

Macrobenthic diversity and community structure at Cochin Port, an estuarine habitat along the southwest coast of India

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Abstract

Estuarine habitats are highly dynamic owing to tidal and seasonal changes in physical and chemical properties, which, in turn, have a profound influence on the diversity and community structure of its living components. At the same time, estuaries have served as centers of maritime trade. Therefore, benthic organisms inhabiting the estuarine environment can act as bio-indicators of natural and anthropogenic changes, but our current knowledge of these components is still poor in the tropics. A study of the macrobenthos (principally comprising polychaetes), along with associated environmental variables was therefore assessed during October 2011 to November 2012 in and around Cochin port, a tropical estuarine habitat influenced by the monsoon and port-related activities. Our results showed that the diversity, abundance and community structure of the macrobenthos varied with season. Maximum diversity and abundance occurred following the southwest monsoon (post-monsoon II; November 2012), while both variables were at their minimum during the monsoon. The abundance of macrobenthos was lower in clayey-silt compared to sandy sediment. Polychaetes were the dominant organisms, followed by oligochaetes and amphipods. Sediment enrichment and seasonal changes in the sediment characteristics led to the dominance of opportunistic species such as *Prionospio* sp., *Paraprionospio* sp., *Nephtys* sp. and *Oligochaeta* observed during different seasons. Polychaete species such as *Prionospio* sp. (an indicator of oxygen depletion) and *Cossuracoasta* (an indicator of sediment instability) were observed during the study. The multivariate index of trophic state (TRIX) indicated highly eutrophic waters and would be the main cause for the seasonal changes in the macrobenthos diversity. This study will serve as a baseline for future studies on the diversity of macrobenthos and benthic ecology of monsoon-influenced coastal habitats especially in a busy port subjected to severe physical and anthropogenic stress.

Keywords: Spatio-temporal variation; Species Diversity; Cochin port; Sediment; Macrobenthos abundance; Biomass

1. Introduction

Estuaries are among the most productive natural ecosystems and perform crucial ecological functions, which include ecosystem services such as nutrient cycling, organic matter decomposition, food for resident and migratory fauna, shoreline protection, and fisheries resources. At the same time, estuaries often serve as commercial harbours (Kennish, 2002; Dolbeth et al., 2003; Paerl, 2006; Dolbeth et al., 2007). Since estuaries are a connecting point of freshwater, sea, and land, they are supplied with large amounts of nutrients and pollutants derived from agricultural, industrial and urban effluents (Lillebø et al., 2005; Paerl, 2006; Dolbeth et al., 2007). As reported by Ramaraju et al. (1979), typically the estuary is highly stratified with respect to salinity during the monsoon season and during the post and pre-monsoon, they are partially mixed owing to a balance between river flows and tidal influence. Cochin Port is one such environment located along the Cochin backwaters of Kerala. The Cochin backwaters are among the largest and most complicated ecosystems in India, which is influenced by the southwest and the northeast monsoons. Heavy rainfall results in stratification, with freshwater at the surface and denser seawater at the bottom. In pre and post-monsoon periods, there is sedimentation due to tidal influence, which brings more silt and clay to the estuarine mouth (Menon et al., 2000).

Ports are considered as the lifeline of a country's economic development. However, maritime trade and transport activities also cause substantial damage to natural habitats owing to their interactions with the port environment, whether accidental (e.g., oil and chemical spills) or intentional (e.g., dredging, reclamation) (Button, 1999; Talley, 2003; Ng and Song, 2010). Port waters are often characterized by low dissolved oxygen and the presence of pollutants in the sediment and water (Danulat et al., 2002; Rivero et al., 2005; Ingole et al., 2009; Musale et al., 2015). Cochin, a natural estuarine port, has been expanded over the years, dredged, and developed with deeper channels for modern cargo handling. The development has led to adverse consequences for the environment, air, water, and sediments (Gupta et al., 2005; Cooper, 2003; Ray, 2008; Grifollet et al., 2011; Dinwoodie et al., 2012; Puig et al., 2014). Ports are also prone to bio-invasion through ballast water due to their empty niches (Rilov and Crooks 2009).

Understanding the ecology of macrobenthic fauna in the Cochin port is crucial, because they play a significant role in the marine community through their involvement in mineralization, sediment mixing, oxygen flux in the sediment, nutrient cycling and recovery of organic matter (Snelgrove, 1998). Polychaetes are significantly diverse, abundant and have ecologically important functions in coastal waters. They also provide sediment stability and adapt to different environments (Simboura et al. 2000). Their short life cycles and limited mobility have led to them being used as bio-indicators in

monitoring studies (Gray and Elliot, 2009). Yet, even though ports are important both ecologically and economically, few studies have been carried out to determine macrobenthic diversity in the ports of India (Anil et al., 2002). The Cochin port is a tropical habitat influenced by the southwest and the northeast monsoons, and the objective of this study is to describe the spatio-temporal variation in the diversity and abundance of macrobenthos and to examine the impact of sediment characteristics and environmental variables on benthic diversity in a dynamic port environment.

2. Materials and methods

2.1. Study area

Sampling was carried out in and around Cochin port (9°34' 48" N, 76° 08' 24"E) located in the state of Kerala along the west coast of India (Figure 1). The port is at the entrance of Cochin backwaters, which is a shallow brackish water system within a tropical estuary (Qasim and Reddy, 1967). It is a complex micro-tidal estuary receiving $2 \times 10^{10} \text{ m}^3 \text{ year}^{-1}$ of freshwater through six rivers (Srinivas et al., 2003). The annual rainfall of the region is around 320 cm, of which more than 60% is accounted for during the southwest monsoon (June–September). During pre-monsoon (February–May), increased tidal activity modifies the flushing characteristics of the estuary considerably (Balachandran et al., 2008). Cochin port is located in the northern part of the Cochin backwaters and is one of the two permanent openings, the other one being at Azhikode, that flush the river water into the Arabian Sea (Figure 1). The estuarine mouth connected to the sea is a ~450 m wide channel through which the water is flushed out during the ebb tide, and the seawater enters the port during the flood tide. The depth of the estuary varies considerably and the major portion of the estuary has a depth range of 2-7 m. A total of 21 sampling (port) stations (see Figure 1) were located along the two channels (Mattancherry channel and Ernakulam channel) in the port area where samples were collected: S01- custom bay, S02- fishery harbour, S03- dry dock, S04- south coal berth, S05- quay 1, S06- quay 2, S07- north coal berth, S08- boat train pier, S09- container terminal, S10- DC jetty, S11- quay-10, S12- Ro-Ro jetty, S13- naval jetty, S14- Cochin shipyard, S15- bunker oil jetty, S16- integrated fisheries project jetty, S17- south tanker berth, S18- north tanker berth, S19- Ernakulam ferry jetty, S20- Cochin oil terminal, and S21- Ernakulam creek mouth. The tides at the port stations are mixed semidiurnal with a range of about 1 m (Qasim and Gopinathan, 1969). Cochin port has three dredged channels where the stations are located with one being the Approach Channel and two inner channels (Figure 1). The Approach Channel is around 10 km in length and ~450 m wide where five stations were located (S1, S9-10, and S19-21). The other two inner channels sampled were the Ernakulam Channel (eight stations: S11-S18) which is ~5 km long and 250 – 500 m wide and the Mattancherry Channel (seven stations: S2–S8), which is about 3 km long with a width of around 170–

250m. The Ernakulam channel and the Mattancherry channel are located on the either side of the Willingdon Island (Menon et al., 2000). Water depth at the port stations varied between 8-10m.

2.2. Sampling and analysis

Sampling was carried out during October 2011 (Post Monsoon I – PM I), May 2012 (pre-monsoon), August 2012 (monsoon) and November 2012 (Post Monsoon II- PM II) representing different seasons. The surface and near-bottom water samples were collected using a Niskin water sampler for the analysis of Chlorophyll *a*, salinity, dissolved oxygen (DO), temperature, and suspended particulate matter following the methods described by Parsons et al. (1984). Nutrients such as nitrate (NO₃), phosphate (PO₄), nitrite (NO₂), ammonium (NH₄), and silicate (SiO₄) were analysed by SKALAR SAN^{plus} analyzer. The seawater samples for analysis were collected in triplicate. Sediment samples were collected from an average depth of 8–10 m using a Van Veen grab (0.04 m²). At each station, sediment samples were collected in triplicate and washed separately through a 500 µm nylon mesh at sea and then transferred to polythene bags and preserved in 10% formaldehyde in seawater containing Rose Bengal stain. In the laboratory, the sediment samples were sieved through a 500 µm metal sieve, and all macrobenthic fauna were sorted and preserved in plastic vials containing 10% formaldehyde solution for further microscopic analysis. Polychaetes were identified to the highest taxonomic level (genus or species) possible with the help of available identification keys (Fauvel, 1953; Day, 1967; Fauchald, 1977; Theodore, 1979). The macrobenthos other than polychaetes were identified to family or genus level. The numerical abundance of each species was recorded and expressed as the number of individuals per square meter (indiv. m⁻²).

Biomass was determined by wet weight method and expressed as milligram per metersquare (mg. m⁻²) (Mason et al., 1982). Organic carbon (OC) and percentage composition of sediment (sand, silt and clay) were determined by standard titration method and pipette analysis, respectively (Wakeel and Riley, 1956; Buchanan, 1984). Organic carbon was expressed as the percentage of sediment dry weight.

Macrobenthic fauna, especially polychaetes, reflect the ecological and environmental status of the seabed and this was assessed in terms of the number of individuals or specimens (N), number of taxa (S), total abundance (A), Margalef species richness (d), Pielou's evenness (J') and Shannon index (H') using log₂ scale at each station (Clarke and Gorley, 2006) (Table 1). Bray–Curtis similarity for species diversity of macrobenthic polychaetes was determined using PRIMER-v5 (Clarke and Gorley, 2006). Seasonal variation in the total macrobenthic community, polychaetes and other invertebrate taxa were performed using SURFER-6 (developed by Golden Software Inc., USA).

Canonical correspondence analysis (CCA) was performed to evaluate the relationship between environmental variables and macrobenthic polychaetes as well as other taxonomic groups. The multivariate index of trophic state (TRIX) method was used to evaluate the trophic status of Cochin port (Vollenweider et al., 1998; Malhadas et al., 2014), which was later used to assess the relationship between sediment and trophic status of water. TRIX was calculated where chlorophyll *a* is in mg m^{-3} , a\%O_2 is the absolute value of the percentage using the equation $\text{TRIX} = (\log_{10} (\text{Chla} \times \text{a\%O}_2 \times \text{DIN} \times \text{DIP}) + k)/m$, of DO saturation ($\text{abs } |100 - \text{\%O}_2| = \text{\%O}_2$) [DIN = dissolved inorganic nitrogen including NO_3 , NO_2 , NH_4 in mg m^{-3} , DIP = dissolved inorganic PO_4 in mg m^{-3}]. The constants, *k*- 3.5 and *m*- 0.8 are scale values obtained from Vollenweider et al., (1998) to adjust TRIX scale values (reads from 0 to 10) with a level of eutrophication in the Cochin Port. According to this method, TRIX scores less than 4 indicate high state of water quality with low eutrophication; scores between 4 and 5 indicate good state of water quality with medium eutrophication; scores between 5 and 6 indicate bad state of water quality with high eutrophication and scores greater than 6 indicate poor state of water quality with elevated levels of eutrophication.

3. Results

3.1. Environmental parameters

Seasonal variation in temperature, salinity and dissolved oxygen across all 21 stations in Cochin port are shown in Table 2. The average values of these parameters were given along with the standard deviation at each station. The average seawater temperature during monsoon season was $25.3 \pm 0.4^\circ\text{C}$ and it ranged from $29.0 \pm 0.7^\circ\text{C}$ to $31. \pm 0.2^\circ\text{C}$ during pre-monsoon and post-monsoon respectively. The mean surface water temperatures during PM I and PM II, pre-monsoon and monsoon were $29. \pm 0.8^\circ\text{C}$, $30.1 \pm 0.4^\circ\text{C}$, $30.1 \pm 0.4^\circ\text{C}$ and $27.5 \pm 0.4^\circ\text{C}$ respectively (Table 2). The near-bottom water temperature, in general, was $1 \pm 0.8^\circ\text{C}$ lower than the surface water temperature. During PM I and PM II, the difference in the tidal amplitude was $0.50 - 0.91 (\pm 0.10)$ m. The tidal amplitude during pre-monsoon and monsoon season was $0.4 - 0.6 (\pm 0.1)$ m and $0.6 - 0.7 (\pm 0.5)$ m respectively. The salinity of surface and near-bottom water during post-monsoon was 24.7 ± 6.5 PSU and 31.2 ± 5.5 PSU, during pre-monsoon 18.9 ± 4.7 PSU and 24.3 ± 5.5 PSU and during monsoon 5.3 ± 1.3 PSU and 20.5 ± 10.8 PSU respectively indicating a wide seasonal variation in the salinity and depth stratification (Table 2). The mean DO of near-bottom water during PMI and PMII was $4.2 \pm 1.4 \text{ mg. l}^{-1}$ and $2.6 \pm 1.1 \text{ mg. l}^{-1}$ respectively and during pre-monsoon season, the mean DO was $3.5 \pm 0.8 \text{ mg. l}^{-1}$. During monsoon season, DO was lower compared to other seasons and it was $1.9 \pm 1.1 \text{ mg. l}^{-1}$ (Table 2). The concentration of nutrients varied across seasons and stations during the study (Supplementary Figure 9). The average value of TRIX was 5.15 during the study, indicating poor water quality

which was highly eutrophic. The TRIX scores ranged from 1.64 to 7.37 during the course of this study (October 2011 to November 2012). Pre-monsoon and monsoon seasons showed a rise in eutrophication, and it was moderate during the post-monsoon seasons (PM I and PM II).

Sediment composition varied spatio-temporally within the port (Figure 2). In general, silt was the most dominant component - $49.5 \pm 22.5\%$ followed by clay - $32.2 \pm 25.4\%$ and sand - $18.3 \pm 15.6\%$ during all the seasons in most of the stations. The percentage of silt in the sediment ranged between 10% at S-20 to 91% at S-06 (Figure 2). The percentage of sand was comparatively lower ranging from 0.3% to 62% and dominated during PM I (Figure 2A), and was merely present during PM II (Figure 2D). Sand showed significant variation during the pre and post-monsoon seasons (pre-monsoon $18.98 \pm 14.2\%$, monsoon $10.7 \pm 12.6\%$ PM I and PM II $29.8 \pm 11.3\%$ and $10.7 \pm 12.6\%$ respectively) (Figure 2). Clay is the second most dominant component of the sediment and ranged between 0.2% at S-08 to 85% at S05. The total organic carbon of the sediment ranged from 1.4% to 3.6% during all the seasons. During PM I and II (Figure 2A, D), higher organic carbon content was observed in the sediment $2.7 \pm 0.40\%$ and $2.6 \pm 0.30\%$ respectively. However, during monsoon and pre-monsoon, the organic carbon content was lower, $1.9 \pm 0.8\%$ and $1.7 \pm 0.6\%$ respectively (Figure 2C, D).

The chlorophyll *a* content was higher in near-bottom water during monsoon at S-19 (82.9 mg. m^{-3}), and lower at S-09 during PM I (0.5 mg. m^{-3}) (Figure 3A). The average chlorophyll *a* content during PM I was $2.2 \pm 1.8 \text{ mg. m}^{-3}$, pre-monsoon: $21.6 \pm 21.4 \text{ mg. m}^{-3}$, monsoon: $13.6 \pm 7.1 \text{ mg. m}^{-3}$ and during PM II, it was $14.6 \pm 0.4 \text{ mg. m}^{-3}$ (Figure 3A). Sediment chlorophyll *a* content during PM I, pre-monsoon, monsoon and PM II was $0.77 \pm 0.1 \text{ mg. m}^{-2}$, $0.74 \pm 0.3 \text{ mg. m}^{-2}$, $0.60 \pm 0.4 \text{ mg. m}^{-2}$ and $0.56 \pm 0.2 \text{ mg. m}^{-2}$ respectively (Figure 3B). The maximum sediment chlorophyll *a* content was observed during pre-monsoon at S-14, and minimum during monsoon at S-21 (Figure 3B).

3.2. Seasonal variation in macrobenthos

The macrobenthos reported during this study comprised of Annelida (Polychaeta and Oligochaeta), Arthropoda (amphipods, and isopods and tanaids), Mollusca (bivalves) and Gobiidae (mud skippers). Among these groups, polychaetes were the most common and abundant organisms during all the seasons. Among the 36 macrobenthic taxa, 21 were polychaetes contributing more than 50% to the total macrobenthic abundance. Spionid and nephtyid polychaetes were observed during all the seasons. The maximum abundance of macrobenthos was during PM II ($9487 \text{ indiv. m}^{-2}$), followed by PM I ($6222 \text{ indiv. m}^{-2}$), pre-monsoon ($2171 \text{ indiv. m}^{-2}$) and monsoon season ($416 \text{ indiv. m}^{-2}$) (Figure 5B). The stations with maximum abundance during PM I, pre-monsoon, monsoon and PM II

are S17- South tanker berth (2494 indiv. m⁻²), S10-DC jetty (2279 indiv. m⁻²), S08-boat train pier, S13-Naval jetty (323 indiv. m⁻²) and S19-Ernakulam ferry jetty (92 indiv. m⁻²) respectively (Figure 5B). The maximum biomass of macrobenthos was reported during PM II - 59797 mg. m⁻² (Figure5A), followed by pre-monsoon 14287 mg. m⁻² (Figure4C), PM I -13466 mg. m⁻² (Figure4A), and it was minimum during monsoon season 6375 mg. m⁻² (Figure4E). Abundance and biomass were directly related to each other during all the seasons except pre-monsoon, where the corresponding biomass was higher even though the abundance was lower (Figure4C-D). The maximum biomass observed during post-monsoon II season was 4249 mg. m⁻² in S08 and the minimum was 24 mg. m⁻² in S14 (Figure4G). During pre-monsoon and monsoon seasons, the biomass was higher at S15 (3030 mg. m⁻²) and S19 (2422 mg. m⁻²), and lower at S14 (108 mg. m⁻²) and S17 (121 mg. m⁻²) respectively (Figure 4C-E). Both abundance and biomass of macrobenthos were higher during PM II. The stations S-08 had the maximum (15084 mg. m⁻²) biomass and S-11 had minimum (251 mg. m⁻²) biomass of macrobenthos during PM II (Figure4G). During pre-monsoon season few stations showed the lower abundance of macrobenthos, whereas the biomass was higher (e.g., S08 and S13 had the abundance of 323 indiv. m⁻²; however the biomass differed between these two stations, S08 - 3001 mg. m⁻² and S13 - 1313 mg. m⁻² respectively) (Figure4 C-D).

During PM I, the maximum abundance of macrobenthic organisms at S10 was contributed by the spionid, *Prionospio*sp. (1910 indiv. m⁻²) which was the dominant taxon (Figure6; Table 3). The number of *Prionospio*sp. was high during PM I season contributing about 77% to the total abundance, followed by Oligochaeta (8%) and *Ancistrosyllis*sp. (3%) (Table 3). Other polychaetes observed during this season were *Capitellacapitata* at S08, *Mediomastus*sp.at S07, S10, S12, and *Cossuracoasta* at S10 and S20 stations (Table 3). The Errantiate polychaetes found during this season were *Nephtys*sp. at S05, S08 and S11 and *Dendronereis*sp. at S01, S05 and S10. The most abundant errantiate polychaete was *Ancistrosyllis*sp. with a total abundance of 246 indiv. m⁻² (Figure6) at S08, S10, S11 and S20 (Table 3).

During the pre-monsoon season, the higher abundance of the macrobenthic organisms was observed at S08 and S13 (Figure5D). The most abundant taxa during this season were Oligochaeta (21%), *Paraprionospio*pinnata (8%) and *Ampithoes*sp. (7%) (Table 3). Among the four genera of amphipods, three were observed during the pre-monsoon season, namely *Ampelisca*sp. (S01, S08), *Ampithoes*sp. (S01, S08) and *Cheirocratus*sp. (S01, S08, S11, S20) with a total abundance of 631 indiv.m⁻² (Figure6; Table 3).

Macrobenthic diversity and abundance were at their lowest during monsoon season compared to other seasons with *Paraprionospio*pinnata and *Ampithoes*sp. contributing 22% and 15% followed by

Ancistrosyllis sp., *Nereis* sp., Oligochaeta and tanaids, each contributing 11% respectively (Table 3) with a total abundance of 416 indiv.m⁻² (Figure4F).

In contrast, during PM II, the abundance (9487 indiv.m⁻²) (Figure6B) and biomass (59797 mg. m²) (Figure5A) were maximum compared to other seasons. The most abundant macrobenthos taxa were the Oligochaeta, *Nephty*ssp. and Cirolanid isopod which contributed 19%, 17% and 7% respectively to the total abundance (Table 3). The variation in the diversity and abundance at all the stations were observed during PM II, unlike other seasons when the organisms were reported from few stations. The most abundant polychaetes were *Capitellacapitata* which was observed at S13 and S18 (200 indiv.m⁻²), *Cossuracoasta* observed at S12, S14, S15, S17 and S18 with a total abundance of 200 indiv.m⁻² (Table 3). The *Nephty*ssp. was the second most dominant (1617 indiv.m⁻²) taxon during the PM II season and was observed at most of the stations (Figure7). Spionids were the most dominant polychaete family and it was represented by four genera which were reported at many stations such as *Paraprionospioinnata* (600 indiv. m⁻²), *Prionospio*sp. (462 indiv. m⁻²), *Polydorakempi* (200 indiv. m⁻²) and *Streblospio*sp. (15 indiv. m⁻²) (Figure6). Amphipods found during PM II were *Ampeliscasp.* (S01, S04, S05) with a total abundance of 231 indiv.m⁻², along with *Ampithoesp.* and *Cheirocratussp.* which had similar abundance (169 indiv. m⁻²). The amphipod, *Gammaropsissp.* was the most abundant (646 indiv. m⁻²) at S05, S08, S10 and S20 (Figure4H & 7; Table 3). Oligochaeta was the second most abundant group of annelids observed in Cochin port. They were found during all the seasons and at most of the stations with maximum abundance during PM II with a total count of 1801 indiv. m⁻² (Figure6) (S06, S08, S09, S11, S12, S15, S17 and S21) (Table 3). Juvenile fishes (Gobiidae) were also observed during PM II at S08.

3.3. Seasonal variation in macrobenthos diversity

Species diversity index at all the stations was estimated based on Margalef species richness (d), Shannon-Weiner index (H') and evenness (J'). The maximum number of species were encountered during PM II at S07 (Table 1). The correspondence values of the Shannon-Weiner index (H') were high during pre-monsoon and PM II, which were 1.77 and 1.92 respectively. During the monsoon season, species diversity was low compared to other three seasons (Table 1), and four species were observed during this season (Table 1). Bray-Curtis similarity index was applied for grouping the stations according to macrobenthic abundance. At 50% similarity level, three and four groups were revealed during PM I and PM II seasons (Figure 7 A-D) respectively. Post monsoon season showed maximum diversity and biomass of macrobenthos with lower DO concentration in near-bottom water (Table 2 and Figure 8). The group I stations were dominated by *Prionospio* sp. (contribution to abundance - 21.3%), *Ancistrosyllisconstricta* (contribution to abundance 2.1%) and *Nephty*ssp.

(contribution to abundance 2.6%). In group I (Figure 7), stations S05, S07, S08, S11 and S18 were closely similar with *Prionospio*sp. being the dominant taxa. In group II (S01, S09, S15 and S20), *Prionospio*sp. was least abundant (11%) compared to Group I and *Ancistrosyllis constricta* was the most abundant taxon with 3% contribution to the total abundance respectively (Figure 7). The group III stations had *Prionospio*sp. as the common organism which contributed 4% to the total abundance. During pre-monsoon season, three groups were reported, group I (S06, S12 and S15), group II (S14 and S17) and group III (S01 and S08) and the organisms which contributed to the total abundance were *Ampitho*sp. (4.3%), *Ampelisc*sp. (3.1%), *Cheirocratus*sp. (3.6%), *Nephtys*sp. (3.4%), *Cossuracoasta* (3%), *Oligochaeta* (2.8%), *Streblospio*sp. (3.3%) and *Aricidea*sp. (2.8%) (Figure 8B). The presence of *Nephtys*sp. and *Cossuracoasta* in all the three stations indicated resemblance in the occurrence of polychaete species in group I stations. In group II, *Nephtys*sp., *Streblospio*sp. and *Aricidea*sp. were common. During pre-monsoon season, group III stations were dominated by amphipods such as *Ampitho*sp., *Ampelisc*sp. and *Cheirocratus*sp. (Figure 7B). During the monsoon season, the similarity was least among the stations due to low species diversity and abundance. Only two stations, S02 and S19 showed resemblance owing to the presence of isopods (Figure 7C). During PMII, the similarity in the stations and the organisms present was higher, and the presence of *Paraprionospio pinnata* (4.8%), *Nephtys*sp. (4.2%), gastropods (2.8%), *Gammaropsis*sp. (4.7%), *Dendronereis*sp. (4.3%), *Oligochaeta* (4.8%) and *Cossuracoasta* (3.6%) were responsible for such grouping (Figure 7D). PM II season had four groups with a 50% resemblance. In group I (S14, S15, S17 and S18), *Nephtys* sp. and *Cossuracoasta* were found in all the stations. Group II (S5, S10 and S21) stations had Nereids, *Dendronereis* sp. and amphipod, *Gammaropsis* sp. in all the stations. The *Nereis* sp. indicated the highest abundance (354 indiv. m⁻²). The group III (S02 and S06) and group IV (S09 and S12) had *Nephtys* sp. which was common to all their stations (Figure 7D).

The CCA and Redundancy analysis (Figure 8 A to D) indicated sediment characteristics and organic carbon were important in determining the community structure of benthic organisms at the sampling stations during different seasons. Length of gradient value >2 was shown during post-monsoon and pre-monsoon seasons and during monsoon, it was <2. The correlation percentages between macrobenthic abundance and the environmental variables during pre-monsoon were 95 %, followed by 82 % during monsoon, and 77% and 76% during PM II and PM I respectively. The canonical correspondence analysis for PM I (Figure 8A) revealed that silt and organic carbon influenced the abundance of the organisms. Sampling stations such as S05, S09, S10, S18 and S20 with high silt and low organic carbon were dominated by sedentary annelids including *Prionospio*sp. and *Oligochaeta*, while at S08 with higher sand content, *Ancistrosyllis*sp., Tanaidacea and isopods were

reported (Table 3). *Prionospio* sp. appeared to be unaffected by changes in environmental variables as they occurred in the majority of the stations during the PMI season. Higher temperatures and salinities (above 28 psu) of bottom water also influenced the abundance of macrobenthos in these stations during PM I.

During PMII (Figure 8D), the highest abundances were recorded when clay was the dominant sediment. Increased clay and organic carbon content correlated with higher abundance of the organisms. Stations with higher DO, higher temperatures and salinities of 30 psu and above generally correlated with higher abundance. The stations S05, S08, S10, S14, S15 and S17 had higher abundance of *Nereis* sp., *Nephtys* sp., *Dendroneri* sp., *Prionospio* sp., *Polydora* sp., oligochaetes, amphipods (*Gammaropsis* sp.), and cirriid isopods (Table 3).

Pre-monsoon (Figure 8B) season showed the highest correlation in diversity of macrobenthos with environmental variables. The stations with the highest abundance of macrobenthic taxa were S6, S8, S12, S13, S15, S17, S20 and S21 (Table 3). In the sediment, sand was present in all the stations which shared the highest abundance with an average organic carbon of 2.5. The organisms found are mostly free-living and active predators such as *Nephtys* sp., and *Syllis* sp. except *Prionospio* sp., which is sedentary. Amphipods such as *Ampelisca* sp., *Ampithoe* sp., *Cheirocratus* sp., *Gammaropsis* sp. were also reported. Environmental parameters also influenced the distribution and abundance of organisms during the monsoon season (Figure 8C) when lowered temperature, salinity and DO in bottom water occurred, as shown in Table 2. The sediment composition during the previous seasons (PMI and pre-monsoon) had higher sand content compared to monsoon and PM II seasons and this may be due to riverine runoff during the monsoon season thereby influencing the abundance and diversity of the macrobenthic community. During the PM II season, *Paraprionospio* sp. occurred in sandy-silt sediment as they can survive in low DO, nutrients and organic carbon.

4. Discussion

4.1 Temperature, salinity and dissolved oxygen

The fluctuations in physical and chemical variables are often associated with changes in regional climatic and biological activity, alterations in the surface water due to evaporation, freshwater influx, the intensity of solar radiation, as well as cooling and mixing with the ebb and flow from adjoining shallow waters (Kumar and Khan, 2013). Previous studies carried out indicated contamination of Cochin backwaters by anthropogenic pollutants due to poor flushing of sediment, enclosed nature of the estuary and adsorption of pollutants in the sediments leading it into a sensitive ecosystem (Martin et al., 2012; Anu et al., 2014). In the present study, the 21 stations located in all three channels were

influenced by the incoming sea water during high tide and outgoing freshwater during the low tide. Water in the Cochin port region derives a large proportion of nutrient load throughout the year from land drainage, agricultural activities and river discharge during the monsoon (Devi et al., 1991; Madhu et al., 2007). Tropic index (TRIX) scores showed that Cochin backwater is highly eutrophic. The hydrography of the Cochin estuary reflected tropical estuarine conditions where seawater temperature gradually increased from post-monsoon to pre-monsoon season, after which a considerable decrease during monsoon was observed. During the monsoon season, stratification intensified owing to increased freshwater influx, which also led to a decrease in salinity from the mouth of the Cochin estuary to upstream. High nutrient supply during monsoonal rainfall is a unique characteristic of an estuary influenced by monsoon (Qasim and Sen Gupta, 1982). During the non-monsoon period, the freshwater influx to the estuary is reduced, and saltwater intrusion can be seen up to 40 km inland from the mouth (Jacob et al., 2013). As reported in earlier studies, high concentrations of phosphate were observed during the post and pre-monsoon periods from December to April (Sankaranarayanan and Qasim, 1969; Martin et al., 2012). This may be due to the result of high salinity/pH combined with tidal activity during the pre-monsoon, which causes the removal of phosphate from the suspended particles (Martin et al., 2008). Near bottom water had low concentrations of dissolved oxygen compared to the surface waters during day time. This net reduction of oxygen reflected typical tropical estuarine conditions, with salinity stratification during monsoon and partially mixed conditions during non-monsoon seasons.

4.2 Sediment and organic carbon input

The distribution of sediment grain size and organic matter determine metal concentrations as well as anthropogenic pollutants such as total nitrogen (TN) and total phosphorus (TP). They are also in turn correlated with the distribution of rare elements in the sediment (Aloupi and Angelidis 2001; Liaghati et al., 2003; Rodríguez et al., 2010). Sediment texture shows significant fluctuations in their characteristics due to water discharge in riverine and estuarine areas, leading to considerable intermixing of sand, silt and clay (Nair and Ramachandran, 2002). Even though sediment showed fluctuations in Cochin port, higher percentage of sandy sediment is seen at the bar mouth (sampling stations S07, 08 and 10; see Figure 1) due to estuarine bed load movement (Nair et al., 1990; Nair et al., 1993; Martin et al., 2012). Higher silty sediment in this estuarine port during pre-monsoon is associated with sedimentation processes leading to the settlement of fine silt particles at the bottom due to weak currents (Joy et al., 1990; Menon et al., 2000). Sediment quality is one of the most important factors that determine the spatio-temporal distribution and abundance of benthic organisms. These are related to various properties of sediment such as permeability, penetrability

which are in turn controlled by sediment erosion and resuspension, and also the water content in the sediment (Sarkar et al., 2005). The present study showed changes in the sediment quality with the seasons, which may have been affected by dredging, tidal flow, sediment erosion and accumulation, currents and monsoon floods. Such changes may have determined the dominance of a particular group of organisms in the sediment in the respective season. Dredging activity in the dock area of Cochin port is of great concern as it leads to turbidity, which reduces productivity affecting greatly the benthic faunal distribution (Rasheed and Balchand, 2001). Dredging activity carried out in the port area and Cochin estuary has had a negative impact on benthic species composition, population density and biomass, resulting in a decrease in diversity (Desprez, 2000; Sarda et al., 2000; Van Daltsen et al., 2000; Rehitha et al., 2017). The present study showed continuous changes in the silt-clay composition of the bottom sediment across the monsoon season, which in turn, has led to changes in the composition of organic matter in the sediment. The higher silt composition in the sediment comprised of mostly decomposable organic matter, which are the food particles for deposit feeders (Sanders, 1958, 1960; Sanders et al., 1962; Jayaraj et al., 2008b). The change in the sediment composition may have led to the eradication of and domination by a few species in some stations and seasons (Figures 3 and 7).

The organic carbon input into the estuarine sediments is mostly determined by the supply of terrestrial material, the deposition rate of organic to inorganic constituents, primary productivity, and sediment texture (Muraleedharan and Ramachandran, 2002). Organic enrichment observed in the Cochin estuary is a sign of environmental deterioration, possibly leading to a reduction in the diversity of the macrobenthos community (Martin et al., 2011). The build-up of pollutants, contaminated inputs from freshwater and discharge of sewage waste in the estuary all contribute to environmental degradation (Menon et al., 2000). Organic carbon enrichment in the sediments may lead to hypoxia, faunal depletion and ultimately an abiotic environment (Pearson and Rosenberg, 1978). In the present study, even though organic enrichment is observed at various stations and it was in favourable percentage during monsoon season, a decrease in the macrobenthic organisms during monsoon seasons can be attributed to water flow and sediment flushing. The distribution of organic carbon in the sediment is dependent on the sediment grain size and due to the higher surface area of finer sediments, they possess higher organic carbon (Valdés et al., 2005; Rodríguez et al., 2010, Paneer Selvam et al., 2012). The present study showed significant spatial variation in the organic carbon content than temporal variation, which may be due to the changes in the sediment constituents in different stations in and around the Cochin port.

4.3 Macrobenthic organisms

Macrobenthic polychaetes comprised the dominant group among the organisms present in Cochin port, and this observation agrees with other locations along the southwest coast of India (Joydas and Damodaran, 2009; Musale and Desai 2011). Spionids were the most dominant taxa among the polychaetes. Studies on Calcasieu estuary (Louisiana), shows spionids as one of the most dominant taxa throughout the estuary in different seasons (Gaston and Nasci, 1988). The change in the abundance and diversity of benthic organisms such as polychaetes, may be due to the influence of discharge in Cochin backwaters as the amount of organic carbon and organic matter are very high and this leads to eutrophication in the estuary (Devi and Venugopal, 1989; Devi et al 1991; Geetha et al., 2010). Seasonal variation was also observed in the diversity as the changes in the sediment texture resulted in a qualitative difference in each season (Figure 2). Influence of waste water has varying effect on the primary producers and consumers with ensuing alterations in food web structure (Geetha et al., 2010). The areas with lower abundance of organisms were mostly dominated by silt and clay sediments, associated with low chlorophyll *a* in both bottom water and sediment. Earlier studies (Cloern, 2001; Bode et al., 2006; Jayaraj et al., 2007; Musale and Desai, 2011) have indicated that clayey and clayey-silt sediments contain a low abundance of organisms, as fine clay particles cause clogging of the feeding apparatus of the filter feeders. The dominant polychaetes in the present study area were the spionid, *Prionospio* sp., which are deposit feeders preferring fine-grain sediment at shallow depths (Jayaraj et al., 2008).

As observed by Hoey et al. (2004) and Jayaraj et al. (2008), benthic faunal distribution is affected by sediment texture. The *Nephtys* sp. was found in the fine sandy sediment, while *Cossuracoasta* preferred both sandy and muddy sediment due to the availability of food particles and increased organic matter, which increases their abundance (Lange, 2013). Most of the polychaetes such as *C. capitata*, *Mediomastus* sp., *Prionospio* sp. and *Streblospio* sp. found in the study area are indicator species for anthropogenic pollution and organic enrichment (Sivadas et al., 2010; Balachandar et al., 2016). High organic enrichment may lead to hypoxic conditions, as well as smothering and reduction in the density of organisms, which result in the dominance of the deposit feeders in estuaries (Pearson and Rosenberg, 1978; Ansari et al., 1986; Mojtahid et al., 2008; Martin et al., 2011). Extreme changes in diversity during each season were observed e.g., *Prionospio* sp. was dominant during PM I followed by *Oligochaeta* during pre and post-monsoon seasons, except monsoon season and during this season *Paraprionospio* sp. was abundant. The dominance of single opportunistic species (*Prionospio* sp.) in the present study area was likely due to the prolonged stress in the environment as observed by Gray (1989). The presence of *Prionospio* sp. shows oxygen depletion

and *C. Coasta* is an indicator species for sediment instability indicating a disturbed environment (Abdul Jaleel et al., 2014; Rehitha et al., 2017). Most of the above- mentioned organisms are deposit feeders which feed on the freshly settled organic matter on the sediment, as observed by Muniz and Pires, (1999) and Dolbeth et al. (2007). The present study shows that the influence of monsoon which brings high freshwater inflow from the catchment area, tidal flow and dredging activity in Cochin port, are major factors influencing the change in the sediment texture and organic matter leading to the change in the species abundance and diversity during different season (Table 3).

Other macrobenthic organisms observed in Cochin port are the Oligochaeta, crustaceans (amphipods, tanaids and isopods), molluscs, as well as larval and juvenile gobiid fishes. Opportunistic species such as Oligochaeta have shown dominance where dredging is carried out regularly and there is a correspondingly lower concentration of amphipods and polychaetes at these stations (Rehitha et al., 2017). It has been observed that the stable conditions may allow organisms to thrive well, and during unfavourable conditions, may lead to a decline in their density; this coincides with the previous studies (Duineveld et al., 1991; Musale and Desai, 2011). The study indicates that the Cochin port is a stressful environment for the benthic fauna, and this observation is supported by Shannon index (H') and species richness (d) values which are 0.6-1.9. For a healthy environment, H' and d should be in the range of 2.5 to 3.5 (Magurran, 1988). Previous studies by Jayaraj et al. (2008) and Musale and Desai (2011) showed that *Prionospio* sp. was found in high numbers along the southwest coast of India especially off Cochin estuary and Cochin port which is organically polluted (Remani et al., 1983). Several studies on southwest coast showed higher benthic biomass and abundance (Neyman, 1969; Harkantra et al., 1980; Parulekar et al., 1982; Jayaraj et al., 2007). Pillai. (2001) has described 30 species belonging to 25 genera of polychaetes in Cochin estuary, but the present study showed 21 polychaete taxa in the study stations which indicates to decreased diversity in Cochin estuary. The observed drastic changes in diversity and density, which may be due to the high organic carbon content and the influence of anthropogenically deposited effluents. Cochin estuary is influenced by petroleum hydrocarbons and dissolved and suspended organic matter in the surface and subsurface waters. These wastes get flushed out during monsoon season except the bar mouth (port area) where they accumulate the waste from the estuary (Menon, 2000). As described by Martin et al. (2011) the above mentioned anthropogenic activities have affected the benthic organisms and lead to the survival of the tolerant species.

5. Conclusions

The study provided information on the community structure and diversity of macrobenthos in Cochin port. A significant spatio-temporal variation in the abundance and macrobenthic community structure

across the year was observed. The diversity and community structure of macrobenthos in the port region were considerably lower compared to other areas of the backwaters indicating that the study area is under stress. A strong seasonal variation in the abundance of macrobenthos, which is highest during PM II and lowest during monsoon season was observed. Such seasonal variation can be attributed to the river run off during the monsoon and reverting back to the normal condition during the non-monsoon months. A seasonal change in the macrobenthic diversity and shifts in the dominance of macrobenthos was prominent, PM I is dominated by *Prionospio*sp. and *Ancistrosyllis*sp. which were replaced by *Ampitho*esp. during pre-monsoon and monsoon, and subsequently replaced by Cirolanidae during PM II season. Oligochaeta is found during all the seasons. This study provides a complete database on the diversity of macrobenthos in Cochin port with regard to changes in the benthic ecology, and is a baseline for future studies.

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Captions for figures

Figure 1. Map showing (A). Cochin estuary and (B). Study areas along the three channels and sampling stations in and around Cochin port. (1) Custom buoy, (2) Fishery harbor, (3) Dry dock, (4) South coal berth, (5) Quay-1, (6) Quay-2, (7) North coal berth, (8) Boat train pier, (9) Container terminal, (10) DC jetty, (11) Quay-10, (12) Ro-Ro jetty, (13) Naval jetty, (14) Cochin shipyard, (15) Bunker oil jetty, (16) Integrated fisheries project jetty, (17) South tanker berth, (18) north tanker berth, (19) Ernakulam ferry jetty, (20) Cochin oil terminal, (21) Ernakulam creek mouth.

Figure 2. Seasonal variation in the sediment texture and organic carbon in Cochin port during (A) Post monsoon I (B) Pre-monsoon (C) Monsoon (D) Post monsoon II.

Figure 3. Seasonal variation in (A) bottom water Chlorophyll *a* (B) sediment Chlorophyll *a* at different stations in Cochin port.

Figure 4. Distribution of biomass and abundance of macrobenthos in Cochin port during different seasons (A, B) Post monsoon I (C, D) Pre-monsoon (E, F) Monsoon (G, H) Post monsoon II.

Figure 5. Seasonal variation in (A) biomass and (B) abundance of total macrobenthic organisms in Cochin port.

Figure 6. Seasonal variation in the abundance of macrobenthic organisms during different seasons (A) Post monsoon I (B) Pre-monsoon (C) Monsoon (D) Post monsoon II in Cochin port.

Figure 7. Dendrogram for hierarchical clustering of macrobenthic polychaetes with Bray–Curtis similarity indices during different seasons (A) Post-monsoon I (B) Pre-monsoon (C) Monsoon (D) Post monsoon II. Stations are grouped with respect to their similarity.

Figure 8. CCA and RDA plots to illustrate the correlation between environmental parameters and species diversity during different seasons (A) Post monsoon I (B) Pre-monsoon (C) Monsoon (D) Post monsoon II at Cochin port.

Captions for tables

Table 1. Number of species (S), Number of specimens (N), Margalef species richness (d), Pielou's evenness (J'), Shannon index (H), of macrobenthic polychaetes during different seasons in Cochin port. (Note: Stations in which organisms were not present are not included in the table during different seasons).

Table 2: - Seasonal variation in the salinity, temperature and dissolved oxygen of surface and bottom water at Cochin port (PM I - post monsoon I, Pre-M – pre-monsoon, M – Monsoon, PM II – post monsoon II, S – surface water and B – bottom water).

Table 3. Variation in the abundance of macrobenthos in Cochin port during different seasons (Table 3A Post monsoon I, Table 3B - Pre-monsoon, Table 3C - Monsoon, Table 3D - Post monsoon II)

Supplementary material - Supplementary Figure

Figure 9. Seasonal variation in the bottom water nutrients in Cochin port (A) Nitrate (B) Nitrite (C) Ammonia (D) Silicate (E) Phosphate.

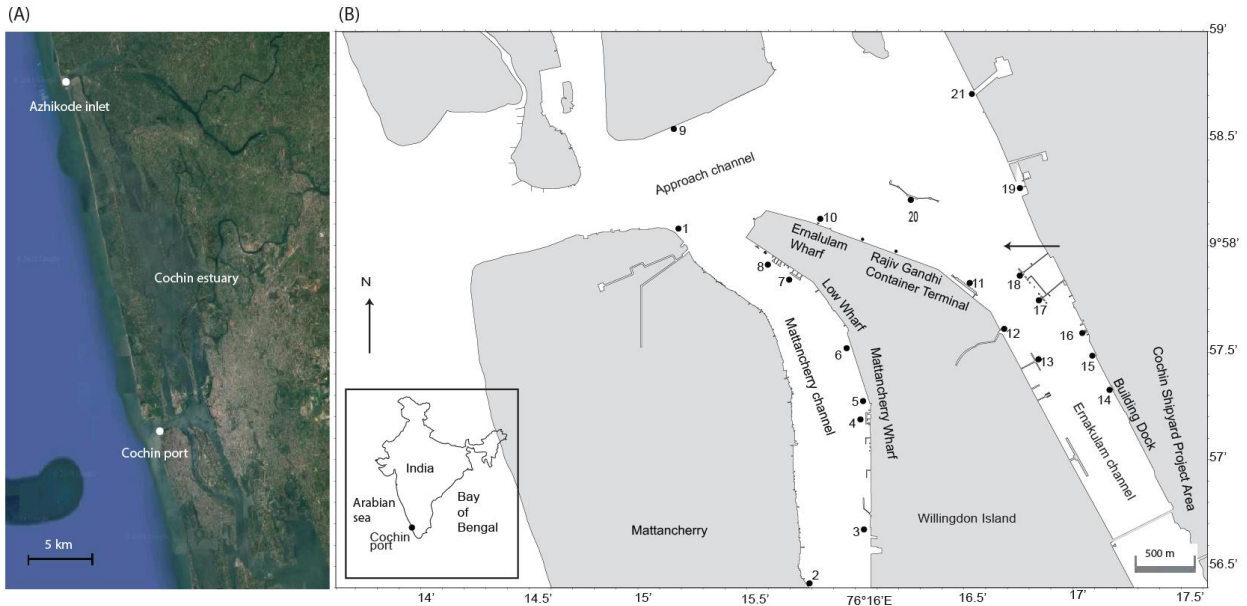


Figure 1. Map showing the (A). Cochin estuary and (B). Study areas along the three channels and sampling stations in and around Cochin port. (1) Custom buoy, (2) Fishery harbor, (3) Dry dock, (4) South coal berth, (5) Quay-1, (6) Quay-2, (7) North coal berth, (8) Boat train pier, (9) Container terminal, (10) DC jetty, (11) Quay-10, (12) Ro-Ro jetty, (13) Naval jetty, (14) Cochin shipyard, (15) Bunker oil jetty, (16) Integrated fisheries project jetty, (17) South tanker berth, (18) north tanker berth, (19) Ernakulam ferry jetty, (20) Cochin oil terminal, (21) Ernakulam creek mouth.

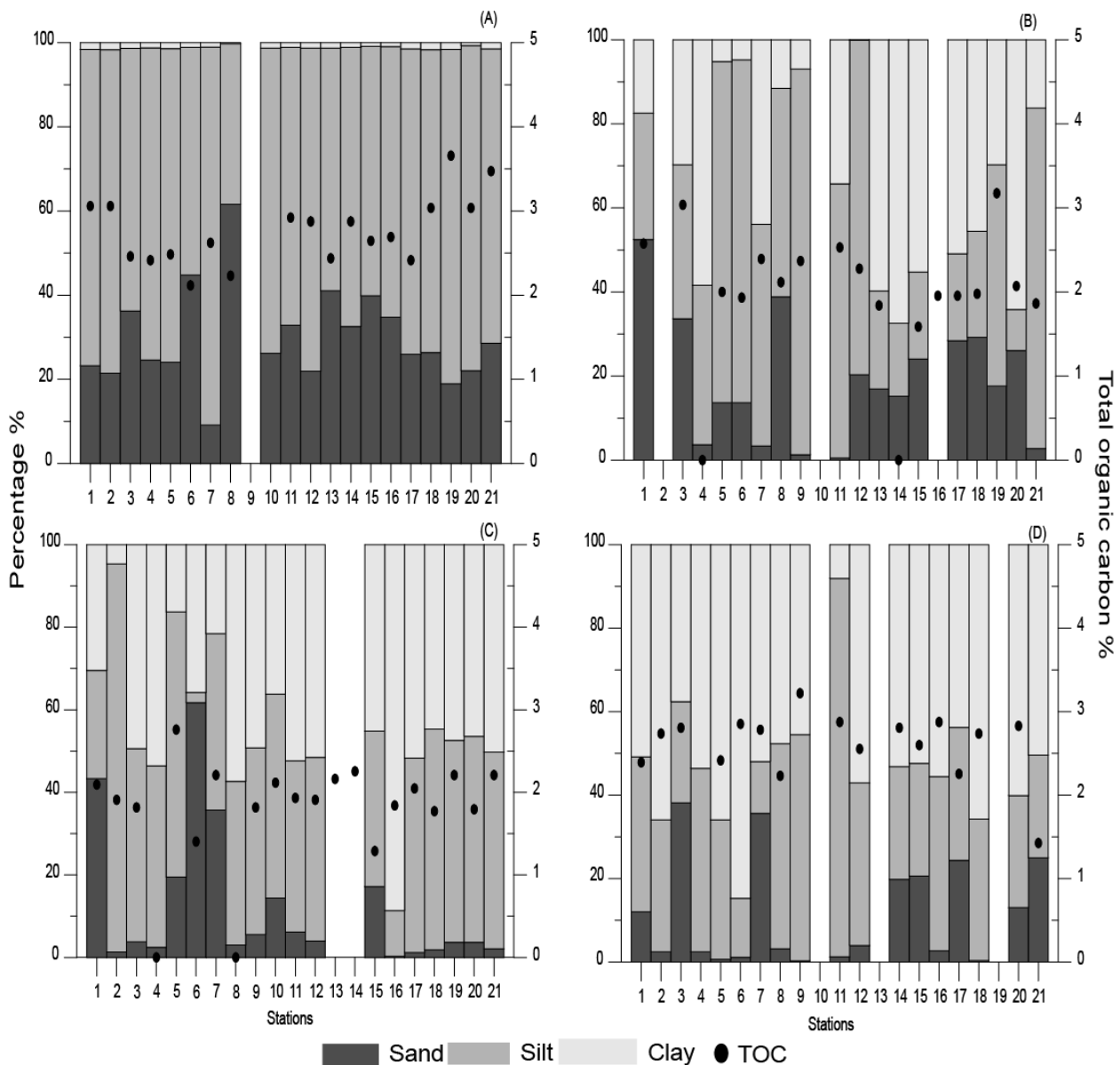


Figure 2. Seasonal variation in the sediment texture and organic carbon in Cochin port during (A) Post monsoon I (B) Pre-monsoon (C) Monsoon (D) Post monsoon II.

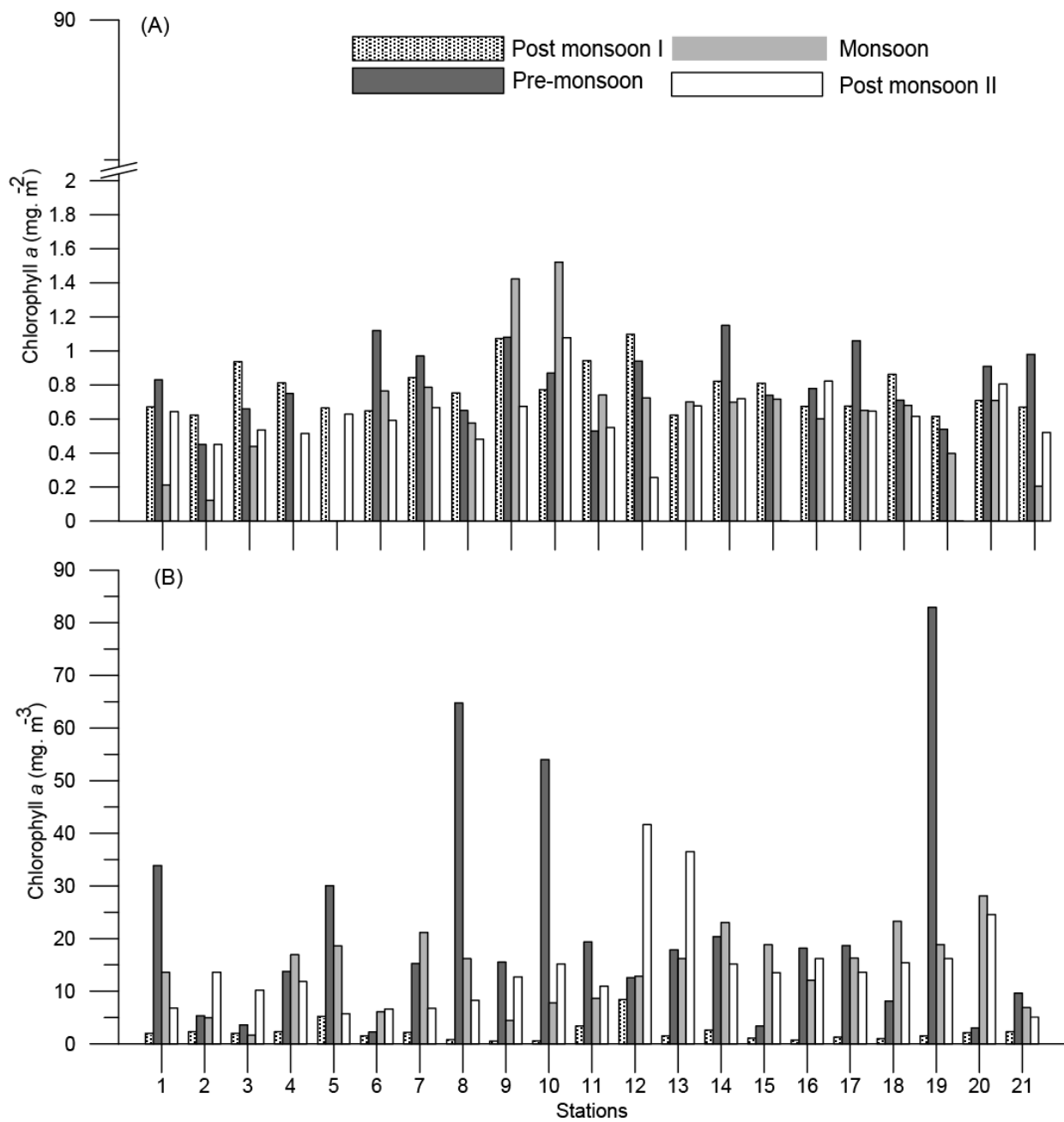


Figure 3. Seasonal variation in (A) bottom water Chlorophyll a (B) sediment Chlorophyll a at different stations in Cochin port.

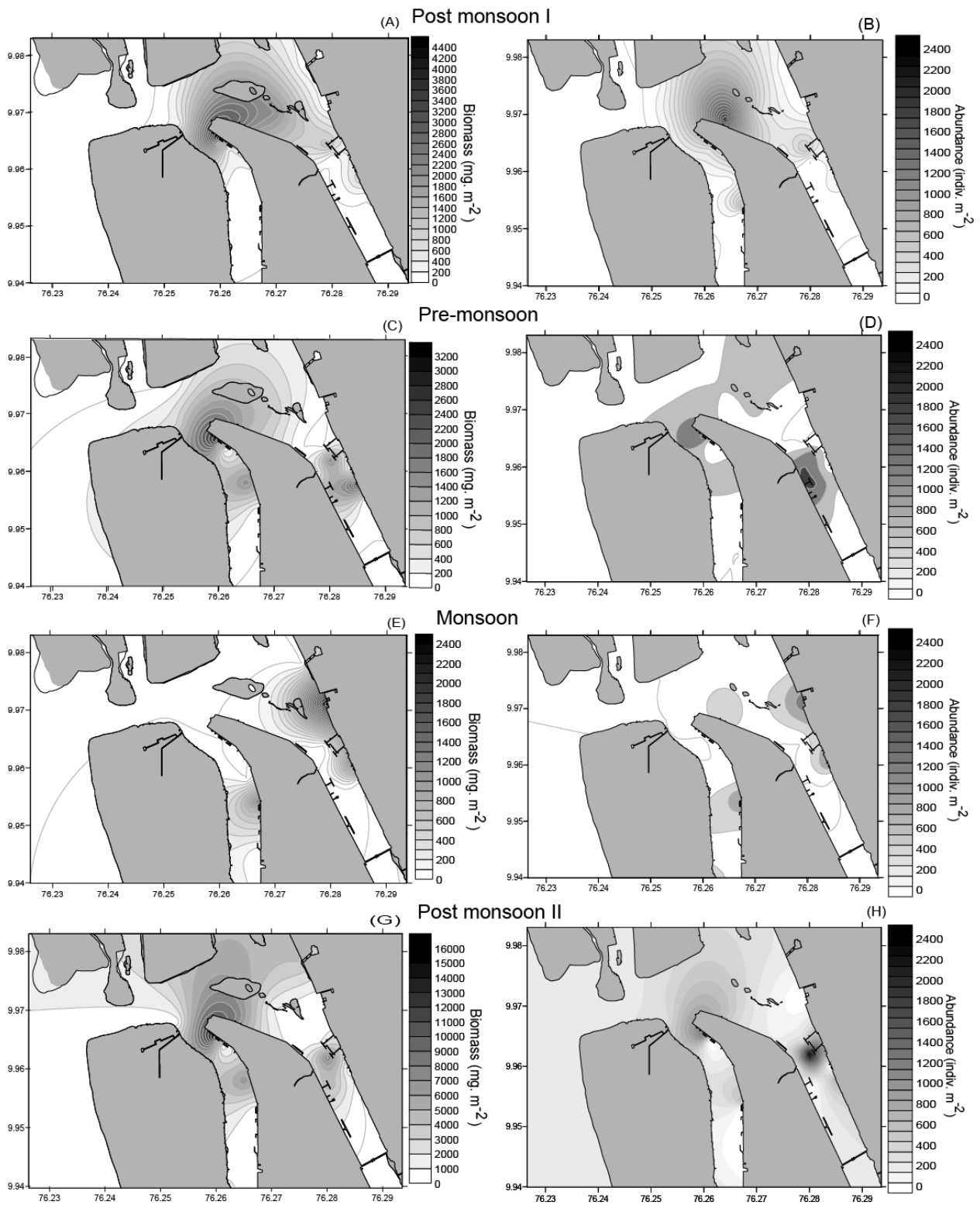


Figure 4. Distribution of biomass and abundance of macrobenthos in Cochin port during different seasons (A, B) Post monsoon I (C, D) Pre-monsoon (E, F) Monsoon (G, H) Post monsoon II.

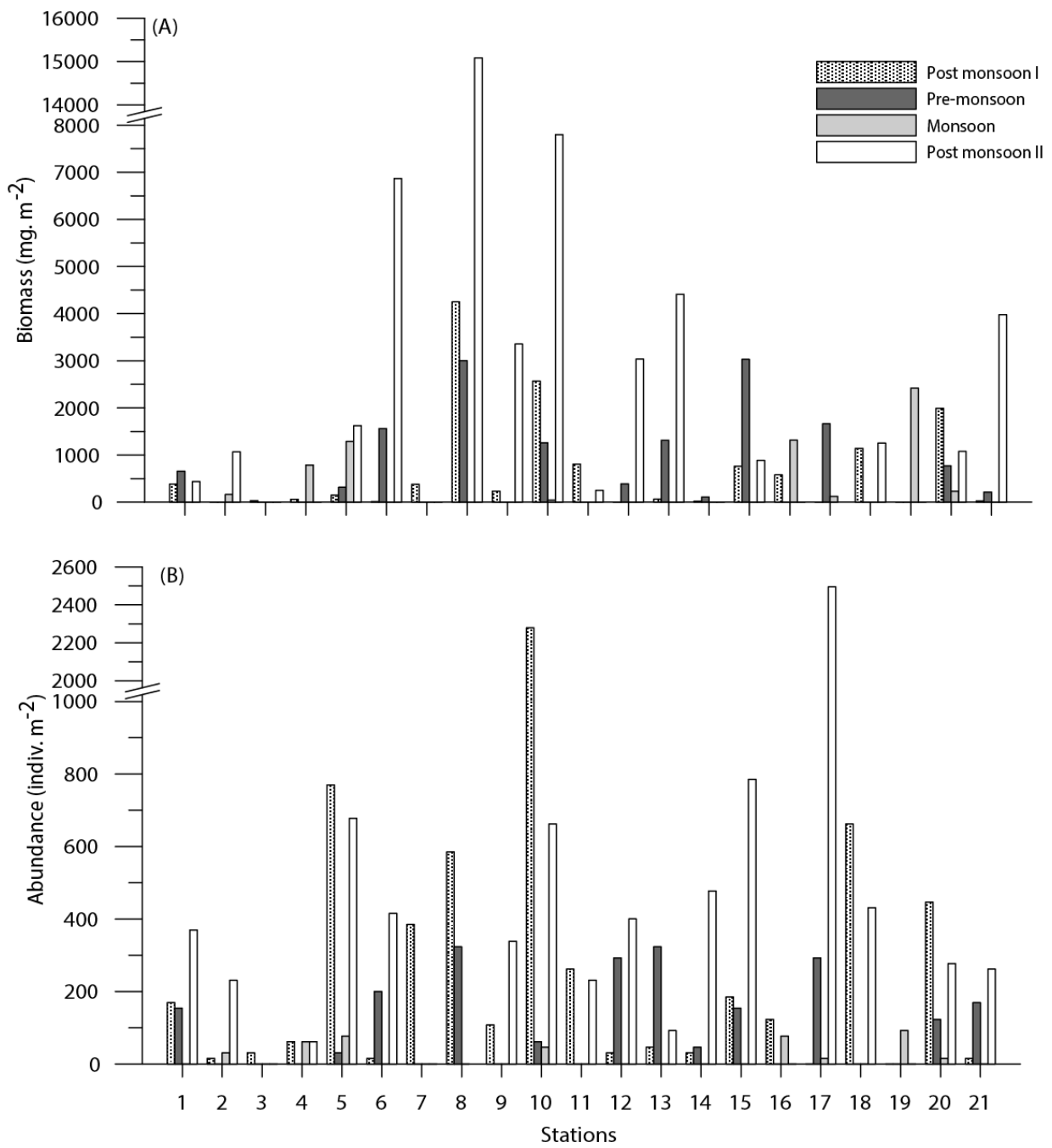


Figure 5. Seasonal variation in (A) biomass and (B) abundance of total macrobenthic organisms in Cochin port.

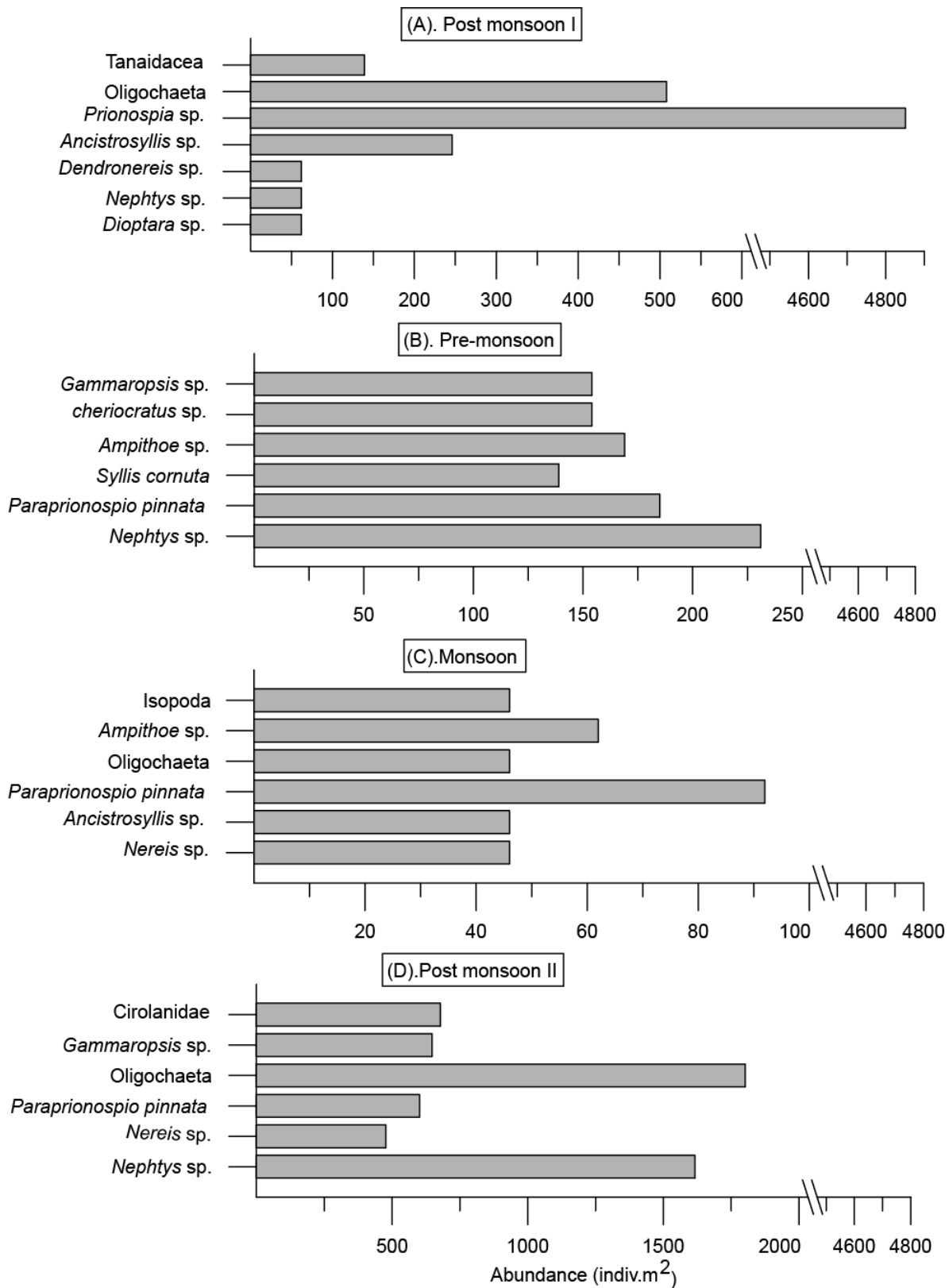


Figure 6. Seasonal variation in the abundance of macrobenthic organisms during different seasons (A) Post monsoon I (B) Pre-monsoon (C) Monsoon (D) Post monsoon II in Cochin port.

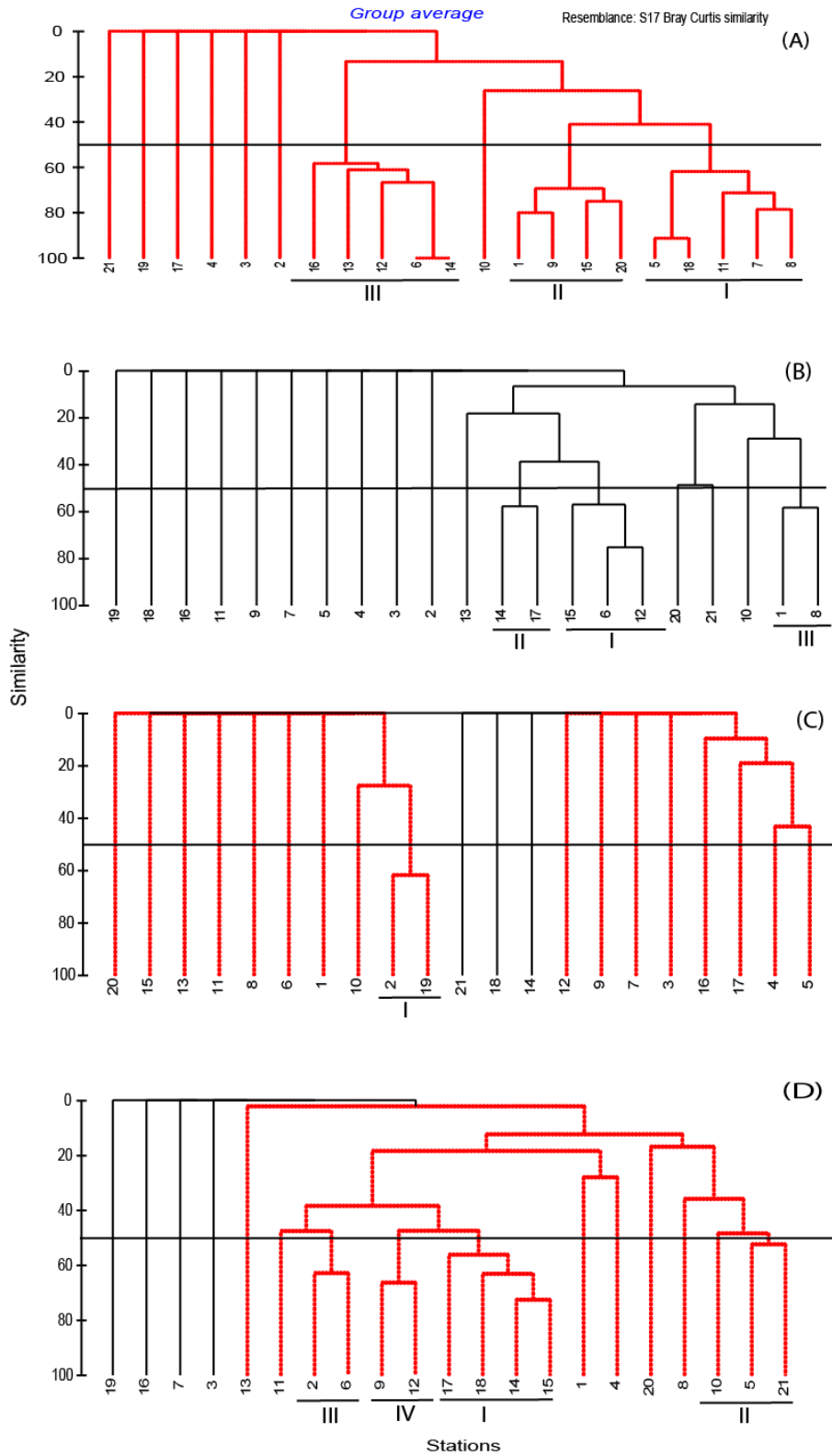


Figure 7. Dendrogram for hierarchical clustering of macrobenthic polychaetes with Bray–Curtis similarity indices during different seasons (A) Post monsoon I (B) Pre-monsoon (C) Monsoon (D) Post monsoon II. Stations are grouped with respect to their similarity.

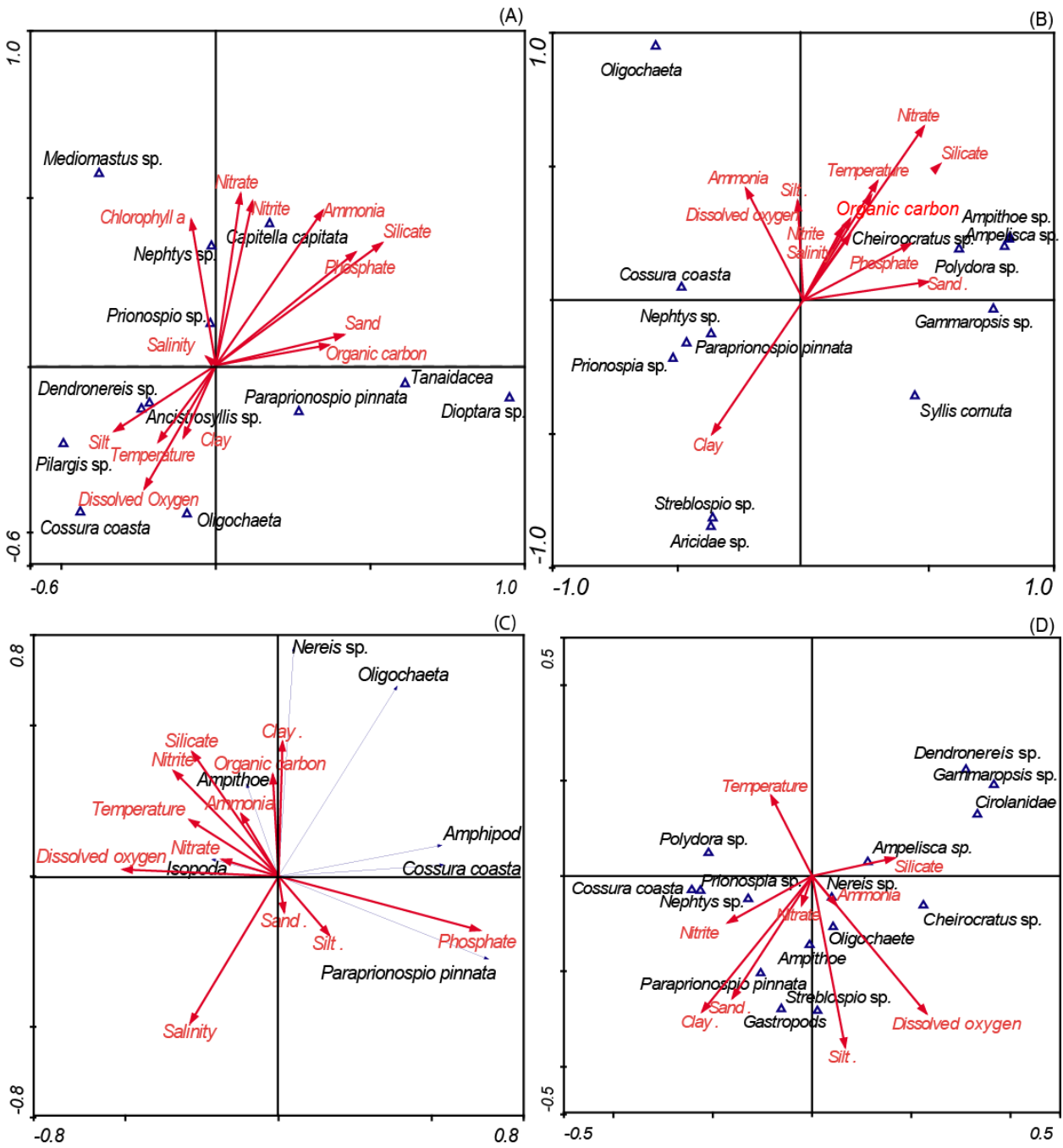
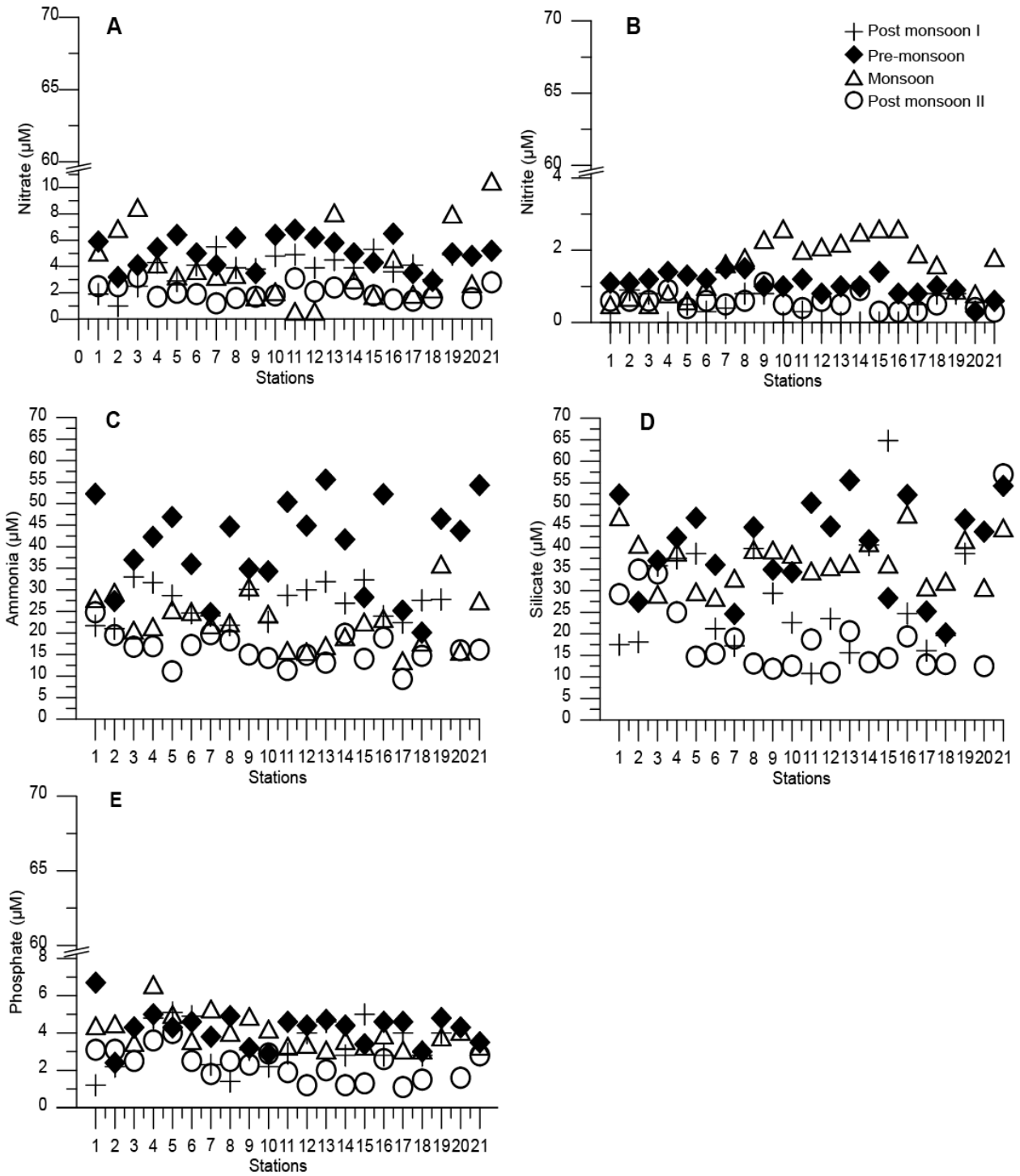


Figure 8. CCA and RDA plots to illustrate the correlation between environmental parameters and species diversity during different seasons (A) Post monsoon I (B) Pre-monsoon (C) Monsoon (D) Post monsoon II at Cochin port.



Supplementary Figure: Figure 9. Seasonal variation in the bottom water nutrients in Cochin port (A) Nitrate (B) Nitrite (C) Ammonia (D) Silicate (E) Phosphate.

| | | | | | | | | | | | | | | | | | | | | | | |
|----|---|---|------|------|-------|--|--|--|--|--|--|--|--|--|--|--|----|---|----|------|------|-------|
| | | | | * | | | | | | | | | | | | | | | | * | | |
| 15 | 2 | 1 | 0.34 | 0.94 | 0.656 | | | | | | | | | | | | 14 | 5 | 2 | 1.30 | 0.99 | 1.598 |
| | | 9 | 23 | 76 | 8 | | | | | | | | | | | | | 2 | 3 | 32 | | |
| 16 | 1 | 6 | 0 | *** | 0 | | | | | | | | | | | | 15 | 5 | 2 | 1.26 | 0.99 | 1.605 |
| | | | | * | | | | | | | | | | | | | | 4 | 5 | 7 | | |
| 18 | 1 | 2 | 0 | *** | 0 | | | | | | | | | | | | 16 | 0 | 0 | *** | *** | 0 |
| | | 5 | | * | | | | | | | | | | | | | | | * | * | | |
| 20 | 2 | 1 | 0.34 | 0.94 | 0.656 | | | | | | | | | | | | 17 | 7 | 3 | 1.68 | 0.98 | 1.923 |
| | | 9 | 23 | 76 | 8 | | | | | | | | | | | | | 5 | 9 | 8 | | |
| 21 | 0 | 0 | *** | *** | 0 | | | | | | | | | | | | 18 | 5 | 2 | 1.31 | 0.98 | 1.588 |
| | | | * | * | | | | | | | | | | | | | | 1 | 8 | 68 | | |
| | | | | | | | | | | | | | | | | | 20 | 2 | 7 | 0.52 | 0.98 | 0.680 |
| | | | | | | | | | | | | | | | | | | | 77 | 17 | 5 | |
| | | | | | | | | | | | | | | | | | 21 | 3 | 1 | 0.77 | 0.99 | 1.097 |
| | | | | | | | | | | | | | | | | | | 3 | 15 | 87 | | |

Table 1. Number of species (S), Number of specimens (N), Margalef species richness (d), Pielou's evenness (J'), Shannon index (H), of macrobenthic polychaetes during different seasons in Cochin port. (Note: Stations in which organisms were not present are not included in the table during different seasons).

Table 2: Seasonal variation in the salinity, temperature and dissolved oxygen of surface and bottom water at Cochin port (PM I - Post monsoon I, Pre-M – Pre-monsoon, M – Monsoon, PM II – Post monsoon II, S – surface water and B – bottom water).

| Stations | Salinity (PSU) | | | | | | | | Temperature (0 C) | | | | | | | | Dissolved Oxygen (mgL-1) | | | | | | | |
|----------|----------------|----|-------|------|------|------|-------|------|-------------------|------|-------|------|-------|------|-------|------|--------------------------|-----|-------|-----|------|-----|-------|-----|
| | PM I | | Pre-M | | M | | PM II | | PM I | | Pre-M | | M | | PM II | | PM I | | Pre-M | | M | | 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 |
| 1 | 30.80 | 36 | 18.24 | 21.6 | 9.36 | 22.5 | 27.09 | 31.0 | 29.07 | 28.1 | 30.36 | 29.5 | 27.04 | 25.5 | 30.25 | 30.3 | 5.50 | 8.1 | 4.30 | 3.5 | 2.40 | 1.0 | 3.30 | 3.2 |
| 2 | 20.50 | 31 | 14.11 | 25.4 | 4.04 | 8.9 | 18.86 | 28.8 | 28.83 | 28.5 | 29.55 | 29.3 | 28.01 | 27.5 | 29.70 | 30.6 | 5.70 | 3.1 | 4.70 | 4.0 | 3.20 | 4.1 | 4.60 | 3.0 |
| 3 | 22.70 | 24 | 18.35 | 29.1 | 4.21 | 4.5 | 25.26 | 29.1 | 28.02 | 28.6 | 30.37 | 28.9 | 27.37 | 27.9 | 30.34 | 30.5 | 4.80 | 3.2 | 4.20 | 2.8 | 4.40 | 4.6 | 3.20 | 3.4 |
| 4 | 27.30 | 35 | | | 7.80 | 14.6 | 23.78 | 32.4 | 29.30 | 28.0 | 29.90 | 28.4 | 27.72 | 24.8 | 30.33 | 30.3 | 5.10 | 5.3 | 3.60 | 3.3 | 5.10 | 1.1 | 4.90 | 2.2 |
| 5 | 21.00 | 29 | 25.61 | 27.0 | 6.20 | 13.2 | 32.02 | 32.5 | 29.23 | 28.4 | 30.02 | 28.9 | 28.13 | 24.7 | 30.20 | 30.2 | 6.00 | 2.4 | 3.90 | 4.4 | 5.50 | 0.6 | 4.30 | 0.8 |
| 6 | 24.90 | 37 | 24.38 | 30.5 | 8.30 | 12.5 | 33.87 | 34.0 | 29.25 | 28.6 | 29.58 | 28.5 | 28.53 | 24.8 | 30.38 | 30.2 | 7.20 | 5.0 | 3.90 | 2.5 | 5.60 | 2.4 | 2.70 | 4.4 |
| 7 | 26.70 | 25 | 32.54 | | 8.04 | 10.7 | 31.70 | 33.1 | 29.68 | 28.5 | 29.60 | 28.2 | 27.32 | 24.8 | 30.55 | 30.5 | 8.40 | 5.6 | 3.90 | 2.8 | 1.00 | 0.5 | 5.10 | 1.6 |
| 8 | 23.40 | 38 | 18.81 | 23.8 | 5.74 | 22.8 | 31.70 | 22.1 | 29.67 | 29.1 | 29.13 | 28.5 | 27.34 | 25.6 | 30.22 | 30.2 | 6.80 | 3.8 | 4.20 | 2.5 | 2.20 | 1.0 | 5.00 | 2.4 |
| 9 | 24.10 | 37 | 21.27 | 34.6 | 5.14 | 23.6 | 20.02 | 35.0 | 30.42 | 28.1 | 30.06 | 28.8 | 27.23 | 24.1 | 29.92 | 30.1 | 6.80 | 5.3 | 4.20 | 3.3 | 2.20 | 1.1 | 6.20 | 3.3 |
| 10 | 25.30 | 30 | 15.97 | 25.5 | 3.78 | 9.6 | 31.91 | 30.1 | 29.42 | 29.1 | 29.29 | 28.8 | 27.54 | 24.9 | 30.33 | 30.4 | 6.00 | 4.6 | 3.60 | 3.3 | 2.60 | 1.7 | 6.20 | 4.2 |
| 11 | 30.00 | 36 | 17.86 | 20.8 | 3.80 | 34.6 | 20.10 | 33.6 | 28.32 | 27.5 | 30.14 | 29.4 | 27.46 | 24.0 | 30.50 | 30.2 | 7.40 | 3.6 | 4.20 | 4.2 | 5.10 | 1.6 | 4.50 | 4.0 |
| 12 | 19.60 | 30 | 17.53 | 21.4 | 3.35 | 32.0 | 33.24 | 34.3 | 28.84 | 27.0 | 30.10 | 29.5 | 27.55 | 24.1 | 29.01 | 30.2 | 6.60 | 3.2 | 4.00 | 3.7 | 5.00 | 1.7 | 4.20 | 3.6 |
| 13 | 14.00 | 33 | 18.64 | 18.7 | 3.48 | 34.2 | 14.49 | 29.8 | 29.07 | 28.0 | 30.00 | 30.0 | 27.39 | 27.6 | 29.88 | 30.5 | 6.40 | 4.9 | 4.00 | 3.9 | 4.90 | 4.0 | 4.80 | 1.3 |
| 14 | 9.80 | 32 | 14.88 | 27.7 | 5.14 | 33.3 | 33.23 | 34.2 | 29.54 | 27.8 | 29.95 | 28.6 | 27.74 | 24.5 | 30.25 | 30.4 | 5.90 | 3.2 | 5.50 | 3.0 | 4.10 | 1.5 | 3.00 | 1.6 |

| | | | | | | | | | | | | | | | | | | | | | | | | |
|----|-----------|--------|-----------|----------|----------|----------|-----------|----------|-----------|----------|-----------|----------|-----------|----------|-----------|----------|----------|-----|----------|-----|----------|-----|----------|-----|
| 15 | 15. 70 | 3 3 | 17. 61 | | 6.1 5 | 33. 6 | 23. 54 | 33. 5 | 29. 40 | 27. 9 | 30. 34 | 28. 4 | 27.6 5 | 24. 1 | 30.2 9 | 30. 3 | 5.9 0 | 3.1 | 5.5 0 | 2.7 | 3.6 0 | 1.4 | 3.3 0 | 1.8 |
| 16 | 15. 70 | 3 6 | | 19. 4 | 6.1 4 | | 29. 49 | 32. 8 | 31. 30 | 27. 1 | 29. 68 | 29. 3 | 27.5 0 | 26. 1 | 30.0 2 | 30. 3 | 8.0 0 | 3.4 | 4.2 0 | 4.5 | 2.1 0 | 1.8 | 3.9 0 | 2.2 |
| 17 | 32. 80 | 3 7 | 13. 88 | 15. 1 | 5.4 8 | 13. 3 | 31. 76 | 33. 9 | 29. 54 | 27. 0 | 30. 46 | 28. 2 | 27.2 3 | 24. 0 | 30.0 8 | 30. 2 | 7.4 0 | 3.2 | 5.6 0 | 2.4 | 2.1 0 | 1.3 | 1.9 0 | 2.2 |
| 18 | 32. 40 | 3 7 | | 34. 4 | 5.6 0 | 35. 3 | 32. 27 | 33. 8 | 28. 03 | 26. 9 | 30. 19 | 28. 0 | 27.5 2 | 24. 0 | 30.2 3 | 30. 2 | 6.4 0 | 2.5 | 5.1 0 | 2.4 | 2.1 0 | 0.9 | 1.6 0 | 1.9 |
| 19 | 29. 30 | 3 6 | 19. 69 | 19. 5 | 3.1 8 | 14. 3 | 19. 57 | 22. 6 | 27. 92 | 27. 5 | 30. 33 | 30. 3 | 27.2 5 | 27. 2 | 29.9 8 | 30. 1 | 6.4 0 | 3.3 | 4.4 0 | 4.6 | 5.9 0 | 2.9 | 3.2 0 | 1.2 |
| 20 | 20. 37 | 2 4 | 13. 20 | | 4.1 2 | 29. 7 | 28. 88 | 33. 9 | 29. 36 | 29. 1 | 30. 93 | 30. 1 | 28.1 1 | 24. 2 | 30.5 2 | 30. 2 | 6.1 0 | 5.4 | 5.5 0 | 5.1 | 3.5 0 | 1.5 | 3.8 0 | 2.3 |
| 21 | 11. 20 | 1 1 | 16. 79 | 21. 5 | 2.6 3 | 6.4 | 15. 59 | 18. 1 | 29. 34 | 29. 3 | 30. 17 | 30. 0 | 27.3 6 | 27. 6 | 30.5 1 | 30. 5 | 5.8 0 | 5 | 4.9 0 | 3.7 | 3.4 0 | 3.0 | 6.6 0 | 3.9 |

Table 3. Variation in the abundance (indiv.m⁻²) of macrobenthos in Cochin port during different seasons (Table 3A - Post monsoon I, Table 3B - Pre-monsoon, Table 3A. Abundance (indiv.m⁻²) of macrobenthic organisms in Cochin port during Post monsoon I.

| Stations | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | Total | |
|-------------------------------|----|----|----|----|-----|----|-----|-----|-----|------|-----|----|----|----|-----|----|----|-----|----|-----|-----|-------|-----|
| <i>Capitellacapitata</i> | | | | | | | | 46 | | | | | | | | | | | | | | 46 | |
| <i>Mediomastus</i> sp. | | | | | | | 31 | | | 31 | | 15 | | | | | | | | | | 77 | |
| <i>Cossuracoasta</i> | | | | | | | | | | 31 | | | | | | | | | | | 15 | 46 | |
| <i>Dioparas</i> sp. | | | | | | | | | | | | | 15 | | 46 | | | | | | | 62 | |
| <i>Glycerasp.</i> | | | | | | | | | | 15 | | | | | | | | | | | | 15 | |
| <i>Nephtys</i> sp. | | | | | 31 | | | 15 | | | 15 | | | | | | | | | | | 61 | |
| <i>Dendroneireis</i> sp. | 15 | | | | 15 | | | | | 31 | | | | | | | | | | | | 61 | |
| <i>Ancistrosyllis</i> sp. | 15 | | | | | | | 46 | | 124 | 15 | | | | | | | | | | 46 | 246 | |
| <i>Pilargis</i> sp. | | | | | | | | | | 15 | | | | | | | | | | | | 15 | |
| <i>Prionospias</i> sp. | 92 | | | | 724 | 15 | 339 | 431 | 108 | 1910 | 231 | 15 | 15 | 15 | 139 | 31 | | 647 | | 139 | | 4851 | |
| <i>Paraprionospio</i> pinnata | | | | 15 | | | | | | | | | | | | | | | | | | 15 | |
| <i>Polydorakempi</i> | 15 | | | | | | | | | | | | | | | | | | | | | 15 | |
| <i>Oligochaeta</i> | 31 | 15 | | | | | | | | 108 | | | 15 | | | 93 | | | | | 246 | 508 | |
| <i>Corophium</i> sp. | | | | | | | | | | | | | | | | | | 15 | | | | 15 | |
| Tanaidacea | | | 31 | 46 | | | | 31 | | | | | | 15 | | | | | | | | 15 | 139 |

Table 3B. Abundance (indiv.m⁻²) of macrobenthic organisms in Cochin port during Pre-monsoon.

| Stations | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 02 | 21 | Total | |
|------------------------------|----|---|---|---|----|----|---|-----|---|----|----|-----|-----|----|----|----|----|----|----|----|----|-------|-----|
| <i>Capitellacapitata</i> | | | | | | | | | | | | | 15 | | | | | | | | | | 15 |
| <i>Cossuracoasta</i> | | | | | | 15 | | | | | | 31 | | | 15 | | 15 | | | | | | 77 |
| <i>Goniadasp.</i> | | | | | | | | | | | | | 15 | | | | | | | | | | 15 |
| <i>Nephtyssp.</i> | | | | | | 31 | | | | 15 | | 62 | | 15 | 15 | | 92 | | | | | | 231 |
| <i>Nereissp.</i> | | | | | 15 | | | | | | | | | | | | | | | | | | 15 |
| <i>Oweniasp.</i> | | | | | | | | | | | | | | | 15 | | | | | | | | 15 |
| <i>Aricidaesp.</i> | | | | | | | | | | | | | | 15 | | | 15 | | | | | | 30 |
| <i>Ancistrotyllissp.</i> | 31 | | | | | | | | | | | 46 | | | | | | | | | | | 77 |
| <i>Prionospiasp.</i> | | | | | | | | | | | | | | | 31 | | | | | | | | 30 |
| <i>Paraprionospiopinnata</i> | | | | | | 77 | | | | | | | | | 61 | | 46 | | | | | | 186 |
| <i>Polydorakempi</i> | 15 | | | | | | | | | | | | | | | | | | | | | | 15 |
| <i>Streblospio</i> | | | | | | | | | | | | | | 15 | | | 46 | | | | | | 61 |
| <i>Syllisicornuta</i> | 15 | | | | | | | | | | | | | | | | 15 | | | 15 | 92 | 137 | |
| Oligochaeta | | | | | | 46 | | | | | | 123 | 293 | | | | | | | | | | 462 |
| Amphipoda | | | | | 15 | 15 | | | | | | 31 | | | | | | | | | 46 | | 108 |
| <i>Ampeliscasp.</i> | 31 | | | | | | | 15 | | | | | | | | | | | | | | | 46 |
| <i>Ampithoesp.</i> | 46 | | | | | | | 123 | | | | | | | | | | | | | | | 169 |
| <i>Cheriacratussp.</i> | 15 | | | | | | | 92 | | 46 | | | | | | | | | | | | | 154 |
| <i>Gammaropsissp.</i> | | | | | | | | 92 | | | | | | | | | | | | | | 62 | 154 |
| Cirolanidae | | | | | | | | | | | | | | | | | | | | | 15 | | 15 |
| Tanaidacea | | | | | | | | | | | | | | | | | | | | | 46 | | 46 |

Table 3C. Abundance (indiv.m⁻²) of macrobenthic organisms in Cochin port during monsoon.

| Stations | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 1 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 2 | 21 | Total | |
|-------------------------------|---|----|---|----|----|---|---|---|---|----|----|----|----|----|----|----|----|----|----|----|----|-------|----|
| Bivalvia | | 15 | | | | | | | | | | | | | | | | | | | | | 15 |
| <i>Cossuracoasta</i> | | | | | 15 | | | | | | | | | | | | | | | | | | 15 |
| <i>Nereis</i> sp. | | | | | | | | | | | | | | | | 46 | | | | | | | 46 |
| <i>Ancistrosyllis</i> sp. | | | | | | | | | | | | | | | | | | | 46 | | | | 46 |
| <i>Paraprionospio</i> pinnata | | | | 62 | 32 | | | | | | | | | | | | | | | | | | 92 |
| Oligochaeta | | | | | 15 | | | | | | | | | | | 32 | | | | | | | 46 |
| Amphipoda | | | | | 15 | | | | | | | | | | | | 15 | | | | | | 30 |
| <i>Ampithoes</i> sp. | | | | | | | | | | 46 | | | | | | | | | | 15 | | | 61 |
| <i>Gammaropsis</i> sp. | | | | | | | | | | | | | | | | | | | | 15 | | | 15 |

Table 3D. Abundance (indiv.m⁻²) of macrobenthic organisms in Cochin port during Post monsoon II.

| Stations | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 1 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 2 | 21 | Total | |
|------------------------------|-----|----|---|----|-----|-----|---|-----|-----|-----|----|-----|----|-----|-----|----|-----|-----|----|----|-----|-------|------|
| Bivalvia | | | | | | | | | | 62 | | | | | | | | | | | | | 61 |
| <i>Capitellacapitata</i> | | | | | | | | | | | | | 92 | | | | | 108 | | | | | 200 |
| <i>Cossuracoasta</i> | | | | | | | | | | | | 31 | | 62 | 62 | | 31 | 15 | | | | | 200 |
| <i>Hesionesp.</i> | | | | | | | | | | | | | | | | | 293 | | | | | | 293 |
| <i>Nephtyssp.</i> | | 62 | | 15 | | 77 | | | 262 | 92 | | 92 | | 139 | 262 | | 416 | 200 | | | | | 1617 |
| <i>Nereissp.</i> | | 46 | | | 354 | | | | | | 31 | | | | | | | | | 46 | | | 477 |
| <i>Dendronereissp.</i> | | | | | 92 | | | | | 46 | | | | | | | | | | | | 62 | 200 |
| <i>Oweniasp.</i> | | | | | | | | | | | | | | 31 | | | 31 | | | | | | 61 |
| <i>Ancistrotyllissp.</i> | 62 | | | | | | | | | | | | | | | | | | | | | | 62 |
| <i>Prionospiasp.</i> | | 31 | | 15 | | | | | | | | | | 169 | | | 185 | 62 | | | | | 462 |
| <i>Paraprionospiopinnata</i> | | 77 | | | | 200 | | | | | 46 | | | 46 | 108 | | 123 | | | | | | 601 |
| <i>Polydorakempi</i> | 31 | | | | | | | | | | | | | 31 | 92 | | | | | | | 46 | 200 |
| <i>Streblospio</i> | | | | | | | | | | | 15 | | | | | | | | | | | | 15 |
| <i>Syllisornota</i> | 77 | | | | | | | | | | | | | | | | | | | 77 | | | 154 |
| Oligochaeta | | | | | | 123 | | 169 | 62 | | 62 | 277 | | | 108 | | 893 | | | | | 108 | 1802 |
| Amphipoda | | | | | 15 | | | | | | 77 | | | | 123 | | | | | | 123 | | 339 |
| <i>Ampeliscasp.</i> | 123 | | | 31 | 77 | | | | | | | | | | | | | | | | | | 231 |
| <i>Ampithoesp.</i> | 46 | | | | | | | | 15 | | | | | | | | 108 | | | | | | 169 |
| <i>Cheriacratussp.</i> | 31 | | | | | | | 92 | | | | | | | | | 46 | | | | | | 169 |
| <i>Gammaropsissp.</i> | | | | | 139 | | | 92 | | 323 | | | | | | | | | | | | 92 | 647 |
| Cirolanidae | | | | | | | | 524 | | 139 | | | | | | | | | | | 15 | | 678 |
| Tanaidacea | | | | | | | | 385 | | | | | | | | | | | | | | | 385 |