

Spatio-temporal variability in macrobenthic communities and trophic structure of a tropical estuary and its adjacent coastal waters

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Abstract

Spatio-temporal distribution of the macrobenthic community (>500 µm) and the trophic ecology of polychaetes were studied for a year in the Cochin estuary (CE) and its adjacent coastal waters. Being a tropical monsoonal estuary, a profound influence of the southwest monsoon (SWM) was evident in the CE during the present study. The sediment texture and macrobenthic density exhibited a pronounced spatial variation in the estuary, while in the coastal waters temporal changes were more prominent. Polychaetes formed the dominant taxa in terms of density and diversity in the estuary (53 species belonging to 25 families) as well as in the adjacent coastal waters (39 species belonging to 20 families). The polychaete species *Diopatra neapolitana* dominating during non-monsoonal periods was found to be replaced by the higher abundance of *Pisione* sp in the CE during monsoon. On the other hand, in the coastal waters *Cossura coasta*, the dominant species during pre-monsoon was replaced by the surface deposit feeder *Paraprionospio pinnata* during monsoon and post-monsoon. The study evidenced the combined influence of sediment texture, salinity and food availability in determining the distribution and abundance of the macrobenthic fauna in the CE and adjacent coastal waters. Feeding guild analysis and trophic importance index showed that carnivores, surface, and subsurface deposit feeders were the dominant and trophically important feeding guilds in the study area. Redundancy analysis showed that the sandy substratum supported a diversified functional composition in the estuary and its adjacent coastal waters, and motile, discretely motile polychaetes and filter feeders were more associated with the sandy substratum. Results of the present study revealed that the seasonally fluctuating polychaete community structure in the study area was predominantly controlled by their diversified feeding habits and the ecological descriptors of the polychaete feeding guilds were linked primarily to the substratum type and food availability.

Key words: Cochin estuary; Feeding guilds; Macrobenthic fauna; Polychaetes

Introduction

Estuaries are naturally stressed, highly variable ecosystems exhibiting wide fluctuations in their environmental characteristics. The changes in the physico-chemical factors at spatial and temporal scales often influence the biotic communities inhabiting these variable ecosystems (McLusky and Elliott 2004) and in turn augment the ability of its inhabitants to attain stable populations by adapting to the alterations in the environment (Elliott and Quintino 2007). Temporal variations, the changes in the biotic community along different time scales have often been used as a proxy in assessing the stability of aquatic ecosystems. The hydrography of the estuaries bordering the Indian coasts is primarily governed by the Indian summer monsoon and associated precipitation patterns (Qasim 2003). The adaptability of the organisms to the seasonally fluctuating estuarine environments brought in by the monsoonal showers and runoff patterns and in turn, their biotic-abiotic interactions enable them to form distinct community assemblages (Cadotte et al. 2013).

Macrobenthic communities are principal components of estuarine and coastal environments, involved in secondary production and nutrient exchange between the pelagic and benthic realm (Snelgrove 1998). Macrobenthic communities form a vital tool in monitoring and assessing the health of coastal water ecosystems (Ganesh et al. 2014), in evaluating the success of conservation efforts and also in their management (Winberg et al. 2007). Polychaetes, the ecologically dominant, and diverse components among the benthic community, have high stability and adaptability to a wide variety of habitats (Simboura et al. 2000; Santos et al. 2005). The possession of diverse feeding modes (trophic levels) and wide adaptability to varied environments, makes them an excellent indicator of species richness and community patterns of the benthic invertebrate assemblages (Fauchald and Jumars 1979; Olsgard et al. 2003). Feeding guilds of polychaetes are determined by the relationships between food particle sizes, feeding habits and the motility patterns (Fauchald and Jumars 1979; Pagliosa 2005). As a predominant group among benthic fauna, distinguished by diverse feeding guilds aiding them in the better exploitation of potential food resources in the sediment, polychaetes form an important link in the benthic trophodynamics (Crisp 1971, Shou et al. 2009) and hence, studies on polychaete trophic ecology attains much importance in the proper elucidation of trophodynamics of estuarine ecosystems.

The Cochin estuary (CE), a semidiurnal micro-tidal estuary covering an area of ~25600 ha (9° 30' - 10° 10' N to 76° 15' - 76° 25' E) and extending between Azhikode in the north and Alappuzha in the south (Qasim 2003; Madhu et al. 2007). The dynamic characteristic of CE is primarily attributed to the short-term changes caused by tides and the seasonal changes induced by the regional climate (Madhupratap and Rao 1979; Vineetha et al. 2015b; Vipindas et al. 2018). The CE plays a vital role in the socio-economic development of the Cochin city in terms of transportation, tourism and fisheries.

Anthropogenic activities in the CE have been started since the second half of the 19th century and it continues even till now (Rehitha et al. 2017; Sheeba et al. 2017). Considering the socio-economic importance, the CE has been included in the Ramsar site (no. 1214) of vulnerable wetlands to be protected in the year 2002 (Wetlands 2002).

Most of the earlier studies on benthos carried out in the CE and adjacent coastal waters have given much attention to the spatial variability of benthic community and the ecology of the dominant benthic taxon, Polychaeta (Unnithan et al. 1975; Jayaraj et al. 2008a; Martin et al. 2011; Musale and Desai 2011). However, very little information is available on the temporal variations in benthic community and the polychaete trophic ecology (feeding ecology) (Jayaraj et al. 2008b; Abdul Jaleel et al. 2014). In view of this, the present study encompasses the comprehensive description of the spatio-temporal variability of macrobenthic fauna of the CE and its adjacent coastal waters using a yearlong monthly data. The major objectives of the present study were (1) to understand the spatio-temporal distribution of macrobenthic community and the factors influencing their community structure in the CE and adjacent coastal waters and also (2) to elucidate the feeding ecology of polychaete community in the study area.

Materials and Methods

Study area

The Cochin estuary (CE), a tropical monsoonal semidiurnal tidal estuary runs parallel to the Arabian Sea (AS) and has two permanent inlets, i.e., one at Cochin and other at Azhikode. A regular intrusion of sea water occurs in the estuary through the tidal incursion (average tidal range is 1m) and it gets reduced significantly with its progression towards the upstream of the estuary (Martin et al. 2012). The CE receives freshwater influx from seven rivers and thus, contributing to an annual freshwater influx of $22,000 \times 10^6 \text{ m}^3$ to the AS (Srinivas et al. 2003). The annual precipitation in and around the regions of the CE is ~320 cm and out of which ~60-70 % occurs during the southwest monsoon period (Qasim 2003). This complex estuarine system (Joseph and Kurup 1989), undergoes a characteristic transformation from a river-dominated system during the monsoon period (June-September) to a tide-dominated system during the pre-monsoon (February-May) (Madhu et al. 2010). The post-monsoon (October-January) period is an intermediate period with reduced freshwater influx and increased tidal activity. River Periyar, one of the largest rivers draining into the northern region of the estuary, has a great influence on the salinity distribution of the CE (Madhupratap 1987). Tides play a crucial role in the ecological characteristics of this estuarine system when the river discharge declines gradually (Madhupratap 1987; Menon et al. 2000; Vineetha et al. 2015a).

Sampling strategy and laboratory analysis

For the present study, monthly sampling was conducted along a salinity gradient in the CE and adjacent coastal waters during the period from January-December 2011 (Fig. 1). Sampling was carried out at eleven stations of which, 7 stations were located in the CE and the remaining 4 were in the adjacent coastal waters (station 1-upstream fresh water dominated zone; stations 2 to 6 - central estuary with mesohaline zone; station 7- Cochin inlet; stations 8 to 11- coastal waters with high salinity). The average time lag between each sampling was maintained between 28 and 33 days. Monthly data were grouped into three different seasonal data sets, based on the monsoonal precipitation along the southwest coast of India. Pre-monsoon season (hereafter PRM; February-May) was characterized by warm environmental conditions without much rainfall; monsoon season (hereafter MN; June-September) was the period with heavy rainfall and the post-monsoon season (hereafter PM; October-January) was categorized as the transitional period with intermediate rainfall. Likewise, four replicates samples were attained for each season.

A conductivity-temperature-depth (CTD 19 plus, Sea-Bird Electronics) profiler was deployed at each station to obtain the temperature profiles. A Niskin sampler (5 L capacity, Hydro-Bios, Kiel-Holtenau, Germany) was used to collect water samples from the bottom for the analysis of water quality parameters, such as salinity, dissolved oxygen (DO), biological oxygen demand (BOD), pH, and suspended particulate matter (SPM). Salinity was estimated using a Digi Auto Salinometer (Model TSK, accuracy ± 0.001). The samples for DO (125 ml) and BOD (300 ml) were collected without air bubbles and estimated using Winkler's titrimetric method (Grasshoff et al. 1983). pH was measured using a pH meter (ELICO LI610, accuracy ± 0.01). For the estimation of suspended particulate matter (SPM), 250 ml of water sample was filtered onto a pre-weighed Millipore membrane filter (47 mm dia; nominal pore size- 0.45 μm) and subsequently dried at 80 °C. The weight of the filter was again measured and the differences in the weight of the filter paper before and after the filtration and drying processes indicated the amount of the SPM (APHA 2005). Sediment samples and benthic fauna were collected using a Van-Veen grab (0.05 m² area). Sediment texture was analyzed according to the method of Krumbein and Pettijohn (1938) and sediment organic carbon was determined by the wet oxidation method (El Wakeel and Riley 1957).

For the community analysis of macrobenthic fauna, the sediments collected were washed onboard through a 0.5-mm sieve (Birkett and McIntyre 1971) and the organisms remaining in the sieve were transferred into a plastic container and preserved in neutral 5% formalin-Rose Bengal mixture. The detailed identification of macrobenthic fauna was carried out using the standard identification manuals, to the lowest possible taxonomic levels (Fauvel 1953; Nayar 1959; Day 1967; Gosner 1971;

Fauchald 1977) after the estimation of numerical density (ind.m⁻²), and biomass (wet weight g.m⁻²). Feeding guild characteristics of the dominant macrobenthic fauna (polychaetes) in the CE were analyzed using the published literatures (Gosner 1971; Fauchald and Jumars 1979; Jumars et al. 2015). To evaluate the degree of the ecological importance of each trophic group, the trophic importance index (TI) was determined according to Paiva (1993) and modified by Muniz & Pires (1999), using the following formula:

$$TI = \sum_{i=1}^s \ln n_{i(+0.1)}$$

where *s* is the number of species of a trophic group in a defined area, *ln* is the natural logarithm, *ni* is the number of individuals (individuals counts) of the *i*th species, and 0.1 is a constant.

Statistical analysis

One way ANOVA was used to test the significance of variance in the data sets between different seasons, considering months as replicates (*n* = 4) for each season. Before the analysis, the D'Agostino and Pearson omnibus normality test was carried out to check their normality in distribution, and based on the result, parametric or nonparametric ANOVA was performed for the variables. Univariate and multivariate analyses of the macrobenthic density were carried out, using the PRIMER (version 6.1.5.); (Clarke and Warwick 2001). Univariate measures included Margalef's richness (*d*) for species richness, and Shannon-Wiener, (*H'*) (log2) for species diversity. To identify the different macrobenthic assemblages, multivariate analyses were carried out on the fourth root transformed density data. Bray–Curtis similarity index and group average linkage, were used for the cluster analysis and non-metric multidimensional scaling (NMDS) (Clarke and Warwick 1994). One way analysis of similarity (ANOSIM, with 999 permutations), which tests for the differences between groups of (multivariate) samples, from different locations was carried out, to define the differences between sites based on macrobenthic densities. CANOCO software (version 4.5) was employed to find out the influencing environmental variables with the macrobenthic fauna and their feeding types.

Results

Environmental parameters

The estuary was slightly warmer (26-33 °C) than the adjacent coastal waters (21.6-31.5 °C). Relatively low water temperature was recorded during MN in the estuary and in the coastal waters (Table 1). Salinity exhibited a significant seasonal variation (*p* < 0.05) in the estuary (0-33.9), while the variation was insignificant in the coastal waters (17.4-35). However, a noticeable decrease in salinity was recorded during MN in both locations. pH was comparatively higher in the adjacent coastal waters

(7.53 to 8.45) than the estuary (6.66 to 8.45). Relatively higher pH was recorded during PM whereas it was lower during PRM in the estuary and adjacent coastal waters. DO concentration varied from 0.20 to 8.04 mg/L in the estuary while it was 0.42 to 7.94 mg/L in the coastal waters. Seasonally, DO was relatively higher during PRM in both locations while lower concentration was observed during PM in the estuary and MN in the adjacent coastal waters. In the case of BOD, a significant seasonal variation ($p < 0.05$) was observed in the estuary (0.59 to 4.60 mg/L), while it was insignificant in the adjacent coastal waters (0.24 to 4.96 mg/L). BOD exhibited a higher concentration during non-monsoonal periods in the study area and a remarkable decrease was observed during MN. Relatively higher SPM levels ($>av.40$ mg/l) was observed in the CE and adjacent coastal waters irrespective of seasons.

Sediment texture showed a pronounced spatial variation in the estuary whereas in the coastal waters temporal variation was more evident. The sand fraction was varied from 0.05 to 82.3 % in the estuary and from 0.08 to 74.5 % in the adjacent coastal waters. The silt content was ranged from 0.61 to 79.58 % in the estuary and 2.21 to 65.5 % in the adjacent coastal waters. The clay fraction ranged from 1.5 to 96.04 % in the estuary and from 0.09 to 69.88 % in the adjacent coastal waters. A higher percentage of sand was observed during PRM in the estuary (av. 35.62 ± 32.97 %) and in the coastal waters (av. 40.84 ± 25.2 %) while, finer fractions (silt and clay) were recorded high during MN and PM (Table 1). The substratum of the upstream and near inlet station was dominated by clayey sand. While the substratum of the medium salinity zone was dominated by silt and clay particles, and the inlet region mostly consisted of silty sand. The substratum of the high salinity zone (except station 9) was mainly comprised of finer fractions of the sediment. Slightly high organic carbon was observed in the adjacent coastal waters (4.21 to 36.62 mg/g) compared to the estuary (2.07 to 34.40 mg/g). Organic carbon was high in stations dominated by finer fractions of the sediment. The significance of seasonal variations in the environmental and biological parameters is given in Table 2.

Macrobenthic community

Relatively high macrobenthic density and biomass were observed in the estuary (6 to 22680 Ind.m⁻², 0.07 to 206.52 g.m⁻²) than the adjacent coastal waters (14 to 2660 Ind.m⁻², 0.04 to 164.98 g.m⁻²). Seasonally, high macrobenthic density was observed during PM (av. 2335 ± 4378 Ind.m⁻²) and low during PRM (av. 1885 ± 1769 Ind.m⁻²) in the CE. While in the coastal waters, macrobenthic density was high during PRM (av. 1814 ± 1769 Ind.m⁻²) and low during PM (av. 821 ± 874 Ind.m⁻²) (Fig. 2a). The macrobenthic biomass exhibited a notable decline during MN period at both the study regions (Fig. 2b). The species diversity index varied from 0.90 to 3.75 in the estuary and from 0.13 to 3.49 in the coastal waters. Monsoon period exhibited apparently less species diversity both in the CE (av.

2.5±0.9) and also in the adjacent coastal waters (av. 1.9±0.7). Similar to diversity, species richness was also higher in the estuary (1.91 to 4.53) compared to the coastal waters (0.92 to 3.61) (Fig. 2c-d).

A total of 88 macrobenthic taxa belonging to 5 phyla were encountered in the estuary throughout the study period. The estuarine macrobenthic fauna mainly comprised of polychaetes (45.7 %), oligochaetes (32.2 %), amphipods (9.5 %), and isopods (5.8 %) during PRM; polychaetes (44.8 %), oligochaetes (39.6 %), and amphipods (10.3 %) during MN and bivalves (36.0 %), polychaetes (32.7 %), oligochaetes (13.2 %), amphipods (10.9 %), and tanaids (3.7 %) during PM respectively. On the other hand, the coastal waters recorded 58 macrobenthic taxa belonging to 6 phyla. During PRM, bivalves (85 %), polychaetes (9 %) and foraminiferans (5 %) were mainly represented the fauna. Polychaetes (57 %), foraminiferans (39 %), and bivalves (3 %) were relatively abundant during MN. Similarly, during PM polychaetes (86 %), bivalves (8 %), amphipods (3 %) and cumaceans (2 %) were the dominant macrobenthic fauna in the coastal waters. Throughout the study, polychaetes formed the dominant group, except during PM in the estuary and during PRM (bivalves dominated) in the coastal waters (Supplem. Table 1).

Among the non-polychaete taxa *Tubificidae* sp (28.2 %), *Perna* sp (9.8 %), *Caprella* sp (2.7 %), *Apeus chilkensis* (2 %), *Photis digitata* (1.6 %), and *Cheriphotis megacheles* (1 %) were the major representatives in the estuary. However, *Perna* sp, (44 %), foraminifera (11.8), *Villorita cyprinoides* (0.9 %), and *Pholas orientalis* (0.8 %) were the major non-polychaete taxa recorded in the adjacent coastal waters (Supplem. Table 1).

Polychaete community dynamics

A total of 53 polychaete species belonging to 25 families recorded in the CE throughout the study period (23 families during PRM, 14 families during MN, and 17 families during PM). Among them, Capitellidae, Onuphidae, Spionidae, Cirratullidae, Sigalionidae, and Pilargidae were the dominant families. Sigalionidae, Glyceridae, Pilargidae, Nephtyidae, Nereidae, Cirratulidae, Spionidae, Capitellidae, Lumbrinereidae, Onuphidae, Cossuridae, and Pectinaridae were the polychaete families encountered in the CE throughout the year (Supplem. Table 1). Species such as *Diopatra neapolitana* (20.8 %), *Mediomastus capensis* (19.7 %), *Prionospio cirrifera*, (11.7 %), *Pisione* sp (8.3 %), and *Sigambra parva* (5.5 %), were identified as the dominant species in the CE. Polychaete species, *Diopatra neapolitana* outnumbered all other species during PRM and PM whereas, during MN *Pisione* sp dominated in the estuary.

In the adjacent coastal waters, a total of 39 polychaete species belonging to 20 families (14 families during PRM, 13 during MN, and 16 during PM) were observed among which 6 species occurred throughout the study period. The major polychaete families encountered in the coastal waters were Spionidae, Cossuridae, Cirratulidae, and Lumbrinereidae. Polychaetes belonging to 7 families were present throughout the year which includes Goniadidae, Cirratulidae, Spionidae, Capitellidae, Lumbrinereidae, Cossuridae and Magelonidae. Species such as *Paraprionospio pinnata* (av. 850 Ind.m⁻²), *Cossura coasta* (av. 124 Ind.m⁻²), *Caulleriella capensis* (av. 51 Ind.m⁻²), *Aphroditidae* sp (av. 45 Ind.m⁻²), and *Lumbriconereis latreilli* (av. 34 Ind.m⁻²) were the dominated in the coastal waters (Supplem. Table 1). *Cossura coasta* dominated during PRM, whereas *Paraprionospio pinnata* was the major species during MN, and PM periods.

Bray-Curtis similarity (hierarchical clustering) based on species density, categorized the estuarine stations into two groups at 40 % similarity level (Fig. 3a). Within the estuary the stations dominated with sandy substratum constituted one group (upstream & near inlet); the stations having finer sediments formed another group (central estuary) whereas the inlet formed a separate group (having high salinity and coarser substratum). Prominent disparity between the stations has been confirmed from the results of ANOSIM analysis (Global R value 0.658, p value 0.1%). The results of the NMDS also showed a similar pattern of distinct groups of the stations. In the coastal waters, Bray-Curtis similarity based on species density categorized the stations into three groups at 40 % similarity (Fig. 3b). The resultant clustering of the coastal stations was mainly based on seasons. Prominent seasonal variation was evident from the ANOSIM analysis (Global R. 0.563, p value 0.3 %) also. Cluster and MDS analysis performed for all the stations together showed a significant disparity between the estuarine and coastal stations (ANOSIM- Global R. 0.844, p value 0.1 %).

Redundancy analysis was performed (CANOCA 4.5) to evaluate the relationship of macrobenthic density, macrobenthic biomass and dominant polychaete species with the environmental parameters. In the estuary, macrobenthic density exhibited a positive relationship with the salinity (during PM -strong affinity), and sand during the entire study period. However, the macrobenthic biomass showed a positive correlation with the abiotic parameters such as salinity, SPM and sand (Fig. 4a-c). The coastal waters showed a positive relationship of macrobenthic density with clay during PRM and MN and with sand during PM (Fig. 4d-f). In addition, macrobenthic density exhibited a positive relationship with SPM during MN and PM periods. Macrobenthic biomass exhibited a positive relationship with SPM and sand during PRM and PM.

Species such as *Sigambra parvae*, *Cossura coasta*, *Nephtys oligobranchiata*, and *Cirratulus filiformis* exhibited positive relationship with clay and organic carbon in the CE (Fig. 4d-f). Species

like *Diopatra neapolitana*, *Paraprionospio pinnata*, and *Lumbriconereis latreilli*, showed positive correlation to sand and salinity. *Diopatra neapolitana*, *Sabellid* sp and *Syllid* sp were exhibited a positive relationship with SPM. In the coastal waters, the species *Cossura coasta* exhibited positive correlation with SPM. Species *Magalona capensis* showed a positive relationship with sand and SPM during PRM and PM periods. Polychaetes such as *Goniada emerita*, and *Paraprionospio pinnta* exhibited a positive relationship to sandy substratum.

Polychaete feeding guild and ecology

Feeding guild analysis organized the polychaetes into 13 guilds in the estuary and 11 types in the coastal waters. In the estuary, the CDJ (carnivorous, discretely motile, and jawed) and the BMX guild (sub-surface deposit feeder, motile, with other structures, usually eversible sac-like pharynges) were the predominant feeding guilds accounting for 32.9 % (dominated by *Diopatra neapolitana*) and 32.7 % (mainly represented by *Mediomastus capensis*) during PRM (Table 3). During MN, the CMJ guild (carnivorous, motile, and jawed- 29.2 %) was dominated followed by the SDT (surface deposit feeder, discretely motile and tentaculate - 27.9 %) and the BMX guild (24.2 %). The CDJ guild (33.2 %) was followed by the BMX (20.8 %), the CMJ (13.4 %) and the SDT (13.3 %) feeding guilds during PM. Hence, along a seasonal scale carnivores (CR) were the dominant feeding mode in the CE during PRM and PM periods (constituted by CMJ, CDJ, CMX, CMJ/CDJ), while surface deposit feeders (SDF) dominated during MN (constituted by SDT, SMT, SDJ, SST, SMX) (Fig. 5a). The BMX was the dominant guild (mainly represented by the species *Cossura coasta*) in the coastal waters during PRM, whereas SDT was the major guild during MN and PM periods (mainly represented by *Paraprionospio pinnata*) (Table 3). Therefore, in the adjacent coastal waters SSDF (sub-surface deposit feeders) was the major feeding guild during PRM (constituted by BMX, BSX, av. 67.2 %) and was replaced by SDF during MN (SDT, SMT, SMX) and PM (constituted by SDT, SMT, SST) season (av. 85.6 %, 72.3 %) (Fig. 5b).

The trophic importance index (TI) values were higher in the estuary (CR av. 5.7 ± 3.9 ; SDF av. 6.0 ± 3.6 ; SSDF av. 3.8 ± 2.3 ; FIL av. 0.8 ± 1.5 ; HR av. 0.1 ± 0.3) than the coastal waters (CR av. 3.1 ± 2.4 ; SDF av. 3.6 ± 2.2 ; SSDF av. 3.1 ± 1.9 ; FIL av. 0.3 ± 0.6 ; HR av. 0.3 ± 0.5) (Fig. 5c-d). Each trophic group exhibited a distinct seasonal variation in the TI index in the study area. In the estuary, CR, SDF and HR showed high TI index during PRM and low index during MN, while SSDF and FIL exhibited relatively higher index during PRM and lower during PM. In the coastal waters, CR exhibited higher TI index during PM and lower during PRM; SDF showed slightly higher index during MN and lower during PRM; SSDF showed high index during PRM and low during MN, and FIL exhibited higher index during PM than MN.

The multivariate analysis performed to understand the relationship between polychaete feeding groups and environmental factors pointed towards the association of diverse feeding guilds with sandy substratum both in the estuary and coastal waters (Fig. 6). Though CR and filter feeders (FIL) were mostly found associated with coarser sediments (sand), the trophic groups exhibited a distinct spatial variation along with the changes of environmental gradients (Fig. 6a-f). The SMT guild (surface deposit feeding, motile and tentaculate) often found to be associated with finer sediments and organic carbon during the study.

Discussion

The existence of biological communities in the aquatic ecosystems depends on the ability of these organisms to cope with the physical environment and their abiotic interactions (Cadotte et al. 2013). The persistent changes in the physico-chemical properties of an aquatic ecosystem directly or indirectly influence the survival of the biotic components of the system. The present study describes community ecology and trophic structure of the macrobenthic fauna of the CE and adjacent coastal waters, which is obviously characterized with distinct hydrographical properties.

In the CE, the bottom of the estuarine region comprises the sediment load brought from the rivers as well as the transport from sea to the estuary through tidal activities (Gopinathan and Qasim 1971; Veerayya and Murty 1974). A higher percentage of coarser particles (sand) observed in the estuary during PRM indicates the transport of sand from the AS to the estuary through tidal currents (Veerayya and Murty 1974; Hossain et al. 2014). The high percentage of sand particles recorded at the inlet location (during PRM) and near inlet location (during PM) clearly validates the above statement. Similar to the CE, the adjacent coastal waters also sustained with a significantly higher percentage of coarser particles during PRM. Spatially, a higher percentage of sand particles apparent at the upstream station in the estuary, during MN indicate its riverine origin. According to Liu et al. (2010), coarser particles are deposited to the upstream of the estuary as a result of the selective deposition. Sediment organic carbon was relatively less in the estuary during MN as estuarine waters normally undergo higher dilution during this period. The heavy flushing out of the estuary might have led to the higher organic carbon in the coastal waters during MN and PM periods. The present study has evidenced higher organic carbon content at stations having finer sediment texture. Fine sediment particles have a greater surface area and greater ability to retain more organic carbon compared to the coarser sediment particles (Nayar et al. 2007). The organic load brought about by the discharge of domestic wastes from the nearby human settlement areas might also contribute towards its increased concentration in the estuarine channels and adjacent coastal area (Anon 1996; Ingole et al. 2009).

The present study has evidenced relatively higher macrobenthic density in the CE compared to the adjacent coastal waters. The higher density of bivalves observed during PM in the estuary and during PRM in the coastal waters contributed correspondingly to higher macrobenthic density in the respective seasons. The observed increase in the density of macrobenthic fauna in the CE after MN period may be the outcome of the intensive recruitment process as part of the stabilization of the environment (Harkantra and Rodrigues 2003). Earlier studies also showed similar results of decreased macrobenthic density during MN and increased density during PM periods (Sivadas et al. 2011).

Generally, in tropical estuaries macrobenthic fauna exhibits a marked decline during MN, and increased recruitment during PM period (Parulekar et al. 1980; Sivadas et al. 2011). In the present study, though the macrobenthic density exhibited an increase after MN through PM, the decline in density evident during the stable PRM indicates towards the increased intensity of anthropogenic pressures, in particular, the dredging activities conducting in the CE. Our recent study documented a significant decrease in standing crop and also the differences in community composition in the CE as a result of continuous dredging activities (Rehitha et al. 2017). Higher macrobenthic biomass observed in the CE during PRM and PM was mainly contributed by the dominance of large sized polychaetes (*Diopatra neapolitana*). In the coastal waters, the larger sized bivalves (*Villorita cyprinoides* and *Pholas orientalis*) contributed to the higher biomass during PM period.

In addition to the standing crop, the number of macrobenthic taxa was also relatively higher in the CE (88 taxa in 5 phyla) as compared to the coastal waters (58 taxa in 6 phyla). A higher number of macrobenthic taxa evidenced in the CE was due to its warm, euryhaline, oxygenated and nutrient enriched waters as compared to the coastal waters. Species diversity was maximum during PM and minimum during MN period. Heavy monsoonal rainfall and associated land runoff apparently lead to severe stress on benthic communities during MN (Pillai 1977; Alongi 1989), resulting in less species diversity. Coastal waters also exhibited a reduction in the benthic species diversity during MN. Heavy precipitation associated with MN and the subsequent salinity variations imparts various types of stress on benthic community (Kinne 1977; Osman 1977; Alongi 1990).

Earlier studies have pointed out the influence of salinity on the distribution of macrobenthic fauna in estuaries (Sanders et al. 1965; Kennish et al. 2004; Sivadas et al. 2011). The present study also evidenced a positive correlation of salinity with estuarine macrobenthic standing stock, as the macrobenthic density increased during PM and biomass exhibited an increase during PRM and PM periods (Fig. 4). In addition to salinity, sediment texture and composition are considered to have a prominent influence on community structure of the macrobenthic fauna (Gray 1974; Mannino and Montagna 1997; Kennish 2001; Kennish et al. 2004). In the CE, the macrobenthic standing stock

(density and biomass) exhibited a positive relationship with the sand fraction of the sediment throughout the study period (Fig. 4a-c). However, in the coastal waters, macrobenthic density exhibited a positive relationship with clay except during PM (positive affinity with sand) (Fig. 4d-f). Macrobenthic biomass showed a positive relationship with sand except during MN (positive affinity with silt). In addition, SPM and organic carbon were also observed to influence the macrobenthic standing stock in the estuary and coastal waters. In view of the above findings, it can be stated that the macrobenthic standing stock in the CE apparently exhibits an intrinsic affinity towards the sediment substratum and also the food availability, though a pronounced seasonal variation exists.

As discussed above, the macrobenthic community of the CE and adjacent coastal waters are dominated by polychaetes as they display high stability and adaptability to different habitats (Simboura et al. 1995; Simboura et al. 2000) with various feeding strategies (Fauchald 1977). Earlier studies in the tropical coastal regions also showed the dominance of polychaetes in the macrobenthic community (Jayaraj et al. 2007; Ingole et al. 2009; Mandal and Harkantra 2013). The polychaete *Diopatra neapolitana*, which are known to inhabit muddy sand bottoms (Conti and Massa 1998; Gambi et al. 1998; Dagli et al. 2005), dominated in the CE (at near inlet and inlet) during PRM and PM. The RDA plot also a positive correlation was observed between the density of the species, salinity and sand. The salinity drop and change in the sediment texture during MN might have resulted in the rapid reduction in the density of this particular species during the season. *Diopatra neapolitana* are tubicolous worms which are known to build tubes out of sand grains and detritus and harbor a variety of other invertebrates on their tubes. The bivalves and amphipods were observed in the tubes of this tubicolous worm. But during MN, *D. neapolitana* was replaced by the higher abundance of *Pisione* sp, at the inlet region. *Pisione* sp is a small interstitial highly motile annelid usually found in high energy habitats with coarse sediments (Withers and Thorp 1978; Vanosmael et al. 1982) or coastal waters stirred by waves (Peres 1967; Quintino et al. 1989). Opportunistic polychaetes such as *Mediomastus capensis*, *Sigambra parva*, *Paraheteromastus tenuis*, and *Prionospio cirrifera* were also found to be abundant in the CE. The dominance of many opportunistic polychaetes recorded in the CE during the present study may be attributed to the presence of organic rich sediments in combination with other anthropogenic disturbances such as dredging activities and discharge of sewage effluents. In the coastal waters, the polychaete species *Paraprionospio pinnata* was observed to dominate throughout the sampling period except during PRM. Their life cycle normally enables them to inhabit disturbed areas quickly. Since they are surface deposit feeders, they can efficiently utilize the organic materials brought about by the monsoonal rainfall and associated land runoff (Blake and Arnofsky 1999; Rouse and Pleijel 2001). The extended branchiae of *P. pinnata* aid them in efficiently capturing suspended

food particles (Levin et al. 2003). *Cossura coasta*, another polychaete species considered as indicators of sediment instability (Ellis et al. 2000) were found to dominate in the coastal waters during PRM. This species has been reported from the CE and coastal waters of AS, where riverine inputs are more (Abdul Jaleel et al. 2014; Rehitha et al. 2017). Among the non-polychaete taxa observed in the CE, tubificid Oligochaeta and Tanaid (*Apseudus chilensis*) exhibited higher density at stations predominated by finer sediments with high organic carbon (central estuary). Pollution indicator and tolerant species such as *Capitella capitata*, *Cossura coasta*, *Dendronereis estuarina*, *Lycastis indica*, *Mediomastus capensis*, *Paraheteromastus tenuis*, *Prionospio cirrobranchiata*, *Prionospio polybranchiata* and *Apseudus chilensis* were also recorded in the CE during the study period. Foraminiferans formed the major non-polychaete taxa in the coastal waters especially at the high saline station, situated nearer to the estuary. Their occurrence at coastal waters indicates their preference for marine habitats. The higher density of foraminiferans in the estuarine mouths during MN period might be associated with the higher food availability brought in by the river runoff.

Spatial variation in the macrobenthic community was more prominent in the CE than its seasonal variations, which was evident from the results of the multivariate analysis (Fig. 3a). However, the trend was slightly reverse in the coastal waters, wherein the seasonal variation in the macrobenthic density was more prominent than the spatial variation (Fig. 3b). From these results, it can be stated that macrobenthic faunal distribution both in the CE and its adjacent coastal waters was primarily linked to the sediment texture. The spatial variation occurring in the sediment texture of the CE was reflected in the macrobenthic density as well. In contrast, the coastal waters exhibited seasonal variation in sediment texture and it was more obvious in the macrobenthic density as well.

Polychaetes usually exhibit a wide range of feeding guilds (Snelgrove 1998), which are known to vary depending on various physico-chemical (e.g. sediment characteristics, salinity) and biological factors (e.g. food availability from detritus, microbial and macrobenthic fauna) (Magalhaes and Barros 2011). SDF and SSDF (together detritivores) are the two modes of deposit feeding exhibited by polychaetes, in which the former ingest the food particles from sediment surface while the latter ingest food particles by burying inside the sediments. The dominance of detritivores both in the CE and its adjacent coastal waters (SDF and SSDF together), indicates the significance of organic detritus as a major energy source for the macrobenthic fauna as evident from the results of the TI index. Earlier studies have revealed the importance of detritus as a food source for many estuarine and inshore organisms (Newell 1965). The sources of organic detritus in the CE include plankton, benthic algae, rooted plants, animal matter, suspended soft mud and silt particles brought down by rivers (Qasim and Sankaranarayanan 1972). The heavy monsoonal rains and runoff bring in high organic matter and

detritus that might be well exploited by the surface deposit feeders leading to their higher proliferation in the estuary during MN and PM. Even though it is a source of energy, the dominance of detritivores is also an indication of a stressed and eutrophic environment (Weston 1990; Hossain 2018).

In the estuary, the carnivores dominated during PRM and PM periods (constituted by CMJ, CDJ, CMX, CMJ/CDJ) among which, the polychaetes family Onuphidae was dominated. The disturbance generated by the heavy rainfall and runoff might have resulted in the decrease in density of the species (family Onuphidae) during MN. Though SSDF (BMX) was the second dominant feeding guild in the CE during PRM, the trophic importance index showed second dominance for the SDF guild (constituted by SDJ, SMT, SST, SDT, SMX, SST). Likewise, during PM, the trophic importance was higher for the SDF group (constituted by SDJ, SMT, SST, SDT) than CR (constituted by CMJ, CMX, CDJ, CMJ/CDJ). Though these species exploit the same food resource, they do not compete with each other as they have different means of motility and different food procuring structures (Muniz and Pires 1999). In the coastal waters, sub-surface deposit feeders (BMX, BSX) dominated during PRM was replaced by surface deposit feeders during MN (constituted by SDT, SMT, SMX) and PM (constituted by SDT, SMT, SST) periods by the effective utilization of the food resources brought by the monsoonal runoff. Previous studies in the nearshore waters of the south-west coast of India suggested the influence of estuarine inputs on coastal sediments (Jayaraj et al. 2008b; Joydas and Damodaran 2009). Filter feeders, though less abundant were comparatively higher in both estuary and coastal environments during PRM. As they need a stable substratum to attach and filter particles, the relatively stable PRM period might have supported the higher density of filter feeders. Filter feeders process the organic matter in the water column whereas the deposit feeders ingested the deposited detritus. Carnivores, by consuming the deposit feeders transfer the nutrients reserved in detritus to the food cycle. Domination of carnivores during non-monsoonal periods indicates higher carbon flux in the estuary.

The sandy substratum supporting diverse feeding guilds in the estuary and the coastal waters may be due to the higher diversity of microhabitats in coarse sediments. Moreover, the occurrence of a higher density of carnivores pointing towards the availability of higher prey items in the sediment interspaces. The trophic importance index also showed higher values at stations predominated by sandy substratum. The affinity of filter feeders to the sandy substratum clearly indicates its preference to high energy habitats with high availability of suspended particles. The energy in these habitats is sufficient to resuspend small quantities of material without causing obstruction to the filtration structures of the organisms (Sanders 1958; Hily and Le Bris 1984; Muniz and Pires 1999). Previous studies also reported on the abundant occurrence of filter feeders in sediments with a lower fine fraction (Garcia-

Arberas and Rallo 2002). Motile and discretely motile polychaetes were also found mostly associated with the sand as they can move easily through it.

Conclusions

The present study brought out comprehensive information on macrobenthic community structure, distribution patterns and polychaete trophic ecology along a tropical estuary, the Cochin estuary (CE) and its adjacent coastal waters for a year. Seasonal species shifts have been evident in the study region with respect to the prevailing environmental changes brought about mainly by the southwest monsoon. Also, the presence of a variety of opportunistic macrobenthic species and detritivores evident in the study clearly points towards the increased stress on the benthic community from several anthropogenic interferences. Polychaetes formed the dominant taxa in terms of species diversity and richness. The analysis of trophic ecology of polychaetes revealed that carnivores and detritivores were the dominant and trophically important feeding guilds. Further, the dominance of detritivores throughout the study period indicates towards the detritus food web sustaining the benthic production of the CE. The present study also reveals the existence of diverse feeding modes in association with the sandy substratum. Since polychaetes are the dominant macrobenthic fauna, studies on their feeding ecology will give information about the benthic ecosystem structure. The spatio-temporal changes occurred in the trophic guilds, as a result of several anthropogenic activities would be ultimately reflected in the food cycle of the estuary to the top predators like demersal fishes.

Acknowledgements

The authors are thankful to the Director, CSIR-National Institute of Oceanography (NIO), Goa and the Scientist-in-Charge, Regional Centre, CSIR-NIO, Cochin for the facilities provided during the study period. Funding provided by Cochin Port Trust (CPT), Cochin is gratefully acknowledged. The first author thanks Council of Scientific & Industrial Research, (CSIR) Govt. of India for providing Research Associate funding. This is NIO contribution number

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Parameter	PRM		MN		PM	
	Estuary	Coastal	Estuary	Coastal	Estuary	Coastal
Temperature (°C)	30.3±0.9	29.2±1.6	28.3±1.6	24.9±2.9	28.9±1.0	29.5±0.9
Salinity	16.3±10.4	28.0±4.4	7.5±8.7	25.8±7.1	18.5±9.2	30.8±4.8
pH	7.6±0.5	8.0±0.3	7.6±0.4	8.03±0.1	7.9±0.3	8.3±0.1
DO (mg/l)	5.02±1.4	5.5±1.3	4.6±1.5	1.6±1.3	4.4±1.5	5.3±1.4
BOD (mg/l)	2.5±1.0	2.8±1.1	1.7±0.8	0.8±0.7	2.2±0.4	2.8±0.8
SPM (mg/g)	41.2±27.7	86.4±67.1	44.5±42.1	86.5±67.5	52.0±35.1	58.2±34.5
Sand (%)	35.6±33.0	40.8±25.2	27.0±22.3	11.1±15.4	30.5±27.5	16.6±17.6
Silt (%)	27.4±14.6	35.1±13.5	29.2±17.3	39.6±13.8	30.4±23.2	30.9±15.0
Clay (%)	36.9±21.5	24.0±19.3	43.7±20.7	44.5±15.0	39.15±20.0	52.5±14.2
OC (mg/g)	18.3±7.5	15.2±5.1	13.1±5.6	19.1±11.8	17.13±8.1	22.0±7.5

Table 1 Seasonal variation of physicochemical parameters in the Cochin estuary and adjacent coastal waters

DO dissolved oxygen, BOD biological oxygen demand, SPM suspended particulate matter, OC organic carbon

Table 2 Results of One way ANOVA of major biotic and abiotic parameters in the Cochin Estuary and adjacent coastal waters (* - p<0.05, ** - p<0.01).

Parameter	Seasonal							
	Estuary				Coastal			
	df	MS	F	p value	df	MS	F	p value
Temperature (°C)	2	37.7	22.2	1.2	2	64.14	21.51	6.34
Salinity	2	906.9	10.1	0.0001**	2	74.8	2.78	0.08
pH	2	0.85	5.54	0.01*	2	0.483	11.88	0.0001*
DO (mg/l)	2	2.5	1.17	0.32	2	46.88	24.83	1.45
BOD (mg/l)	2	3.9	6.3	0.002* *	2	12.64	14.93	1.77
SPM (mg/g)	2	939.3	0.75	0.48	2	4049.6	1.23	0.30
Sand (%)	2	423.4	0.56	0.58	2	2804.5	6.95	0.003**
Silt (%)	2	53.1	0.15	0.86	2	207.56	1.02	0.37
Clay (%)	2	282.5	0.66	0.52	2	2834.3	10.7	0.0002*
OC (mg/g)	2	179.2	3.49	0.04*	2	158.75	2.49	0.10
Density (Ind.m ⁻²)	2	143766	0.15	0.86	2	513092	0.39	0.67
Biomass (g.m ⁻²)	2	1499.2	1.13	0.33	2	761.4	1.36	0.26

DO dissolved oxygen, BOD biological oxygen demand, SPM suspended particulate matter, OC organic carbon

Table 3 Density (%) of different feeding guilds of polychaetes in the Cochin estuary and adjacent coastal waters displayed in the three letter codes, the letter in first position indicates major mode, the second the motility pattern, and the last letter the morphological structure used in feeding; in position 1- B, subsurface deposit feeder; C, carnivore; F, filter feeder; H, herbivore; S, surface deposit feeder; in position 2-D, discretely motile; M, motile; S, sessile; in position 3-J, jawed; P, pumping; T, tentaculate; X, other structures, usually eversible sac-like pharynges.

Taxa	Feeding guilds		Estuary			Coastal		
			PRM	MN	PM	PRM	MN	PM
<i>Aphroditidae</i>	CMJ	CR	0.46	0	0.17	0	0.00	6.49
<i>Etone</i> sp	CMX	CR	0	0	0.08	0	0	0
<i>Sthenelais boa</i>	CMJ	CR	0.08	0	0	0	0	0
<i>Harmathoe</i>	CMJ/CDJ	CR	0.08	0	0	0	0	0
<i>Amphinomidae</i>	CMX	CR	0.31	0	0	0	0	0
<i>Amphinomea rostrata</i>	CMX	CR	0.08	0.10	0	0	0	0
<i>Ophiodromous</i> sp	CMJ	CR	0.08	0	0.00	0.75	0.26	0.00
<i>Goniada emerita</i>	CDJ	CR	1.05	0	0.17	2.24	0.26	3.10
<i>Glycera longipinnis</i>	CDJ	CR	0.46	0.14	0.34	0.00	0.00	0.00
<i>Sigambra parva</i>	CMJ	CR	8.54	4.72	3.24	2.24	0.00	0.00
<i>Sigambra</i> sp	CMJ	CR	0.10	0.19	0.00	0.00	0.79	0.00
<i>Pisione</i> sp	CMJ	CR	0.00	21.38	2.35	0.00	0.00	0.00
<i>Syllid</i> sp	CMJ	CR	0.00	0.00	2.85	0.00	0.00	1.44
<i>Nephtys dibranchia</i>	CMJ	CR	0.08	0.00	0.00	1.49	0.00	0.00
<i>Nephtys oligobranchia</i>	CMJ	CR	2.69	1.37	2.73	0.00	0.00	2.89
<i>Nephtys polybranchiata</i>	CMJ	CR	0.08	0.10	0.01	0.00	0.00	0.02
<i>Nephtys lyrochaeta</i>	CMJ	CR	0.00	0.07	0.00	0.00	0.00	0.00
<i>Lycastis indica</i>	CMJ	CR	0.31	0.50	1.01	0.00	0.00	1.26
<i>Lumbriconereis latreilli</i>	CMJ/CDJ	CR	2.38	0.86	2.10	3.73	3.93	1.33
<i>Lumbriconereis</i> sp	CMJ/CDJ	CR	0.61	0.00	0.10	0.75	0.79	0.00
<i>Ninoe pulchra</i>	CMJ	CR	0.15	0.00	0.00	0.00	0.52	0.14
<i>Diopatra neopolitana</i>	CDJ	CR	31.34	1.01	32.69	0.75	0.00	0.56
<i>Nereis</i> sp	CMJ/CDJ	CR	0.84	0.86	1.01	0.00	0.26	0.00
<i>Dendronereis estuarina</i>	SDJ	SDF	1.30	5.06	2.22	0.00	0.00	0.00
<i>Cirratulus cirratus</i>	SMT	SDF	1.46	0.22	0.67	0.75	0.26	0.00
<i>Cirratulus filiformis</i>	SMT	SDF	1.30	0.38	6.89	0.00	0.00	0.00
<i>Caulleriella capensis</i>	SMT	SDF	0.10	8.63	2.01	0.00	2.62	5.59
<i>Dodecaceria</i> sp	SST	SDF	0.61	0.19	4.78	0.00	0.00	0.20
<i>Prionospio cirrifera</i>	SdT	SDF	4.68	17.76	12.40	0.00	0.52	0.00

<i>Prionospio</i>								
<i>cirrobranchiata</i>	SDT	SDF	0.84	0.07	0.08	0.00	0.00	0.00
<i>Paraprionospio pinnata</i>	SDT	SDF	0.08	8.13	0.01	16.42	76.18	66.26
<i>Prionospio</i>								
<i>polybranchiata</i>	SDT	SDF	0.00	0.72	0.00	0.00	0.00	0.00
<i>Laonice cirrata</i>	SDT	SDF	0.38	0.65	0.00	0.00	0.00	0.00
<i>Prionospio</i> sp	SDT	SDF	0.23	0.36	0.01	0.75	0.26	0.00
<i>Spionidae</i>	SDT	SDF	1.56	0.10	0.08	0.00	2.88	0.02
<i>Scolecopsis squamata</i>	SDT	SDF	0.15	0.14	0.00	0.00	0.26	0.00
<i>Aricidea</i>								
<i>longobranchiata</i>	SMX	SDF	0.08	0.07	0.00	0.75	1.31	0.00
<i>Aricidea capensis</i>	SMX	SDF	0.00	0.00	0.00	0.00	0.26	0.00
<i>Owenia fusiformis</i>	SDT	SDF	0.54	0.00	0.76	0.00	0.26	0.18
<i>Streblosoma</i> sp	SST	SDF	0.15	0.00	0.00	0.00	0.00	0.00
<i>Pectinaria</i> sp	BMX	SSDF	0.20	0.38	3.11	0.00	0.79	0.18
<i>Capitella capitata</i>	BMX	SSDF	1.23	0.36	0.54	0.00	0.00	0.00
<i>Mediomastus capensis</i>	BMX	SSDF	24.61	18.55	16.04	6.72	0.52	1.86
<i>Paraheteromastus</i>								
<i>tenuis</i>	BMX	SSDF	4.83	3.81	1.02	0.00	0.00	0.02
<i>Capitellidae</i>	BMX	SSDF	0.00	0.86	0.08	0.00	0.26	0.02
<i>Cossura coasta</i>	BMX	SSDF	1.87	0.24	0.03	44.78	4.19	4.11
<i>Sternaspis scutata</i>	BMX	SSDF	0.00	0.00	0.00	9.70	0.00	1.12
<i>Magalona cinta</i>	BMX	SSDF	0.00	0.00	0.00	4.48	0.00	0.25
<i>Megalona capensis</i>	BMX	SSDF	0.00	0.00	0.00	0.00	1.31	0.18
<i>Maldane sarsi</i>	BSX	SSDF	0.00	0.00	0.00	1.49	0.00	0.00
<i>Polydora ciliata</i>	FDT	FIL	0.31	0.00	0.00	1.49	0.00	0.00
<i>Polydora capensis</i>	FDT	FIL	0.00	0.00	0.00	0.00	0.00	0.00
<i>Boccardia polybranchia</i>	FDT	FIL	0.77	2.01	0.34	0.00	0.00	0.05
<i>phalacrostemma</i>								
<i>elegans</i>	FST	FIL	0.31	0.00	0.00	0.00	0.00	0.00
<i>Sabellaria</i> sp	FST	FIL	2.30	0.00	0.00	0.00	0.00	0.00
<i>Serpulidae</i>	FST	FIL	0.08	0.00	0.00	0.00	0.00	0.00
<i>Chaetopteridae</i>	FSP	FIL	0.15	0.00	0.00	0.00	0.00	2.71
<i>Lumbriconereis</i>								
<i>impatiens</i>	HMJ	HR	0.15	0.00	0.10	0.75	1.31	0.00

Figures

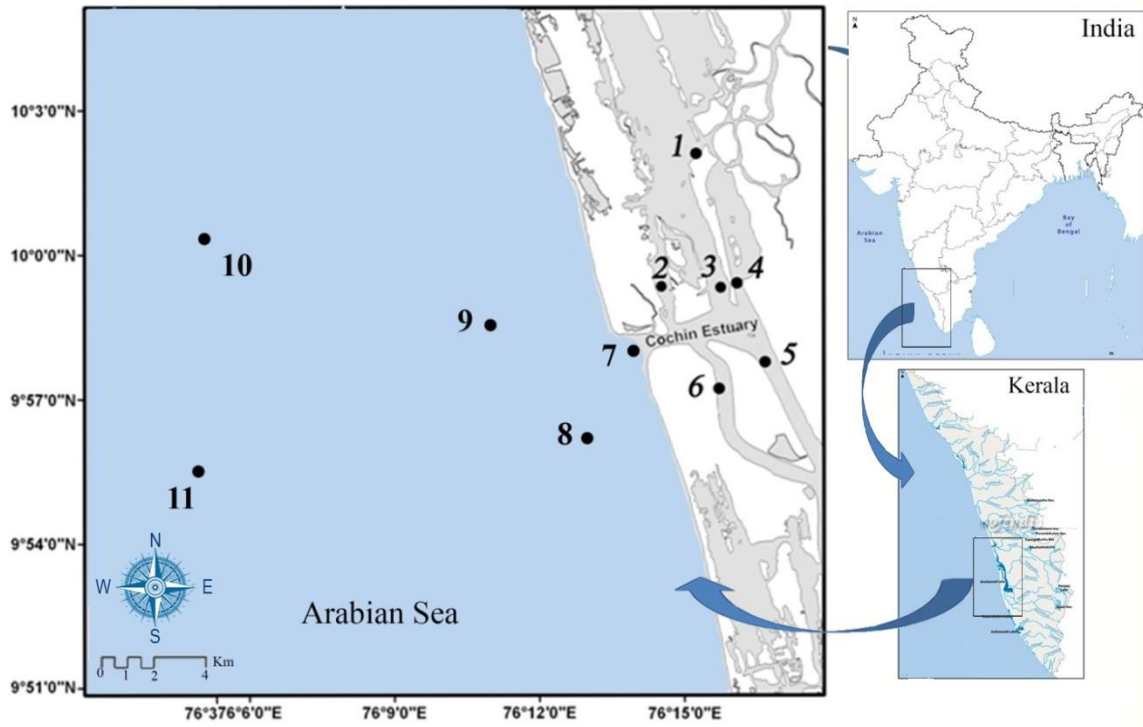


Fig.1. Study area and sampling locations.

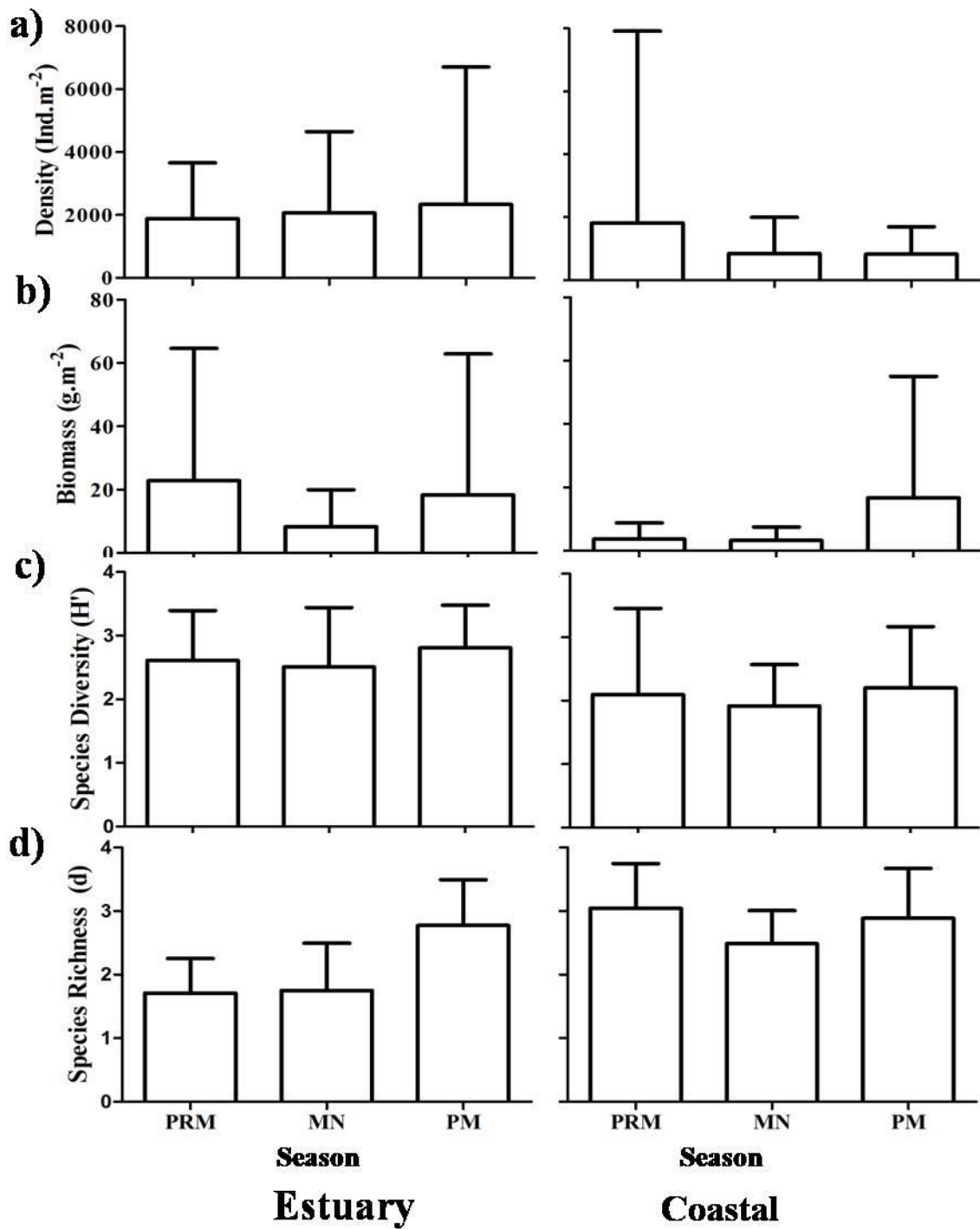


Fig. 2. Seasonal distribution of (a) macrobenthic density, (b) macrobenthic biomass, (c) species diversity and (d) richness in the Cochin estuary and adjacent coastal waters.

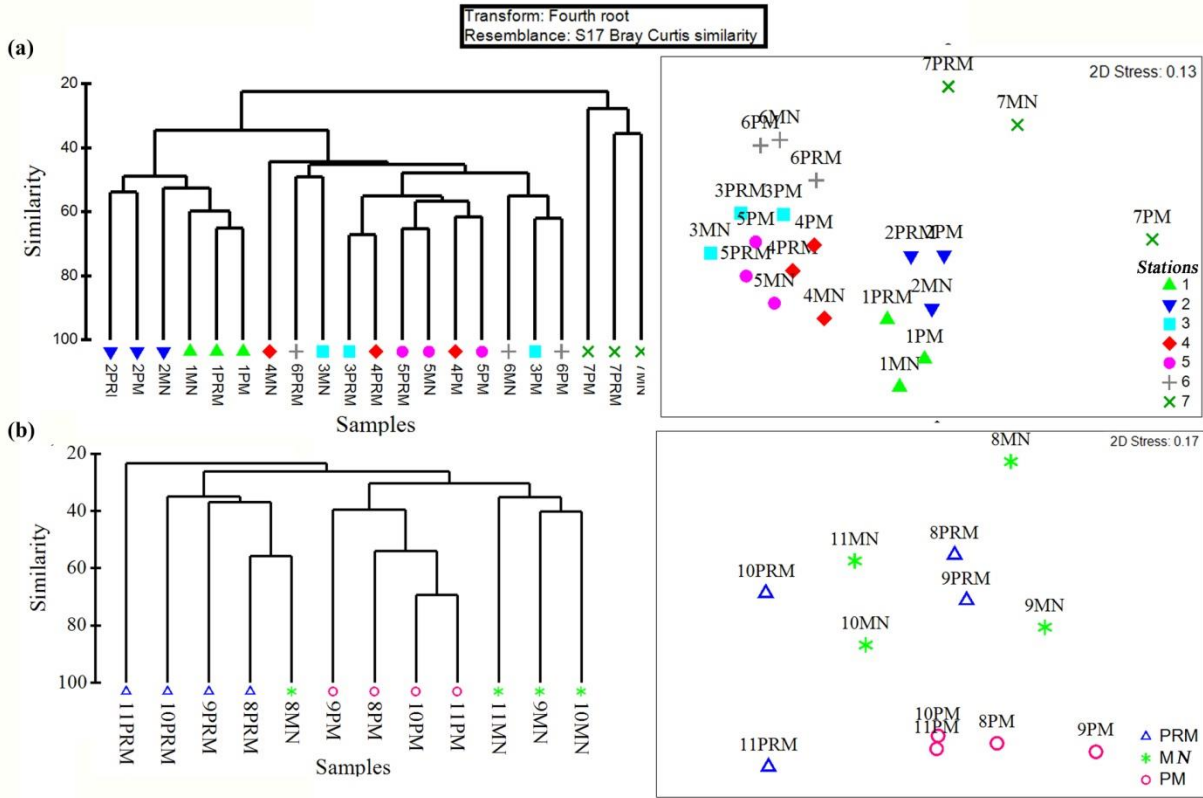


Fig. 3. Bray Curtis similarity based on hierarchical clustering of stations manifested through dendrogram and NMDS (non-metric multidimensional scaling) showing macrobenthic assemblage pattern a) in the Cochin estuary and b) the adjacent coastal waters.

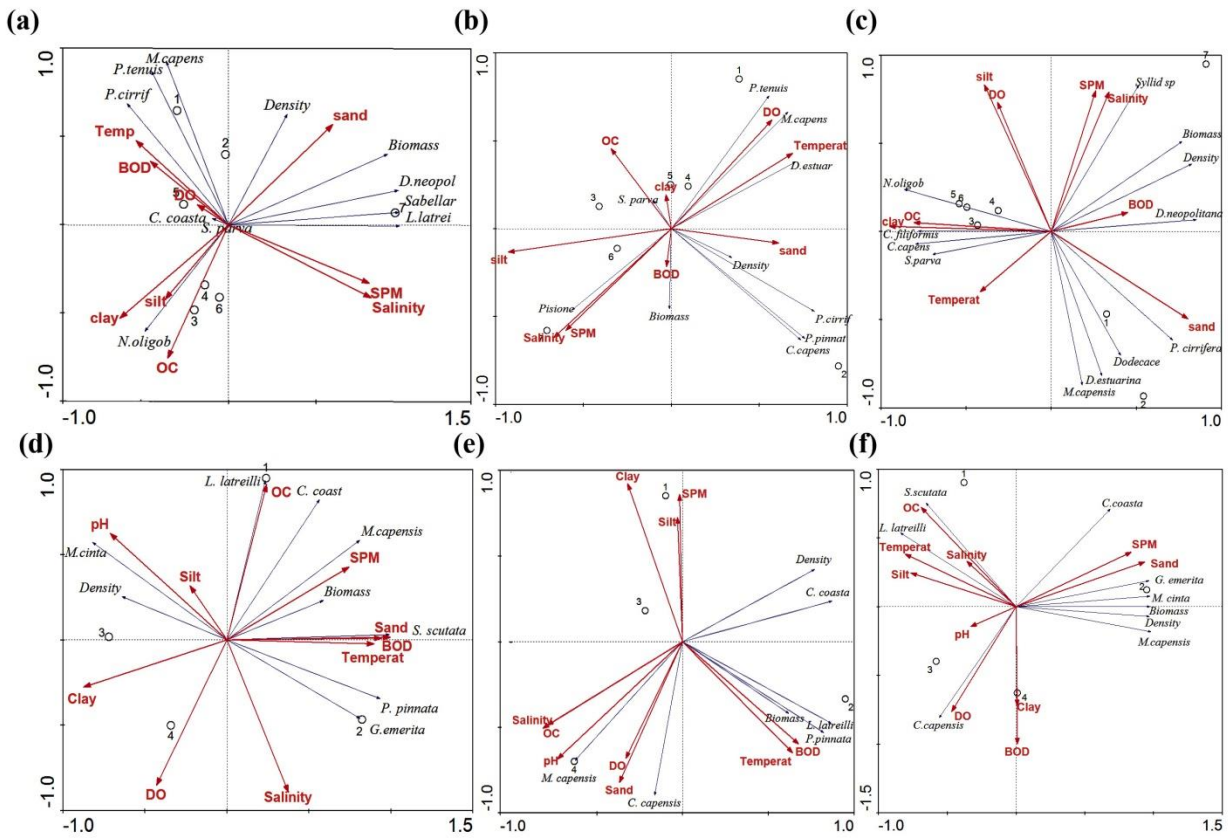


Fig. 4. The RDA plot showing the factors influencing on the macrobenthic community in the Cochin Estuary (a-c) and adjacent coastal waters (d-f) during pre-monsoon, monsoon and post monsoon season respectively.

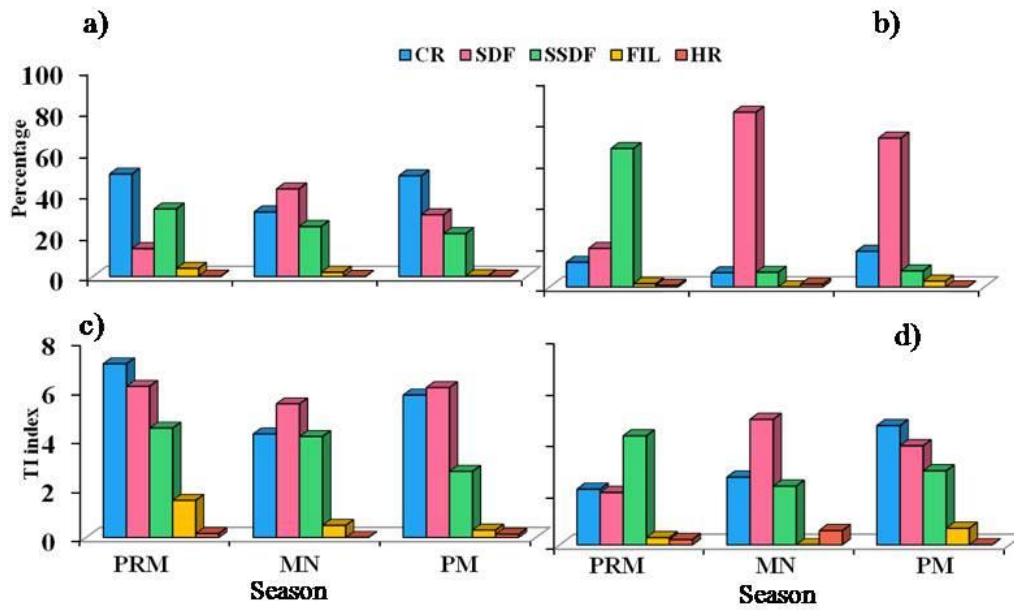


Fig. 5. Seasonal variation of polychaete feeding guilds and the trophic importance index (Ti index) in the Cochin estuary (a & c) and adjacent coastal waters (b & d) (CR-Carnivore, SDF- Surface deposit feeder, SSDF-sub-surface deposit feeder, FIL-filter feeder, HR-herbivore) respectively.

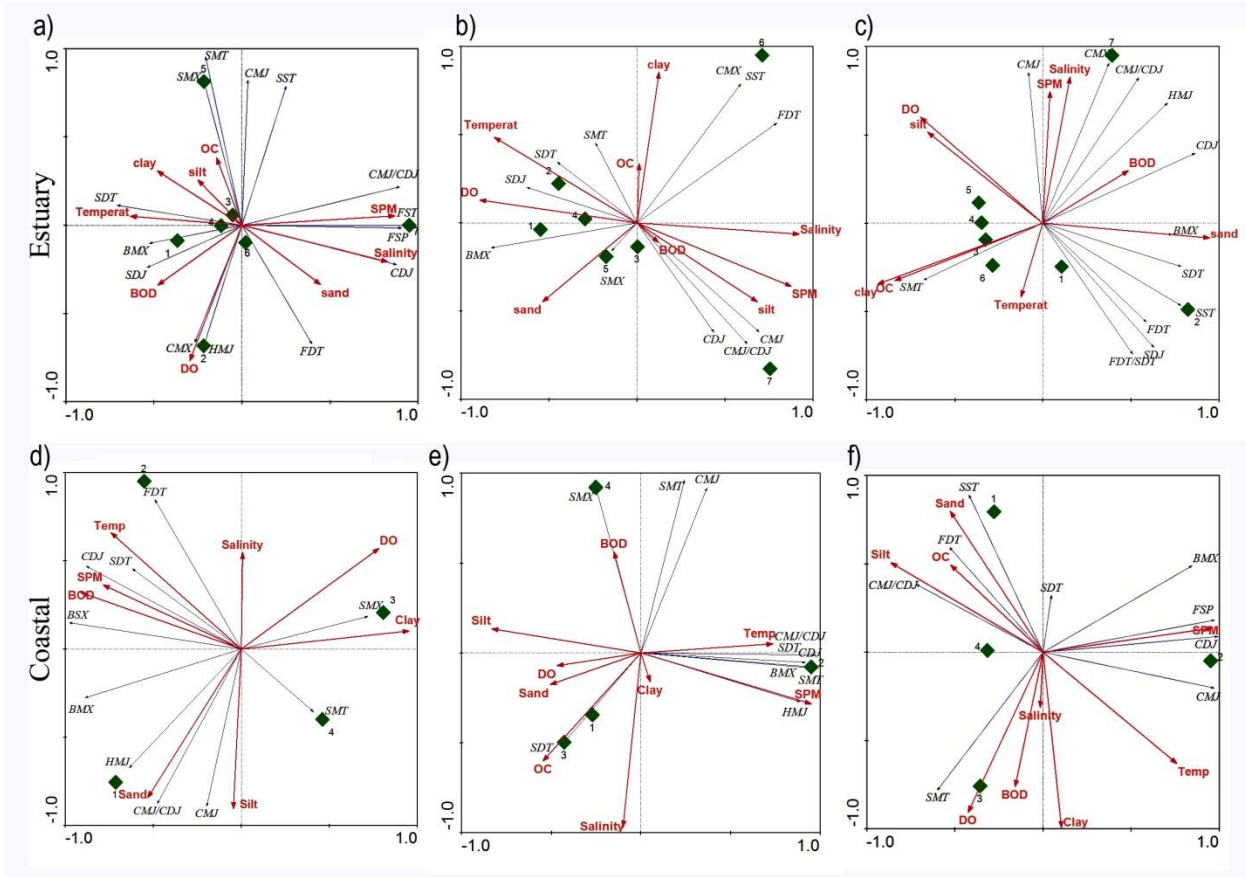


Fig. 6. The RDA plot showing the influencing factors on the polychaete feeding guilds in the Cochin estuary (a-c) and adjacent coastal waters (d-f) during pre-monsoon, monsoon and post-monsoon season respectively.