of near-bottom seawater during PM I was 1.3 ± 1 mg.m^{-3} and it was lower then sediment chlorophyll-*a* (Table I). 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 ± 2.5 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 I). 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 I). During this season average sediment chlorophyll-*a* was 8.2 ± 3.9 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 ± 3.9 mg.m^{-3} and in the sediment the chlorophyll-*a* was 7.3 ± 2.7 mg. m^{-2} (Table I).

Nutrients

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-botttom seawater and sediment (pore water), except ammonium.

Macrobenthic community

A total of 61 macrobenthos taxa belonging to 8 phyla were recorded during the study. The number of taxa were 9, 32, 21 and 47 during PM I, PreM, MON, and PM II respectively. The abundance of macrobenthic organisms varied significantly between the stations and seasons (Fig. 3; Spplementray Table I). The abundance was 1063 no.m^{-2}, 9440 no.m^{-2}, 3835 no.m^{-2}, and 16139 no.m^{-2} during PM I, PreM, MON and PM II respectively (Fig. 3A-D; Supplementary Table I). The biomass of macrobenthic organisms also varied significantly with the seasons (Two-way ANOVA; $P < 0.001$) (Table II). The macrobenthic taxa comprised of polychaetes, crustaceans, molluscs, oligochaetes, sipunculans and nemerteans. Polychaetes were the most abundant organism's contributing to the total abundance during PM I, MON and PM II, however, during PreM season the amphipod, *Ampelisca* sp. was abundant (Supplementary Table I). A significant variation in the abundance of polychaetes was observed between PM I (1001 no.m^{-2}) and PM II (15277 no.m^{-2}). At st-18 (situated in the channel) maximum abundance of macrobenthic organisms was observed during all the seasons (Fgiure 3 A-D; Supplementary Table I).

During PM I, *Prionospio* sp., *Cossura* sp. and *Polydora* sp. dominated and they contributed ~ 75% to the total macrobenthic community (Fig. 4; Supplementary Table I (A)). Macrobenthic organisms belonging to the family *Cirratulidae* and the Chaetognatha, *Serratosagitta* sp., (31 no.m^{-2} in both LCA and HCA areas) also contributed to the total abundance (Supplementary Table I (A)). The *Prionospio* sp. was dominant in HCA (34%) and OFW (100%), however, in LCA, *Cossura* sp. was dominant (48% contribution) followed by *Prionospio* sp., and this points out that *Prionospio* sp. was distributed in all three areas of the port. Minimum abundance of macrobenthic organisms during this season was observed in the OFW area when compared to other two areas within the port (Fig. 3; Supplementary Table I (A)). During PreM, the amphipod, *Ampelisca* sp., was dominant followed by *Magelona capensis*, Pelecypod, and *Cossura* sp.

(Supplementary Table I (B)). The abundance of Isopod and *Tharyx filibranchia* was comparatively high during PreM. During this season 7192 no. m^{-2} macrobenthic organisms were reported from the HCA area, and *Ampelisca* sp. contributed 62% to the total macrobenthos, whereas, in LCA (1987 no.m^{-2}) and OFW (262 no.m^{-2}) the to total abundancewas comparatively low (Fig. 3B; Supplementary Table I (B)). In LCA, *Cossura* sp. and Pelecypod were dominant, whereas, in OFW, *Cossura* sp. was dominant followed by Gastropod, during this season, Pelecypods were reported in all three areas of the port. In the MON season, the abundance of polychaetes was 3835 no. m^{-2} MON, and *Prionospio* sp. was dominant (47%) followed by *Cossura* sp., *Tharyx filibranchia*, and Pelecypod (Supplementary Table I (C)). During this season also the abundance of macrobenthic organisms was high in the HCA (2772 no.m^{-2}) and *Prionospio* sp. was dominant (contributed 63%) along with Pelecypods and *Magelona capensis*. Whereas, the abundance was comparatively low in LCA (755 no.m^{-2}) and OWF (308 no.m^{-2}), and in both these areas *Cossura* sp. was dominant (Supplementary Table I (C)).

Overall, the maximum abundance of macrobenthic organisms (16139 no. m^{-2}) was observed during PM II (Supplementary Table I (D); Fig. 3D). The polychaetes, *Mediomastus capensis* (6545 no. m^{-2}), *Magelona capensis* (2264 no. m^{-2}) and *Tharyx filibranchia* (1925 no.m^{-2}) were dominant along with *Prionospio pinnata* and *Cossura* sp. (Fig. 4; Supplementary Table I (D)). The abundance of macrobenthic organisms was higher in HCA (9024 no.m^{-2}) compared to LCA (6191 no.m^{-2}) and OFW (924 no.m^{-2}) area (Supplementary Table I (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 I (D)). The macrobenthic diversity index values were maximum during PM II and PreM season (Table IIIA). 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 IIIA) 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 IIIB).

Relationship between environmental variables and macrobenthic community

Cluster analysis indicated stations clustering in different groups based on the abundance of macrobenthic organisms (Fig. 5A-D), and the CCA analysis indicated the correlation between the abundance of macrobenthos speceis and physico-chemical variables and sediment characteristics in different regions of the port during different seasons (Fig. 5E-H). The CCA axes 1 and 2 (Eigenvalues 1 and 0.799 during PM I; 1 and 0.707 during PreM; 1 and 1 during MON and 1 and 0.765 during PM II respectively) explained the relationship between the macrobenthos and physico-chemical variables and sediment characteristic (Fig. 5E-H) between different areas of the port (LCA, OFW, HCA). In general, during all the seasons, Eigenvalues were greater than 0.5 indicated relatively good dispersal of species along different axes (ter Braak 1986). The CCA derived correlation between macrobenthic abundance and physico-chemical and sediment characteristics was 54.9% during PM I, 38.6% during PreM, 45.9% during MON and 47.4% during PM II (Fig. 5E-H). 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 relatively low DO and supported higher abundance of *Nereis* sp., whereas, at st-17, the higher abundance of *Ancistrosyllis* sp. was influenced by higher percentage of sand and moderate silt, along with PW silicate, sediment OC, salinity and temperature (Fig. 5E). At st-18 higher abundance of *Cossura* sp. and lower abundance of *Magelona capensis* was weakly correlated to DO and silt. In this season, OFW stations (st-13 and 14) formed group I, and these stations had higher abundance of *Prionospio* sp., and were weakly correlated with ammonium and near-bottom seawater temperature. The group II, represented by st-2 and st-8 located in LCA area (Fig. 5A) were dominated by *Cossura* sp., and represented by high sediment OC, while in the same areas, group III stations (3, 4, 5 and 6) had higher abundance of *Cossura* sp., *Prionospio* sp., *Cirratudiae*, *Tharyx filibranchia* followed by *Serratosagitta* sp. In both these groups (II and III) macrobenthic abundance was correlated to the concentration of DO, temperature, PW phosphate, PW ammonium, OC and percentage of clay (Fig. 5E).

During PreM, four clusters were observed and few stations did not group to form clusters (Fig. 5B). In the OFW, st-14 had higher abundance of *Tharyx filibranchia* influenced by high percentage of sand and nutrients (PW ammonium and silicate). The st-11 and st-12 from this area in group I (Fig. 5B) dominated by *Cossura* sp. followed by Gastropods (Fig. 5F). In HCA, every station had different dominant macrobenthic organism (*Mediomastus capensis* at st-9, *Cossura* sp. at st-17, and amphipod at st-18), and their abundance was correlated with the near-botttom seawater temperature, salinity, nitrate and percentage of silt (Fig. 5F). In LCA, at st-2 high clay and OC content was directly correlated with *Tharyx filibranchia* which was dominant at this station. Station 1 in this area had higher abundance of Pelecypods and it was correlated with silt. However, in group II, at st-3 and st-7 (Fig. 5B) Pelecypoda was dominant and the percentage of silt was high (Fig. 5F). The st-4 and st-8 (group III) dominated by *Cossura* sp. followed by Nemertea and Gastropods, and they were influenced by sediment texture (Fig. 5F). In group IV (st-5 and st-6) *Cossura* sp. and *Magelona capensis* were dominant which was correlated to the concentration of nutrients and near-bottom seawater temperature and salinity (Fig. 5B&F).

During MON, at st-18 (HCA) *Prionospio* sp. was high in abundance followed by Pelecypoda, *Magelona capensis*, macrobenthos belonging to Class Insecta and their abundance was correlated to the sediment characteristics (texture and OC), PW phosphate and silicate (Fig. 5C&G). The st-15 and st-19 (group I) in the HCA (Fig. 5B) had moderate abundance of *Cossura* sp. indicating none of the environmental variables or sediment charactristics influenced their abundance during MON season (Fig. 5F). In LCA, st-6 did not cluster and the higher abundance of *Tharyx filibranchia* at this station was correlated to OC and near-bottom seawater DO (Fig. 5C&G), and these parameters also influencd the moderate abundance of Nemertea and Ostracoda. In group II stations (stations 2, 3, 4, 5, and 8), *Cossura* sp. was dominant and was supported by low percentage of silt, low near-bottom seawater salinity and higher PW ammonium at st-5 and high silt and clay content at st-2 (Fig. 5C&G). At st-14 in OFW area, low OC and higher percentage of sand inluenced higher abundance of *Prionospio* sp. followed by *Polydora* sp. and *Tharyx filibranchia*. The dominance of *Cossura* sp. at st-13 was favored by moderate concentration of silicate and ammonium along with near-bottom seawater temperature, salinity, and DO (Fig. 5C&G). The high Eigen value (1) of axes 1 and 2 indicates a high degree of correspondence between the abundance of macrofauna and physico-chemical variables and sediment characteristic during MON season. 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). In group I, st-4 and st-17 had higher abundance of *Mediomastus capensis* followed by *Magelona capensis* which were influenced by high sand, low clay and silt and OC content (Fig. 5H). During this season, among the non-clustered stations, at st-18 (HCA) higher abundance of *Mediomastus capensis* along with other macrobenthos was observed and and this was the most abundant macrobenthic species during this season. At this station higher abundance of Phyllodocidae was correlated with near-bottom seawater temperature and salinity. In group II, stations from LCA (stations 1, 2, 5, 6 and 8) were grouped, and *Cossura* sp. and *Tharyx filibranchia* were dominant and their dominance was correlated by higher percentage of sand and low OC (Fig. 5D&H), and their dominance at st-1 and st-2 was correlated to low OC and sand indicating that they can survive and grow in habitats with multiple sediment characteristics.

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 macrobenthic abundance, biomass and community structure along with sediment characteristics and environmental parameters is discussed in the following sections.

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, specifically at st-15 where the habitat was hypoxic (0.9 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 mg.L^{-1}) has also been reported by Levin et al. (2009). The *Prionospio* sp. is a deposit feeder and the dominance of sand during this season when compared to other seasons and this could be a reason for the higher abundance. The *Cossura* sp. and *Polydora* sp. which are also deposit feeders were dominant indicating they can primarily feed on the sediment organic carbon. Earlier studies have indicated that higher organic carbon possibly caused by depletion in oxygen cand lead to decline in the species diversity, abundance and biomass (Jorgensen 1977; Revsbech and Jorgensen 1986; Snelgrove and Butman 1994; Hyland et al. 2005; Musale and Desai 2011). The sediment organic carbon during this season was moderate and abundance of detritivores was higher which are able to feed and proliferate on moderate to high organic carbon. The detritivorous macroebnthic organaisms 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. It can be noted that the tidal exchange of seawater between the port and the open sea was maximum in HCA, and this will result in healty bottom water condition owing to higher exchange of seawater and could be atttibuted to higher abundance and biomass of macrobenthos in this area. The deposit feeders, *Prionospio* sp. 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. Musale et al. (2015) reported that in the Visakhapatnam port, *Prionospio* sp. was abundant in the outer harbor 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, indicating the preference of *Prionospio* sp. to sandy-silt habitat with OC ranging between 2–3%. *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 semi-polluted environment and it can be a good indicator of benthic habitat. 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; Dzulynski 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.

Scenario during Pre-monsoon (PreM)

During PreM season, the macrobenthic abundance was dominated by the benthic amphipod, *Ampelisca* sp. (48% to the total), a surface deposit feeder followed by the Pelecypods (10%), and the abundance of Pelecypods was higher in LCA. Increase in tube building amphipods favor sedimentation of fine particles (Mills 1967) and this also stimulates the recruitment of other benthic species (Glemarec et al. 1986; Dauvin and Bellan-Santini 1990). Moreover, amphipod tubes may make it difficult for bivalve larvae 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. 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 have a significant negative influence on the hydro- and sediment dynamics (Levinton 1991; Alferink 2016). It can be noted that the Pelecypods were abundant in LCA followed by OFW and HCA. 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). On the other hand, in LCA the sediment surface may have mats of amphipod tubes and polychaete worms (Family Cirratulidae), and this might reduce the water flow overlying the sediment and allow the Pelecypods to have stable conditions further allowing siphoning of water at the sediment-water interface. During this season the concentration of chlorophyll-*a* in the near bottom sweater 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. 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. 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). In the New Mangalore Port, 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 and also during other seasons. 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. A method was developed by Grifoll et al. (2010) to assess the water degradation risk owing to port activities considering the characteristics and mature 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. was abundant in OFW followed by gastropods and pelecypods (12%). The *Cossura* sp. might have survived in this area over a long duration and might have enhanced their growth in anthropogenically disturbed area and can be termed as an indicator species. 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 (Two-way ANOVA; $P < 0.001$). As observed in other seasons, during monsoon also higher abundance of macrobenthic organisms was reported in HCA and lower in OFW. The near-bottom seawater DO concentration indicated hypoxic concicitions, and most of the organisms reported were deposit feeders which 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 the severity of 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. The OC was maximum during the monsoon, 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). In general, all stations in the OFW had low DO concentration and this region had minimum abundance of benthic organisms during monsoon. Such a condition may not impact certain macrobenthic polychaete species such as *Prionospio* sp. and *Cossura* sp. which can surive hypoxic conditions (Levin et al. 2009) which are generally found in low numbers and are called opportunistic species. The abundance of macrobenthic orgnaims 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%) condtion 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%) benefitting the opportunistic species (*Cossura* sp., *Prionospio* sp. *Polydora* sp.). Among these, *Cossura* sp. is a well-known opportunistic species (Sivadas et al. 2010) and also the most dominant species in OFW area.

Scenario during Post-monsoon II (PM II)

During PM II the abundance of macrobenthos was maximum and *Mediomastus capensis*, *Tharyx filibranchia* and *Cossura* sp. contributed nearly 60% to the total abundance, while about 50% of the sediment was silty-clay and OC was ~ 3% and such conditions contributed to their higher abundance. The *M. capensis*, and the species belonging to Genus Mediomastus, which subsurface deposit feeders are predominantly found in silty and clayey sediments (Stewar 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 et al. 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. In this season, *Mediomastus capensis* was dominant at st-18 (station located at the port mouth) which has been considered as a disturbing 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 feeders (*Tharyx filibranchia*) and sub-surface deposit feeder (*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 this port, which indicates to the seasonal variation in the macrobenthic community. The dominant species were *Mediomastus capensis*, *Tharyx filibranchia* and *Cossura* sp., which are deposit feeders capable of feeding on freshly settled organic carbon and the subsurface deposit feeders (SSDF) capable of feeding on aged organic matter in the sediment.

The maximum abundance in HCA was 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 (station 10) in OFW, the macrobenthic organisms were not reported or absent during all the seasons except during PM II. It has been reported that in Bahrain 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 shift in the community structure and also the dominance of macrobenthic species within the port area. Such a shift in the community can be attributed to the significant variations in the sediment characteristics mainly the texture, organic carbon and the sedeiment chlorophyll-*a*. The higher bottom water column 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 cms and then resuspended. 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 waste water is flown into the region where the circulation or flushing is low in the port, it can deteriorate the habitat owing to increase in phytoplankton as a resultant of eutrophication (Champ 2003). This points out the importance of water column chlorophyll-*a* in structuring benthic diversity and community structure. 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 of macrobenthic organisms during PreM and MON season contributed by deposit feeders and suspension feeders. During PM II, maximum abundance of macrobenthos was observed specifically in the HCA followed by LCA. During this season the sediment chlorophyll-*a* was maximum in the HCA followed by LCA 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 correlation between the abundance of macrobenthic speceis 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.

Conclusion

This is the first report on the distribution of macrobenthic organismsin the New Mangalore Port, a tropical monsoon-influenced environment. Seasonal variation in the abundance and biomass of macrobenthic organisms was observed, and it varied with different areas within the port owing to the variation in the sediment characteristics, environmental variables and perturbations in the region. The variation in the hydrodynamics conditions with the seasons had significant impact on the occurrence and distribution of macrobenthic organisms. 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 port to the open sea can be attributed to its dual mode of feeding and preference to hydrodynamically unstable conditions. The baseline information on the benthic biodiversity generated in this study will be helpful for future research and to compare the potential impact at the port environment.

Declarations

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Authors Contribution:

AP: Formal analysis, Investigation, Methodology

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

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

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Tables

Table I: 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.

	Temperature (°C)								**Salinity**								**Dissolved oxyger**		
	PM I		**PreM**		**MON**		**PM II**		**PM I**		**PreM**		**MON**		**PM II**		**PM I**		**Pre**
St. no.	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
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	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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
AVG ± STD	29.6 ± 0.2	29.5 ± 0.1	29.5 ± 0.3	28 ± 0.3	26.1 ± 0.5	25.1 ± 0.2	29.2 ± 0.2	29.1 ± 0.1	35.9 ± 0.1	35.9 ± 0.3	35.7 ± 0.4	36 ± 0.4	34.4 ± 0.3	34.7 ± 0.2	34.7 ± 0.1	34.7 ± 0.2	3.5 ± 1.1	2.6 ± 1	5.1 ± 1.7

Table II: 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	Type III 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-a	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-a	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

Table IIIA: 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	S	N	d	J'	H'(log2)
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	*S*	*N*	*d*	*J'*	*H'(log2)*
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	**S**	**N**	**d**	**J'**	**H'(log2)**
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	*S*	*N*	*d*	*J'*	*H'(log2)*
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 IIIB: 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 with respect different areas (LCA, OFW and HCA) within the port New Mangalore Port.

Post-monsoon I						Pre-monsoon					Monsoon					Post-monsoon II			
LCA						LCA					LCA					LCA			
St.	S	N	d	J'	H' (log2)	S	N	d	J'	H' (log2)	S	N	d	J'	H' (log2)	S	N	d	J'
1	0	0	-	-	0	6	18	1.719	0.991	2.561	0	0	-	-	0	5	19	1.369	0.982
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
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
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
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
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
7	0	0	-	-	0	1	3	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
OFW						OFW					OFW					OFW			
10	0	0	-	-	0	0	0	-	-	0	0	0	-	-	0	12	42	2.941	0.988
11	0	0	-	-	0	3	8	0.940	1	1.585	0	0	-	-	0	6	18	1.735	0.995
12	0	0	-	-	0	3	9	0.908	0.995	1.577	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	-
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
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
15	3	11	0.841	0.982	1.557	1	3	0	0	0	1	4	0	0	0	0	0	0	-
16	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
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
19	0	0	-	-	0	0	0	-	-	0	1	3	0	0	0	3	11	0.847	0.985

Figures

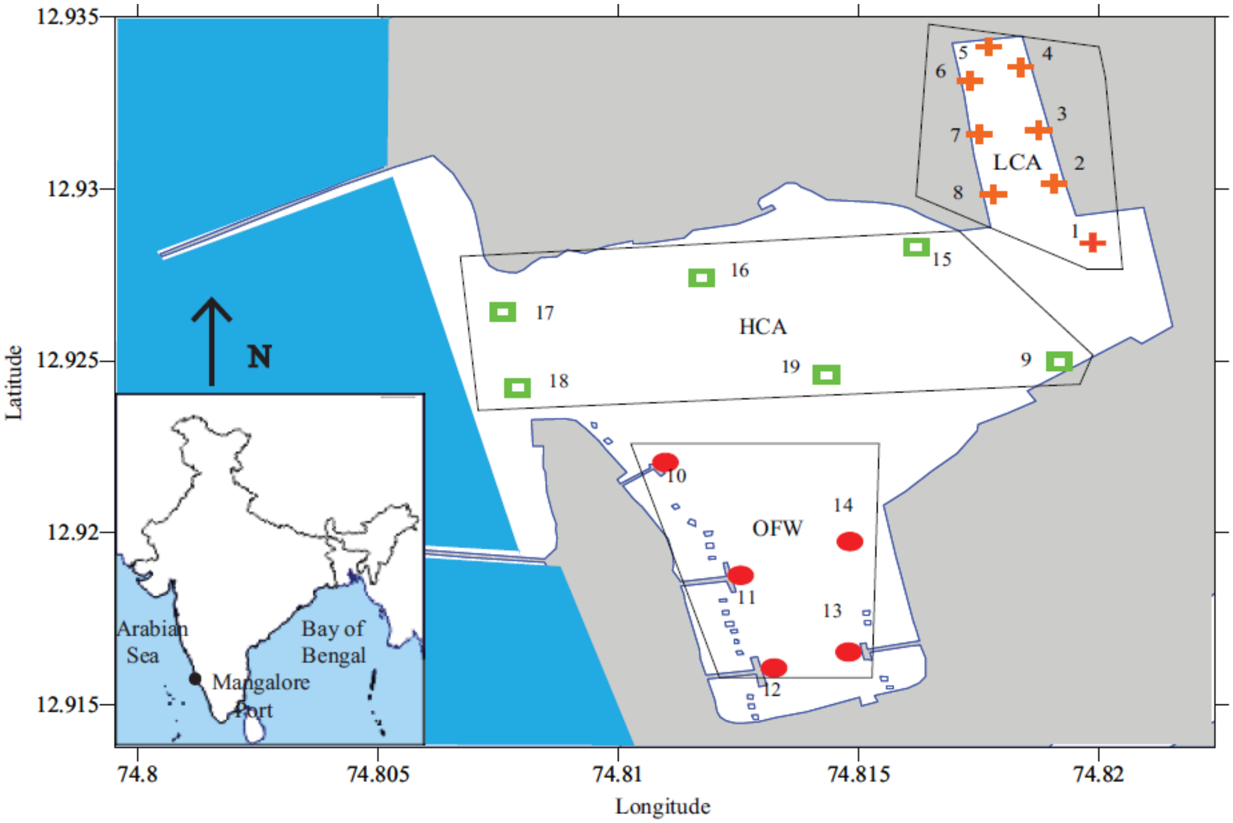


Figure 1

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).

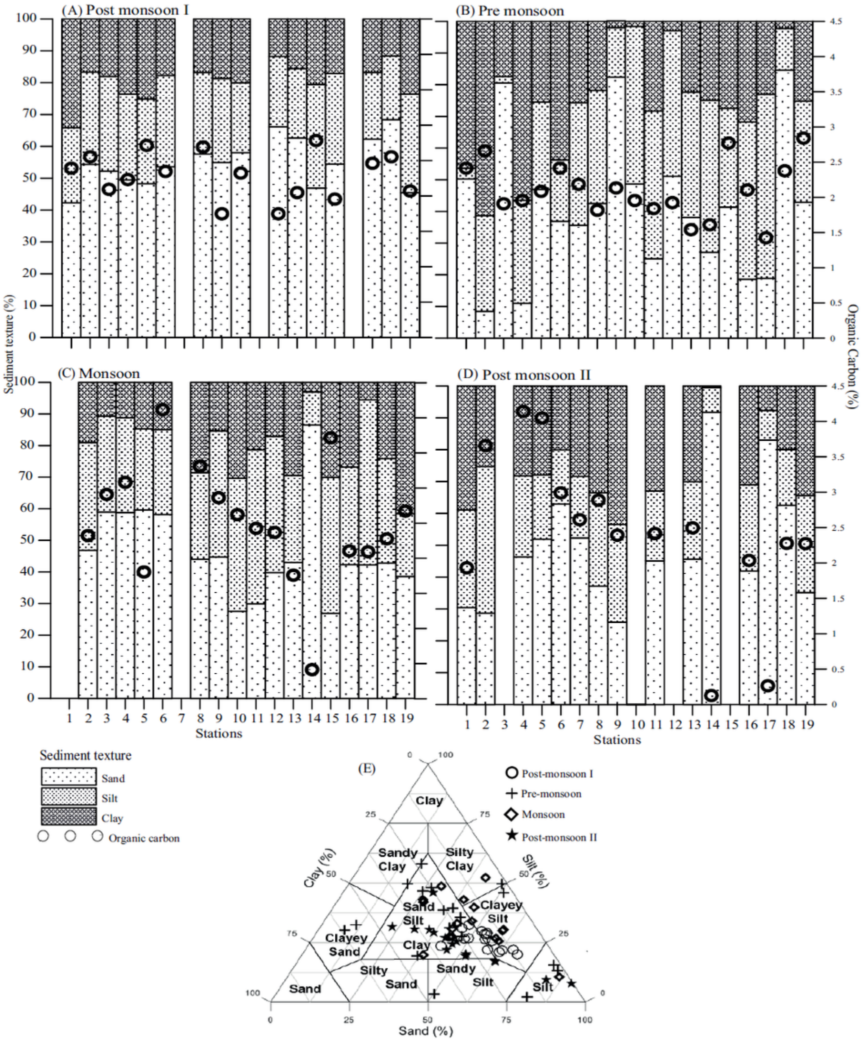
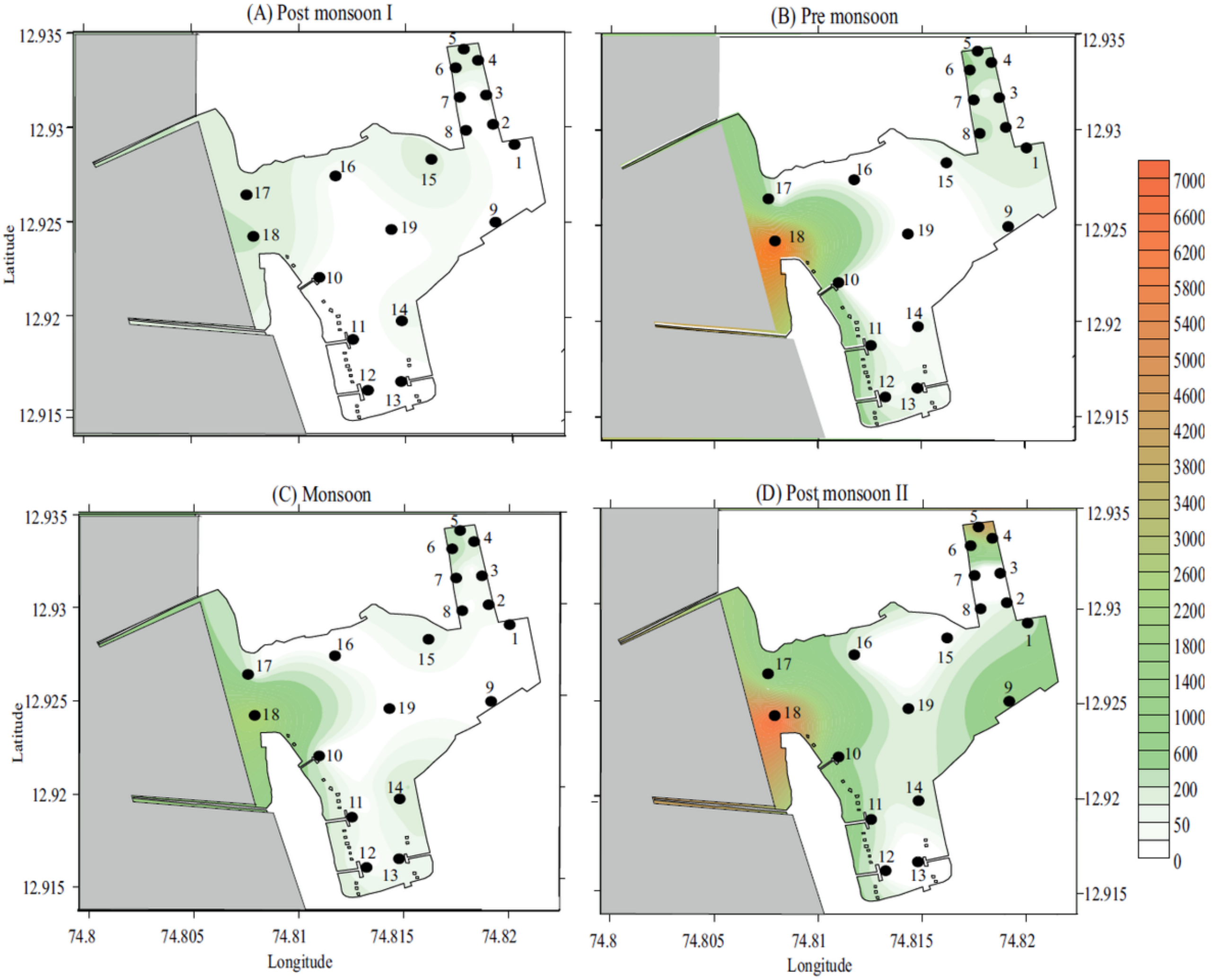


Figure 2

Seasonal variation in the sediment characteristics (percentage) in New Mangalore port (A) post-monsoon I (B) pre-monsoon (C) monsoon (D) post-monsoon II (E) ternary triangle.


(A) Post monsoon I

(B) Pre monsoon

(C) Monsoon

(D) Post monsoon II

Figure 3

Seasonal variation in the abundance (no. m-2) of macrobenthic taxa at different stations in New Mangalore port (A) Post monsoon I (B) Pre monsoon (C) Monsoon and (D) Post monsoon II.

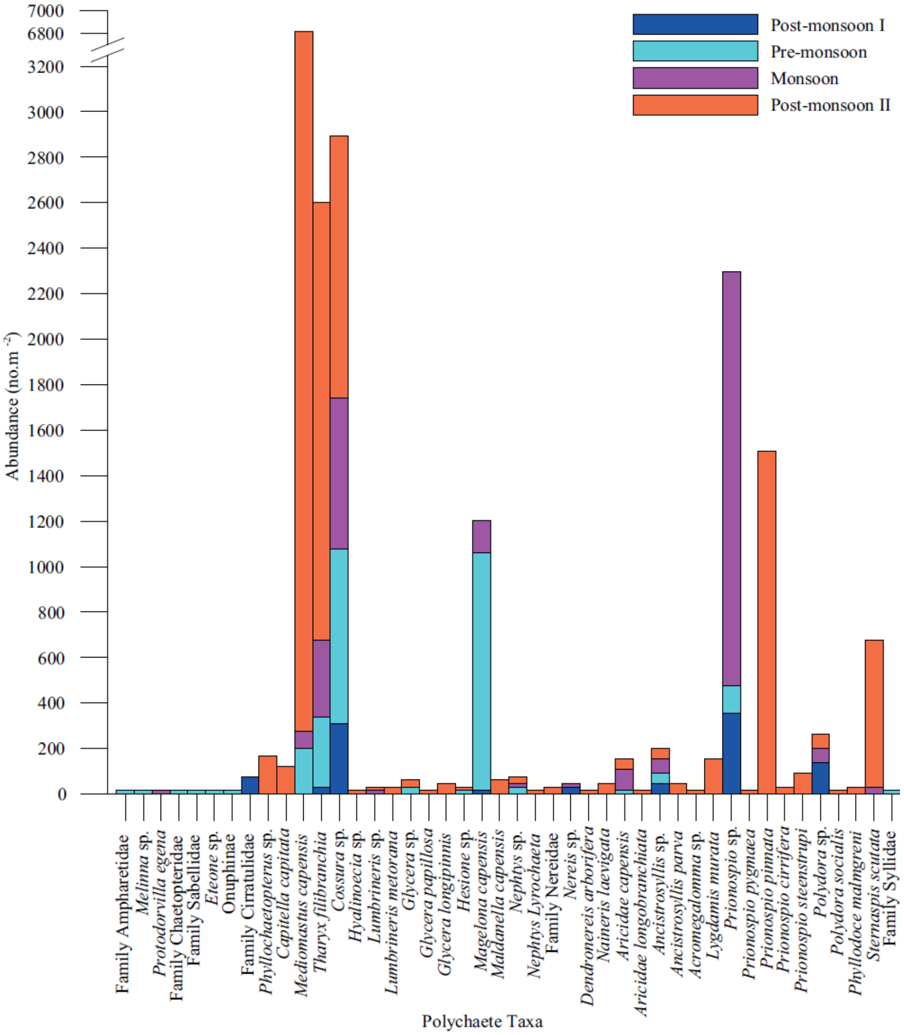


Figure 4

Seasonal variation in the abundance (no. m-2) of polychaete taxa in New Mangalore port.

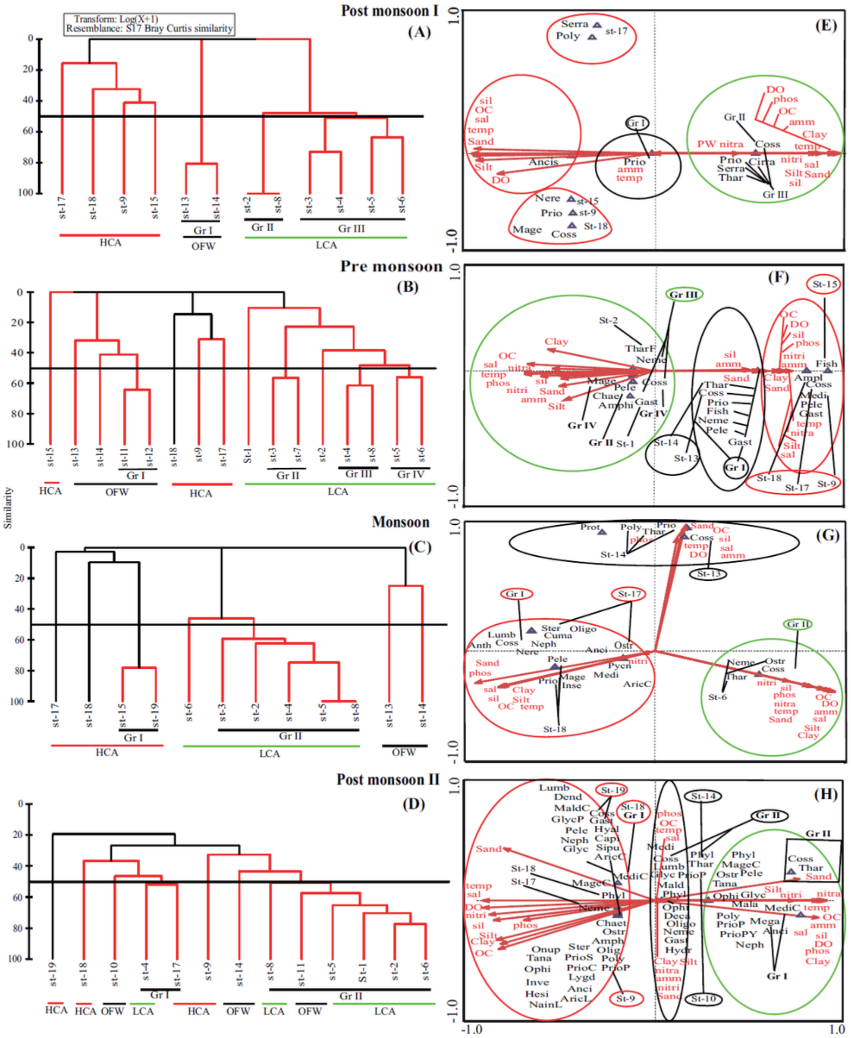


Figure 5

Analysis of cluster and SIMPROF of the stations from different areas showing relation between abundance of macrobenthos with environmental variables and sediment characteristics during different seasons (A) Post monsoon I (B) Pre monsoon (C) Monsoon (D) Post monsoon II. The tables represent the grouping of stations based on the occurrance of macrobenthic species and the environmental parameters and sediment charcateristcs influencing the macrobenthic species. The macrobenthos taxa have been abbreviated as follows: Cirratudiae: Cirr; Tharyx filibranchia: TharF; Cossura sp.: Coss; Magelona capenis: MageC; Nereis sp.: Nere; Ancistrosyllis sp.: Anci; Prionospio sp.: Prio; Polydora sp.: Poly; Serratosagitta sp.: Serra; Mediomastus capensis: Gastropods: Gast; Pelecypods: Pele; Amphipods: Amphi; Ostrocods: Ostro; Nemertea: Neme; Insecta: Inse; Phyllodocidae sp.: Phyl; Different bottom water environmental parameters, pore water nutrients are abbreviated as follows: Pore water silicate: sil; Pore water nitrate: nitra; Pore water nitrite: nitri; Pore water ammonium: amm; Pore water phosphate: phos; Bottom water temperature: temp; Bottom water salinity: sal; Bottom water dissolved oxygen: DO; Sediment OC: OC.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- SupplementaryFigure1.eps
- SupplemetaryTable1.docx