

Macrobenthos community response to the seasonal hypoxia associated with coastal upwelling off Kochi, along the Southwest Coast of India

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Abstract

This study presents the seasonal macrobenthic assemblages in the nearshore environment off Kochi along the southwest coast of India, which is exposed to the freshwater influx, and coastal upwelling associated seasonal hypoxia during the Southwest Monsoon [(SWM) (June - September)]. Monthly observations were made from three locations in different depth zones [inshore (6m), nearshore (13m) and coastal (28m)] along a cross-shore transect off Kochi for one year (2014-15). During the SWM, the study area underwent a significant lowering of salinity in the surface waters due to enhanced freshwater influx and a remarkable oxygen deficiency in the subsurface waters due to upwelling. The Pre-Monsoon [(PRM) (March-May)] macrobenthic community was dominated by gastropods, which transformed into a less diverse and hypoxia adapted opportunistic species of polychaetes (*Paraprionospio pinnata* and *Cossura coasta*) and foraminifers (*Bolivina* sp.) during the SWM. This study showed a seasonal decline of the sensitive fauna and the dominance of opportunistic species as the effect of hypoxia in the study area during the SWM.

Keywords -Macrobenthos, hypoxia, coastal upwelling, Southwest coast India, Arabian Sea

1. Introduction

Globally, the spreading of oxygen-deficient waters is a potential threat to marine fauna in the coastal environments (Holland et al., 1977; Diaz and Rosenberg, 1995; Levin, 2003; Diaz and Rosenberg, 2008). The stress of hypoxia on different fauna could occur at physiological, individual, or community levels (Holland et al., 1987; Diaz et al., 1992; Breitburg et al., 1997; Taylor and Eggleston, 2000). The impact of low oxygenation is most significant on macrobenthos, the fauna living in or on the bottom sediment, which plays a substantial role as primary and secondary consumers in aquatic ecosystems (Popchenko, 1971). Due to low mobility, macrobenthos mostly is the permanent dwellers of the bottom sediments (Chainho et al., 2007) and also contribute to remineralisation to enhance the efficiency of the food chain (Schweitzer, 1974). The macrobenthos, depending upon their type and duration of exposure, are susceptible to varying levels of oxygen deficiency (Herman et al., 1999).

The southwest coast of India receives significant freshwater input primarily from around 50 rivers originating from the Western Ghats (Jyothibabu et al., 2010). The present study area off Kochi is exposed to the estuarine influx of the Kochi backwaters that gather the freshwater discharge of seven rivers originated in the Western Ghats (Jyothibabu et al., 2008). At the same time, the inner shelf along the west coast of India has the most prominent seasonal oxygen-deficient zones of the global ocean (Naqvi et al., 2000). This yearly pollution event (oxygen deficiency) is associated with the strong coastal upwelling that occurs in the region during the Southwest Monsoon (June - September). Banse, (1959 & 1968) showed that the oxygen-deficient water that spread in the subsurface waters of the shelf region along the west coast of India could harm the bottom fauna. However, still, there is a lack of comprehensive information on how macrobenthic assemblages in the nearshore waters of the Indian western shelf responds to the simultaneous occurrence of oxygen-rich estuarine freshening on the surface waters and coastal upwelling associated oxygen-deficiency in the subsurface waters. Therefore, this study based on a high-resolution monthly time-series observation on the macrobenthic assemblages of the Kochi coastal environment addresses the three primary objectives (a) to identify the impact of oxygen deficiency on the macrobenthic composition and abundance during the SWM (b) to understand how and when the recolonisation of the diverse macrobenthos assemblages occur after the oxygen deficiency and (c) to track the influence of the enhanced estuarine influx on macrobenthic assemblages during the SWM.

2. Materials and Methods

2.1. Study Area

The nearshore waters off Kochi along the southwest coast of India, located between 9.56° N and 76.04° E to 9.57° N and 76.12° E, is sampled in this study (Figure 1). The region receives an enormous amount of estuarine flux from the Kochi backwaters, the most extensive estuarine system along the west coast of India (Srinivas et al., 2003). The Kochi backwater is a microtidal system with tidal amplitude of ≤ 1 m (Jyothibabu et al., 2006). During the PRM, river discharge into Kochi backwater is the seasonal lowest and hence its lower reaches behave as a section of the Arabian Sea (Madhupratap, 1987; Menon et al., 2000; Jyothibabu et al., 2006). During the SWM, heavy river discharge cause limnetic conditions over a large portion of the Kochi backwaters and intense flushing of the system through the Kochi inlet (Madhupratap, 1987; Jyothibabu et al., 2006). Also during the SWM, the entire Indian western coast is under the influence of upwelling and associated spreading of oxygen-deficient waters over the shelf (Shetye et al., 1985; Muraleedharan and Prasanna Kumar, 1996; Gupta et al., 2021). The massive river discharges during the period considerably lowers the salinity and increase the nutrients, detritus, and turbidity in the study region (Nair et al., 1992).

2.2. Materials and Methods

Monthly field sampling was carried out onboard a mechanised boat over a complete year from April 2014 to March 2015. Standard oceanographic equipment and methods are utilised in this study. Vertical profiles of salinity and temperature at each sampling location were obtained using a Conductivity Temperature Depth (CTD) Profiler (SEA-BIRD). Water column transparency was measured using a turbidity meter based on nephelometric principles. Water samples were collected with 5 L Niskin bottles from 1 m below the surface (surface sample) and 2 m above the seabed (subsurface sample). The waters samples for dissolved oxygen were carefully collected into oxygen bottles, which were the fixed on-board using Winkler's method (Grasshoff et al., 1983). Water samples were also collected for macronutrients such as nitrate and phosphate and analysed using a spectrophotometer (Shimadzu 1650PC) following the standard procedures (Grasshoff et al., 1983).

Sediment samples were collected from three locations (in duplicate) using a Van Veen Grab (0.04 m²) capable of a sediment penetration of 10 cm. The sediment was washed over a standard sieve (0.5 mm mesh) to separate the macrofauna and preserved in 5% Rose Bengal-formaldehyde solution. Subsamples of sediments were collected and stored in plastic bags and later, sent for texture analysis using Laser Diffraction Particle Size Analyser (McCave and Syvitski, 1991) at NCRR, Chennai.

Chlorophyll-*a* was extracted from the surficial sediment and analysed as per standard procedure (UNESCO, 1994). Sediments were dried at 60°C and made homogeneous for the estimation of organic carbon and total nitrogen (TN). The dried samples were analysed using Elemental Analyser (Flash EA, Thermo) (Verardo et al., 1990). Benthic organisms were sorted to the group level, while polychaete was identified to individual-level using keys (Fauvel, 1953; Fauchald and Jumars, 1979; Day, 1967). The taxonomic status of genera recorded was also checked and updated from the WoRMS (World Register of Marine Species) website. The remaining taxa were identified to the maximum taxonomic resolution possible.

AZTI's Marine Biotic Index (AMBI) is a useful tool to analyse the response of macrobenthic assemblages to changes in environmental quality (Borja et al., 2000 & 2003). In this analysis, species are classified into five ecological groups depending on their sensitivity to environmental stress, and the index is based on the relative abundances of species in each group. AMBI is used in this study also as an environmental indicator to classify the macrobenthic organisms into different groups. The five groups of species grouped as per AMBI are (a) sensitive (EG I), (b) indifferent (EG II), (c) tolerant (EG III), (d) first-order opportunistic (EG IV), and (e) second-order opportunistic (EG V).

Using TAXDTEST in PRIMER v5, the macrobenthic diversity based on Shannon Wiener Index (H') can be modified to an advanced diversity index termed taxonomic distinctiveness ($\Delta+$). This measure of biodiversity, based on taxonomic or phylogenetic relatedness of species in a sample is useful for testing the biodiversity loss (Clarke and Warwick, 1998). The TAXDTEST analysis in this study was carried out using the PRIMER V6+ PREMANOVA software (Clarke and Gorley, 2006). Average taxonomic distinctness (Δ TD) gives an average length of a classified tree between a pair of species indicating the taxonomic breadth of that pair (Clarke and Warwick, 1998). An advantage is that these analyses are not influenced by sampling effort, as it considers only the taxonomic relationship of each species in a sample. The average taxonomic distinctness ($\Delta+$) of the sampling locations is presented as the funnel diagram. Variation in taxonomic distinctness (Var TD) is the variance of the taxonomic distinctness between each pair of species about their mean value. The average taxonomic distinctness ($\Delta+$) of the sampling locations is presented as the funnel diagram. The funnel diagram was explained on basis of thick lines; indicate limits of the 95% confidence interval and the dotted line indicates the Mean $\Delta+$ (Clarke and Gorley, 2006).

2.3. Multivariate analyses

Non-metric multidimensional scaling (nMDS) was performed using the Euclidean distance matrix. A similarity profile (SIMPROF) test was carried out for identifying statistically significant

clusters. The pooling of sampling months was carried out by the non-metric multidimensional scaling (nMDS) method using PRIMER V6 (Clarke and Gorley, 2006) software. The interrelationship between the biological and environmental variables was evaluated using RDA (CANOCO 4.5). The biological variables were centered and log-transformed before the analysis. The ordination significance was tested with Monte Carlo (499 unrestricted permutations) test ($p < 0.05$). The results of the RDA were presented as Triplots with stations as points while species and environmental parameters were represented by arrows (Leps and Smilauer, 2003).

3. Results

3.1. Hydrological parameters

The major hydrographical parameters in the study domain and their seasonal variations are presented in Table 1. The SIMPROF analysis based on major hydrographical parameters (salinity, temperature and turbidity) clustered the entire sampling into three distinct seasons based on similarity in the hydrography (Figure 2). Accordingly, the period July-September was grouped as Southwest Monsoon (SWM); October - January as Northeast Monsoon (NEM) and February - May as PRM. The salinity distribution (Figure 3) in the surface layers showed significant seasonal variations (ANOVA, $P < 0.05$;;) (Figure 3). Irrespective of stations, surface salinity, was high during the PRM and least during the SWM. On the other hand, the bottom water salinity, in general, was relatively high during the SWM period compared to PRM and NEM. The salinity stratification was stronger during the SWM and also at that time there was a significant lowering of salinity in the entire water column in the inshore waters (location 1 at 6m) (Figure 3). Vertical distribution of temperature showed a significant difference between seasons (Figure 4). The entire coastal environment was warm during the PRM (Table 1). During SWM, the subsurface waters became remarkably cooler due to the upwelling and at that period the turbidity and nutrient levels were found higher compared to PRM and NEM in all three locations. The dissolved oxygen (DO) levels showed a significant temporal difference, especially in bottom layers during SWM due to the incursion of oxygen-deficient waters in the subsurface and bottom (Figure 5). Soon after the SWM, the oxygen level in the subsurface and bottom has increased. The concentration of nutrients (nitrate, phosphate and silicate) was high during SWM compared to the other two seasons. **Nutrients** The overall pattern of the hydrographical parameters showed that SWM was characterised by cold, nutrient-rich, and less oxygenated subsurface waters whereas PRM by warm, nutrient-poor, and oxygenated waters.

3.2. Sediment characteristics

The seasonal and spatial variation of sediment texture in the study region is presented in Figure 6. Sandy-silt sediment was the dominant one in the study region throughout the study. The concentration of sediment chlorophyll-*a* showed high values during SWM compared to PRM and NEM periods (Figure7). Sediment chlorophyll-*a* was high in inshore locations compared to the locations further offshore. The variations in the sedimentary organic carbon (OC) and total nitrogen (TN) are presented in Table 1. The OC was found high in all locations during PRM compared to SWM and NEM. TN content was higher in all the locations. In the inshore and coastal region, TN was higher during the SWM compared to NEM and PRM.

3.4. Macrobenthic abundance and diversity

The macrobenthic assemblage was comprised of 42 taxa belonging to 9 macrofaunal functional groups; Polychaetes, foraminifers, bivalves, gastropods, decapods, nematodes, amphipods, isopods, and harpacticoid copepods. The monthly variation of macrobenthic assemblage is furnished in Figure 8 & Table 2. At the inshore location, total macrobenthos abundance during PRM (1230 - 5000 No.m²) compared to NEM (540 - 860 No.m²) and SWM (130 - 260 No.m²). The macrofaunal abundance and species diversity varied between locations and seasons. Gastropods were the most dominant species (>75%) contributing to the macrofaunal community during PRM. The two dominant gastropods observed during the PRM were *Solariella sp.* and *Littorina sp.* There was a significant shift in the macrofaunal composition in the study area. The dominant gastropods during PRM were replaced by polychaetes during SWM. The polychaetes found in the study area were *Minuspio cirrifera*, *Lepidonotus sp.*, *Dendronereis aestuarina*, *Paraprionospio pinnata*, *Priniospio polybranchiata*, *Platynereis sp.*, *Lumbrinereis simplex*, *L. impatiens*, *Glycera longipinnis*, *G. alba*, *Capitella capitata* and *Nephtys sp.* *Paraprionospio pinnata* and *Cossura coasta* (Polychaete) were found mostly during the SWM period. Similarly, Foraminifera abundance also increased significantly during the SWM. Nematodes recorded in the study area were *Daptonema sp.*, *Microlaimus sp.*, *Rhabditis sp.*, and *Mesorhabditis sp.* Based on the AMBI diversity index, the macrofaunal community was classified according to their sensitivity towards stress (Table 3).

Species richness was high during the PRM and least during the SWM period (Table 4 & Figure 9). Like the species richness, Shannon diversity was also high during the PRM compared to NEM and SWM. The spatial difference in species diversity between the locations during all the seasons was found low (ANOVA, F=1.21; p>0.05).

It can be seen that $\Delta+$ values of all locations during the entire observations were falling within a 95% confidence limit, though their positions varied. During SWM, most of the locations were oriented towards the broader part of the funnel and closer to the lower limit of 95% confidence level. On the contrary, during PRM, the locations were oriented towards the tail of the funnel and closer to the upper limit of 95% confidence level. Detailed representations of Shannon diversity and average taxonomic relatedness during each season and location are furnished in the line plots. Low $\Delta+$ during SWM are indicative of a disturbance to the system caused by death or shift of sensitive species or habitats. There was a significant seasonal difference in taxonomic distinctness in the sampling locations (Table 5). The taxonomic distinctness was low during SWM compared to NEM and PRM. The species richness and cumulative dominance are found to be the lowest during SWM. The macrobenthos diversity was also found the lowest during the SWM compared to the NEM and PRM seasons.

3.5. Redundancy Analysis

The interrelationships among the macrofauna groups and hydrographical variables are presented in Figures 10 (a-c). The ordination was computed using the Monte Carlo permutation test. Arrows of variables in the same direction indicate a positive correlation, whereas negative correlation is indicated by arrows in the opposite direction. The hydrography, in general, explained 62%, 68%, and 70% of the variation in benthic assemblages at locations 1, 2, and 3, respectively. The common message in all three locations studied is that a high abundance of total macrofauna and all the major groups of macrobenthos were found during the NEM and PRM periods characterised by high temperature, dissolved oxygen and increased percentage of sand in the bottom substratum. On the other hand, foraminifers and some species of polychaetes showed a positive correlation with the SWM condition characterised by the low temperature, dissolved oxygen and increased percentage of the silt and clay on the bottom substratum. In location 1 in the inshore waters (6m), enhanced freshwater influx caused a decrease in salinity during the SWM and hence its axis in the RDA plot-oriented to the right side and opposite to the SWM collections. During SWM, it is clear in the RDA that the high turbidity and low salinity were closely linked to the low macrofauna abundance

4. Discussion

Oxygen deficiency in the subsurface and bottom waters along the southwest coast of India is natural oceanic processes that occur during periods of upwelling (Qasim, 1982; Gupta et al., 2016; 2021). Oxygen depletion creates stress on benthic organisms, which is evidenced either by the replacement of sensitive species by tolerant ones or even by mass mortality (Levin et al., 2009).

Oxygen deficiency also affects the physiology, reproduction, and life cycle of benthic organisms. When oxygen concentrations go below hypoxic levels, mobile organisms will move away, and burrowing organisms will come to the sediment surface, while all the sessile organisms will perish (Levin et al., 2009). The stress on the benthic environment is determined not only by oxygen deficiency but also by the extent of exposure (Rabalais et al., 2010). Therefore, a shift in the macrobenthic community structure is always an indication of a stressful environment (Warwick, 1993; Villnäs et al., 2012). The present study elaborates on the impact of seasonal hypoxia on the macrobenthic assemblages of the Kochi coastal environment.

During SWM, the increased freshwater flow from KBW limits the upwelling to the subsurface of the Kochi coastal environment (Banse, 1968; de Souza et al., 1996; Karnan et al., 2019). However, the overall nutrient enrichment in the coastal environment off Kochi during SWM is associated with the combined effect of freshwater input from KBW and upwelling (Jyothibabu et al., 2006). The study region was relatively turbid during SWM due to freshwater flux high suspended sediments. High turbidity could reduce the visibility of prey to benthic organisms and thereby inhibition of faunal richness (Lunt and Smee, 2014). However, the response of macrofauna to variations in oxygen, compared to their response to temperature, salinity, or turbidity, is more unpredictable (Rainer and Fitzhardinge, 1981). Surface stratification can also increase the oxygen deficiency in the bottom (Diaz et al., 2009; Zhang et al., 2010).

Bottom sediment provides habitat and food for benthic fauna (Palmer et al., 2000). However, during the present study, the sediment was found to be sandy-silt throughout the study period. Fine clay and silt cause congestion to the filter feeders (Harkantra et al., 1982) influencing the macrofaunal assemblages. Benthic habitats with high silt-clay contents are usually found to sustain poor macrofauna (Boesch, 1973; 1977; Ricciardi and Bourget 1999; Seitz et al., 2006), whereas coarser sediments can support diverse macrofauna (Gray, 1974). These corroborate the view that the texture of sediment has a significant role in controlling the feeding, burrowing, tube-building, respiration, ventilation, and excretion of macrobenthos (Rhoads and Boyer, 1982). Sediment rebuilding after hydrological changes mainly depends on the deposition of inorganic sediments and influx (Day et al., 2011). Sediment organic carbon content also influences the macrofaunal community composition in coastal environments (Pearson and Rosenberg, 1978; Herman et al., 1999). It was observed in the present study that the high organic matter during the PRM was one of the reasons for the increased diversity and abundance of macrofauna during that period.

The present study shows that during the oxygen-deficient period (SWM), the macrobenthos in the study domain was considerably reduced in species abundance and richness as observed elsewhere

under similar conditions (Rabalais et al., 2001). It has been shown that a significant change in the benthic community would induce only when prolonged oxygen deficiency exists in a region, which may hinder the new recruitment and colonization of the fauna (Conley et al., 2007). Some organisms can, to a certain extent, alter their physiology and size to survive, which are pollution indicators, as they respond to environmental perturbations (Chapelle and Peck, 2004; Lourido et al., 2008). The disturbance caused by river runoff and turbidity could impact the juvenile and sedentary fauna compared to the mobile fauna, which can shift to suitable habitats (Lunt and Smee, 2014). However, the surface freshening and oxygenation of the estuarine influx in the present study area seems to have an impact only in the inshore location (6m depth), as their influence in the further offshore locations were restricted only to the upper water column. Clarke and Warwick (1998) reported that sediment disturbance could affect the benthic community at different levels. Hypoxic conditions are often found to result in massive benthic mortality (Pearson and Rosenberg, 1978; Santos and Simon, 1980; Officer et al., 1984; Gaston, 1985). However, the macrofaunal abundance during the present study was not severely affected during SWM, since the intensity and duration of hypoxia were relatively weak and only for a short period.

Oxygen depletion inhibits recruitment, growth, and ultimately lead to mass mortality through asphyxiation (Forbes and Lopez, 1990; Diaz and Rosenberg, 1995). They also stop feeding to lower cell metabolism for ultimate survival (Diaz and Rosenberg, 1995). Therefore, highly tolerant macrobenthos only survive under such an environment. There are only limited studies on benthic responses to hypoxia in the Indian inner shelves (Carruthers et al., 1959; Joydas and Damodaran, 2001; Joydas, 2002; Jayaraj et al., 2007; Jaleel, 2014, 2015) and Indian estuaries (Kurian, 1971; 1972; Desai and Krishnankutty, 1967; Sanders, 1958; Parulekar et al., 1976; Saraladevi, 1986; Lu, 2005; Remani et al., 1983; Ingole et al., 2010). Larger organisms such as crustaceans and echinoderms are found to be relatively more sensitive to hypoxia than smaller ones such as annelids, sipunculans, molluscs, and cnidarians (Vaquer-Sunyer and Duarte, 2008). Calcareous foraminifera and nematodes are particularly tolerant of low oxygen-deficient conditions and may occur abundantly in the region of hypoxia, but they are then exposed to easy predation (Rosenberg et al., 1991; Long et al., 2008). Tolerant organisms can tolerate (or survive within) a certain range of a particular factor, but cannot survive if there is too much or too little of that factor. On the other hand, opportunistic species are adapted to exploit newly available habitats or resources and are typically found in unpredictable, transient, and variable environments. The opportunistic species of polychaetes, on the other hand, continue to flourish even after the withdrawal of hypoxia or turbidity (Dauer et al., 1992). Thus, although the high turbid waters altered the benthic community of

Mandovi estuary during Monsoon, the benthic community was found to re-colonise quickly due to the high organic content in the suspension (Harkantra and Rodrigues, 2004). The macrobenthic population in the study region showed only a moderate change because of the river discharge in the surface waters.

Taxonomic distinctness is useful to compare the biodiversity of large marine areas where habitat is largely heterogeneous and environmental disturbance is insignificant (Bevilacqua et al., 2009). TAXDTEST based on the present data depicted a relatively large variation in $\Delta+$ between stations. There were distinct variations in $\Delta+$ with a minimum number of species during SWM, which indicates that only highly disturbing regions would exhibit more significant change and reduced taxonomic distinctness (Clarke and Warwick, 1998; Jayachandran et al., 2019). Even though some areas may have low $\Delta+$ value naturally, it will not decline rapidly unless there is stress (Clarke and Warwick, 1998). It can be seen from Figure 10 that during PRM, the number of species was high towards the tail of the funnel, which shifted towards the head of the funnel during SWM. In the funnel diagram, the points falling out of the envelope to have a low $\Delta+$, indicating a deviation from the normal value (Clarke and Warwick, 2001). Recently, Sivadas et al., (2016) have used ellipse plots to distinguish the different habitat. Applying the above criteria in the present study, it can be concluded that the present study area could sustain high species richness only during the NEM and PRM indicating a heterogeneous system (Sanciango et al., 2013).

A schematic picture of the seasonal response of the macrobenthos community in the study area is given in Figure 11. During PRM, the abundance of macrobenthic assemblage (especially gastropods) was high in the inshore regions having high organic matter. The dominance of polychaete during all seasons clearly that they are the most tolerant species in the area. Enrichment of selected macrofaunal species (Polychaeta) during adverse conditions is a common survival strategy to avoid competition and predation. Some studies have shown an increased abundance of foraminifera in sediments under the hypoxic environment (Mazumder et al., 2003). In our study, *Bolivina* was the dominant foraminifera during hypoxia, which are short-lived, stress-tolerant, and relatively mobile organisms (Nigam et al., 2007). The abundance of foraminifera along with polychaetes during SWM, can also be considered as a tendency to increase the heterogeneity under hypoxia. Opportunistic species such as *Paraprionospio pinnata* and *Cossura coasta*, which are morphologically adapted to hypoxia (Dauer, 1985), were present throughout the study period. In this study, nematodes were found absent or very low in abundance during the oxygen-deficient SWM, but their abundance subsequently increased during the NEM and PRM. This is because nematodes are also migratory, and hence, they can move away from oxygen-deficient conditions during the SWM (Wetzel et al.,

2001). Based on the AMBI index, the most abundant macrofauna in the study domain were the tolerant species (EG III) and opportunistic 2 species (EG IV).

5. Conclusion

Based on a monthly time series observation, the present study investigated the temporal variations in the macrobenthic assemblages and their ecology in the coastal waters of Kochi, along the southwest coast of India. The macrobenthic community in the study area showed noticeable seasonal variations with a rich and diverse community during the NEM and PRM periods and a significantly less diverse and hypoxia tolerant opportunistic species of polychaetes (mainly *Paraprionospio pinnata* and *Cossura coasta*) and foraminifera (*Bolivina* sp.) during the SWM. However, the complete retrieval of the oxygen-deficient conditions in the study area by early NEM facilitated the recolonisation and recruitment of a diverse macrobenthic community. On the other hand, the impact of the surface freshening and increased turbidity of the estuarine influx on the benthic assemblages in the study area were found to be less significant, except in the inshore (6m depth), as their influence is restricted only to the upper water column. Taxonomic distinctness and AMBI index confirmed that the dominant macrofauna present in the study region during the oxygen-deficient conditions were the opportunistic species of foraminifers and polychaetes. The high abundance of polychaetes in the study area during the SWM can be attributed to the soft bottom sediments and their adaptability in oxygen-deficient coastal environments.

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Declarations

Ethical Approval

The manuscript does not involve the use of any animal or human data or tissue hence it is not applicable.

Consent to Publish

The manuscript does not contain data from any other person, hence no consent is applicable.

Author's contribution

Pandiya rajan Rethinam Subramanian: Conceptualization, Methodology, Data Curation, Writing - Original Draft, Visualization.

Jyothibabu Retnamma: Conceptualization, Methodology, Data Curation, Visualization, Writing - Review & Editing, Supervision, Funding acquisition.

Arunpandi Nagarathinam: Conceptualization, Methodology, Visualization, Formal analysis

Jagadeesan Loganathan: Conceptualization, Methodology, Data Curation, Visualization

Santhi Krishnan Sobharadhakrishan: Software, Methodology, Visualization.

Parthasarathi Singaram: Visualization, Data Curation.

Competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Availability of data and materials

The datasets generated and/or analysed during the current study are available in the National Institute of Oceanography, Goa, India repository.

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

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Figure Captions

Figure 1 - Study area and sampling locations in the coastal waters of Kochi. Time-Series sampling was carried out from 3 locations (1,2,3) at monthly intervals from April 2014 to March 2015.

Figure 2 - Cluster/SIMPROF overlaid nMDS plots based on the similarity in the hydrographical parameters during different sampling months at locations (a) 1, (b) 2 and (c) 3.

Figure 3 - Time series of the vertical distribution of salinity at locations (a) 1, (b) 2 and (c) 3.

Figure 4 - Time series of the vertical distribution of temperature at locations (a) 1, (b) 2 and (c) 3.

Figure 5 - Time series of the vertical distribution of dissolved oxygen (ml L^{-1}) at locations (a) 1, (b) 2 and (c) 3.

Figure 6 - Time series of the percentage contribution of sand, silt and clay in sediments at (a) 1, (b) 2 and (c) 3.

Figure 7 - Time series of (a) Sediment chlorophyll *a* and (b) Macrobenthos in the study region.

Figure 8 - Shannon diversity (H' (loge) and Taxonomic distinctness ($\Delta +$) various observations in inshore, nearshore and coastal locations. Diversity and taxonomic distinctness were temporally differed between the observations and found relatively fewer values during the southwest monsoon periods.

Figure 9 - (a - c) Funnel plot for average taxonomic distinctness and K dominance curve (d - f) in locations 1, 2 and 3. In funnel plot thick lines, indicate limits of the 95% confidence interval and the dotted lines indicates the Mean $\Delta +$. The sampling observations in all three locations were located within 95% confidence interval. In all three locations, SWM period observations were located in the wide portions of the funnel diagram. K dominance curves represent the variations of the species dominance between the sampling periods in all three locations. Cumulative dominance curve varied between the sampling periods.

Figure 10 - RDA Triplots presenting the distribution of hydrographical and biological parameters and their interrelation at locations (a) 1, (b) 2 and (c) 3.

Figure 11 - Schematic representation of the water column in the sampling location during (a) the non-monsoon period and (b) Monsoon period.

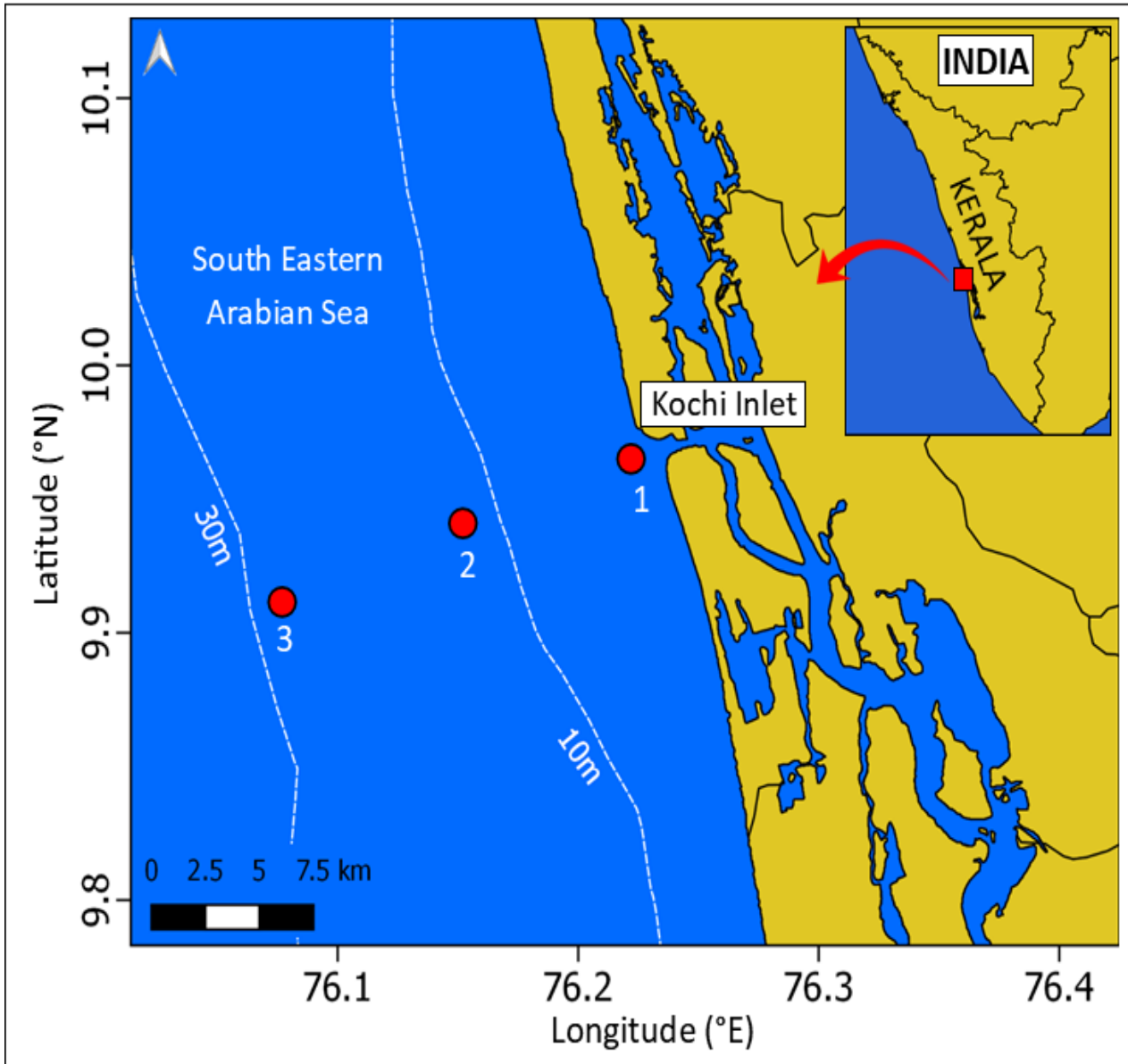


Figure 1

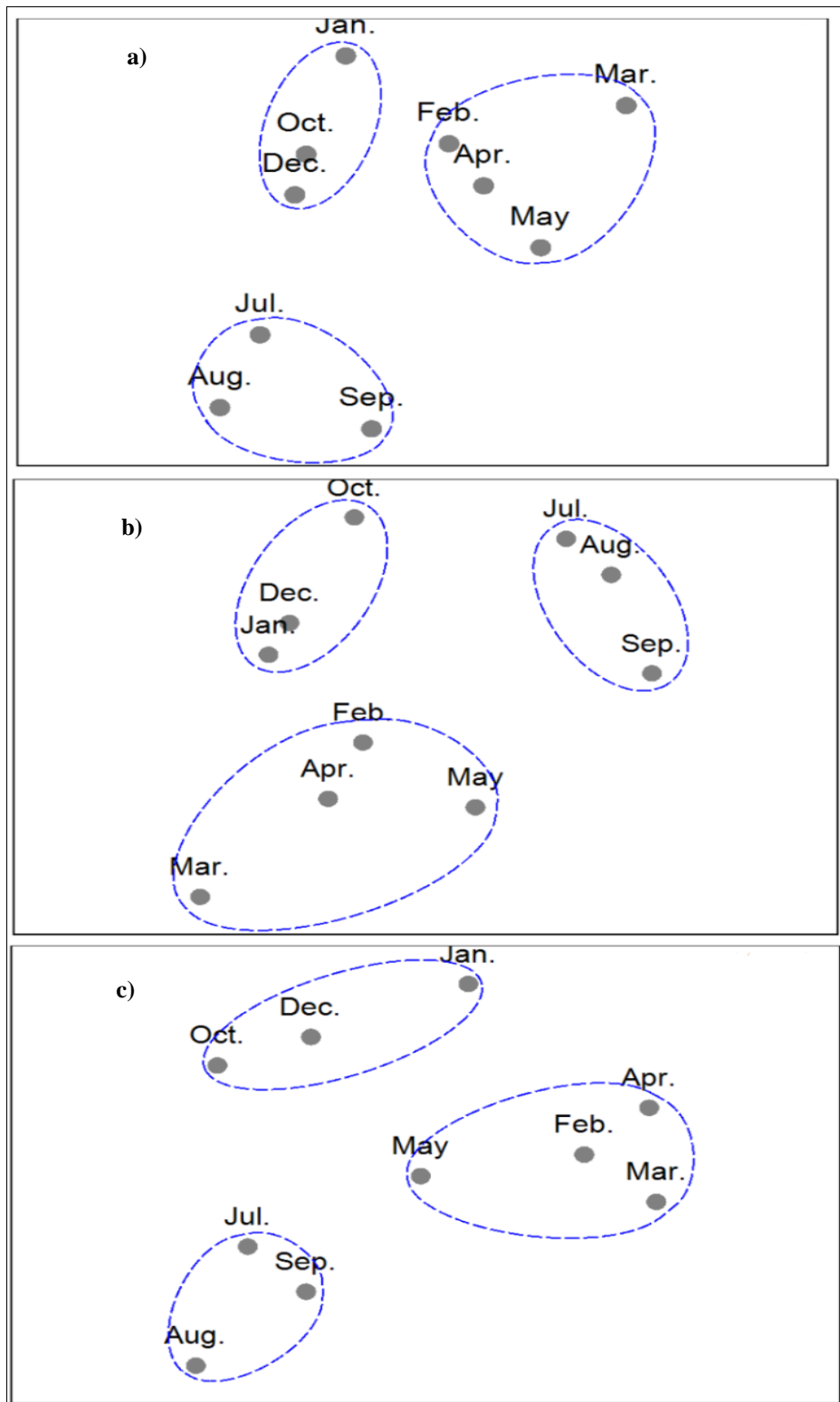


Figure 2

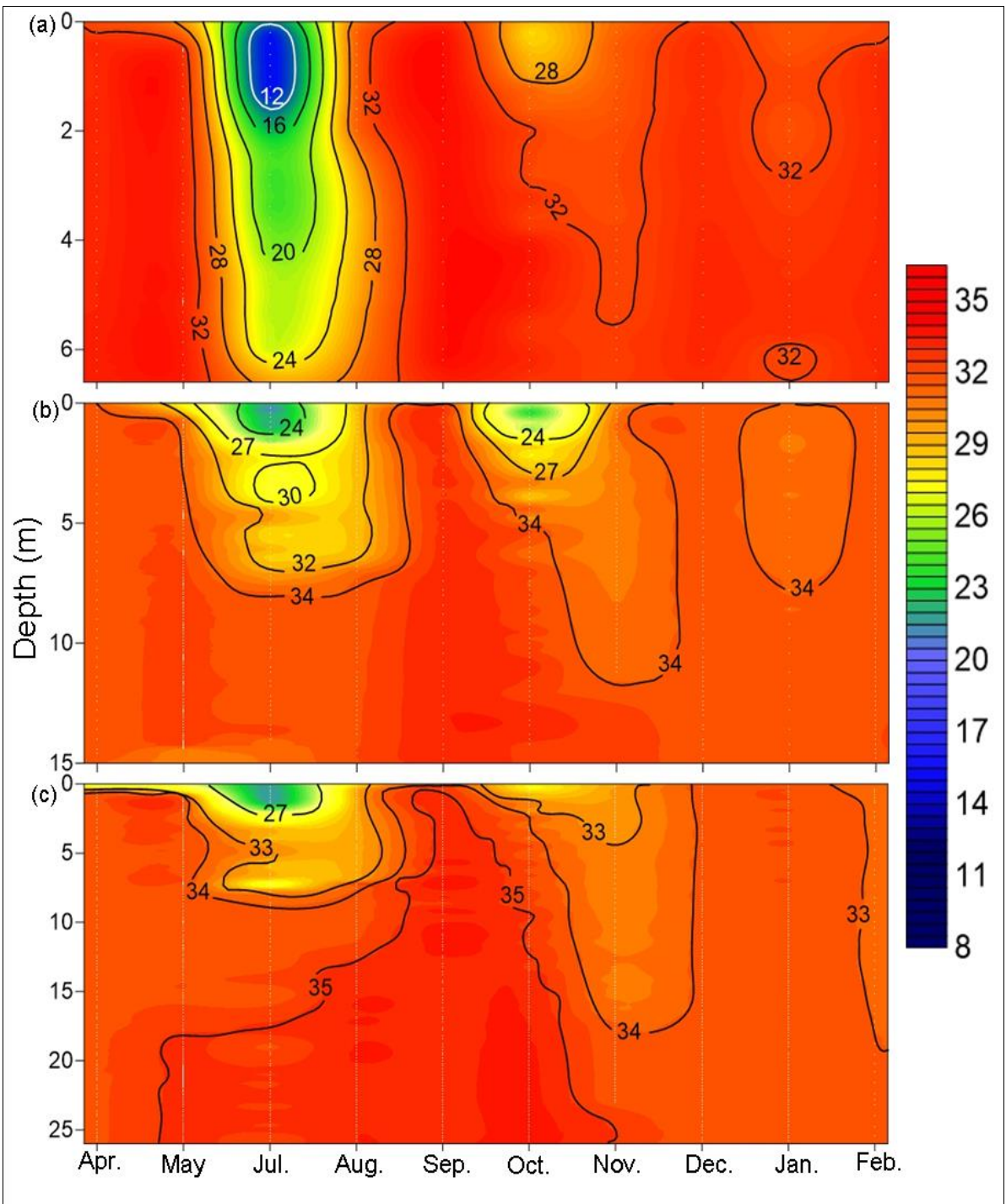


Figure 3

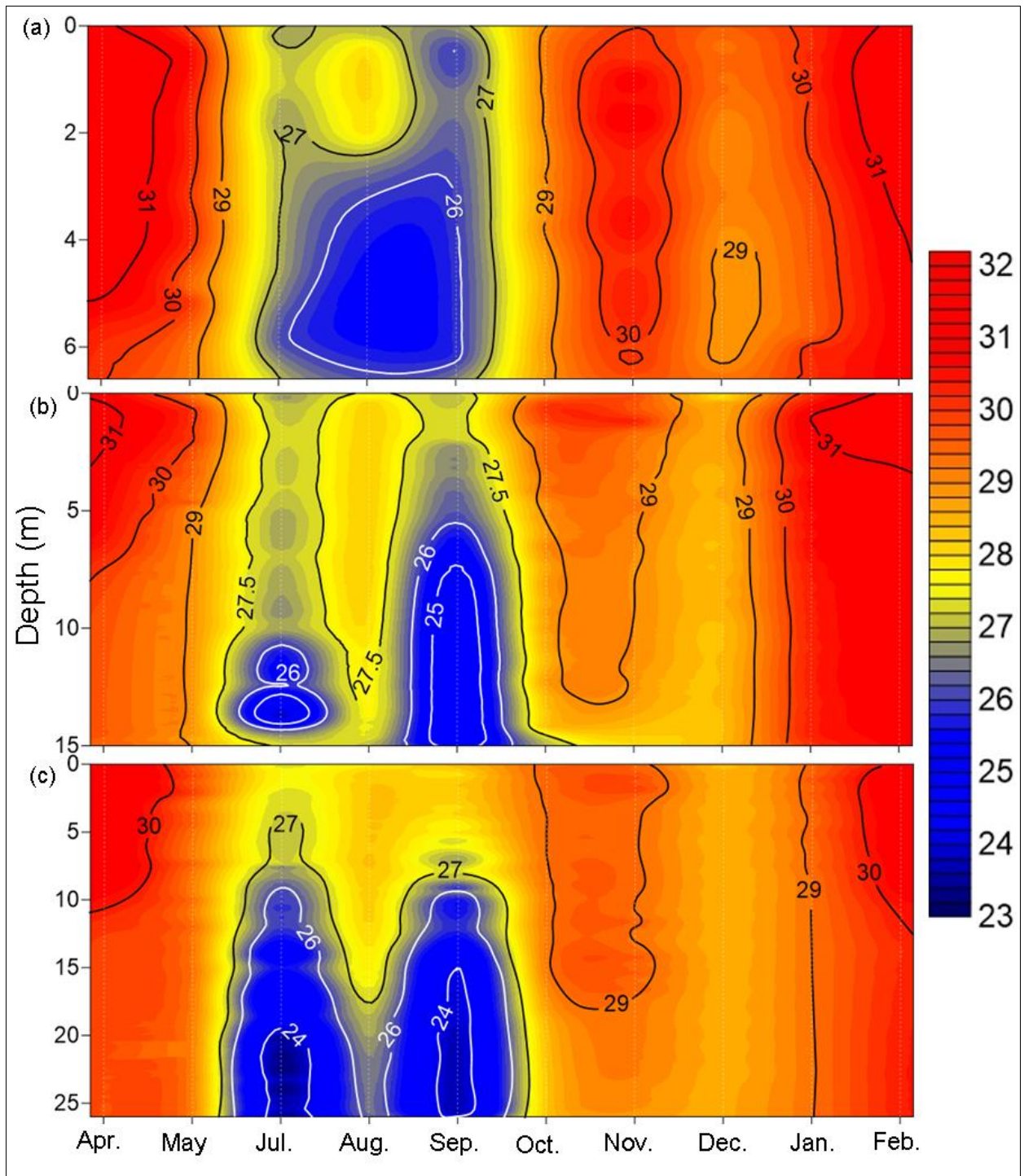


Figure 4

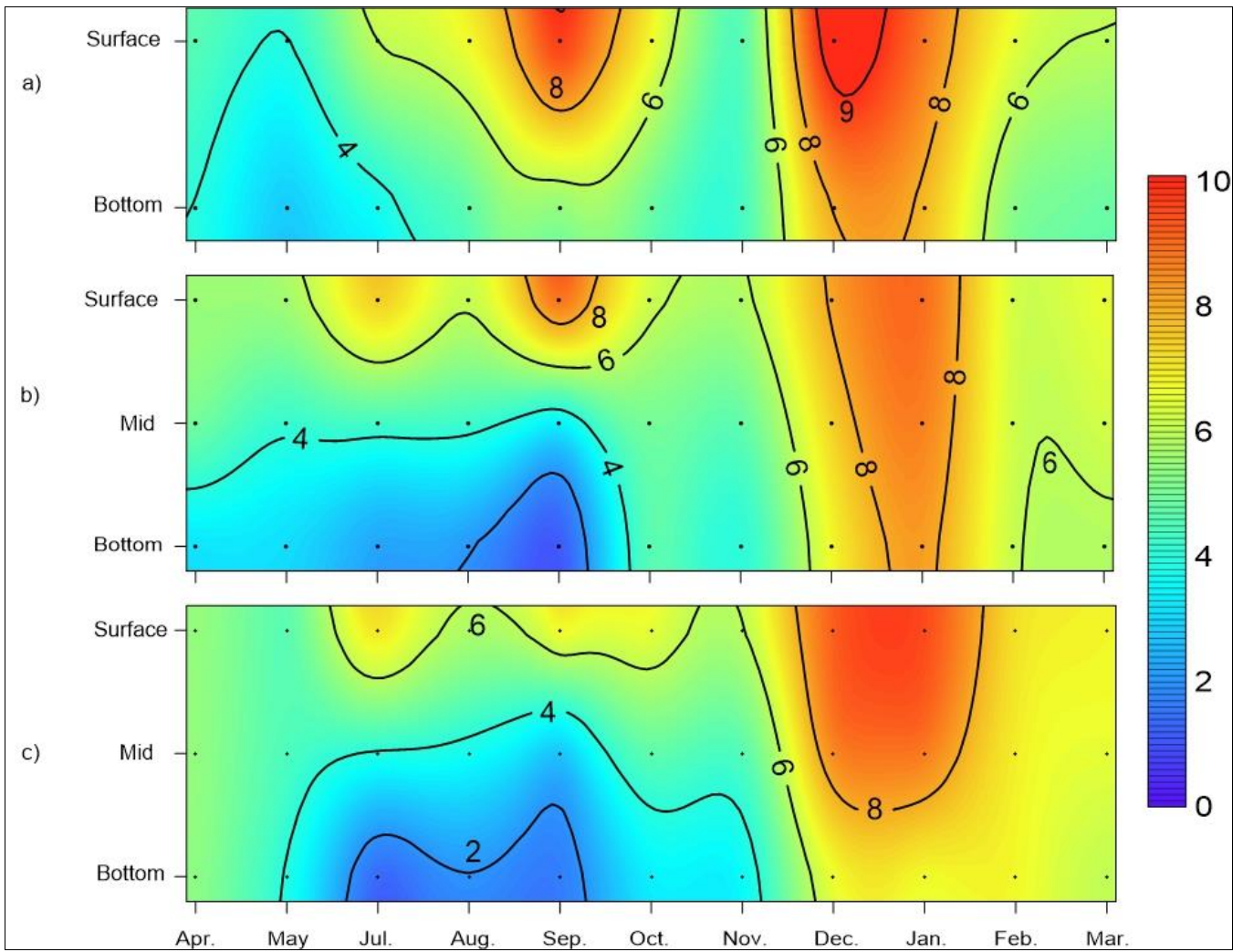


Figure 5

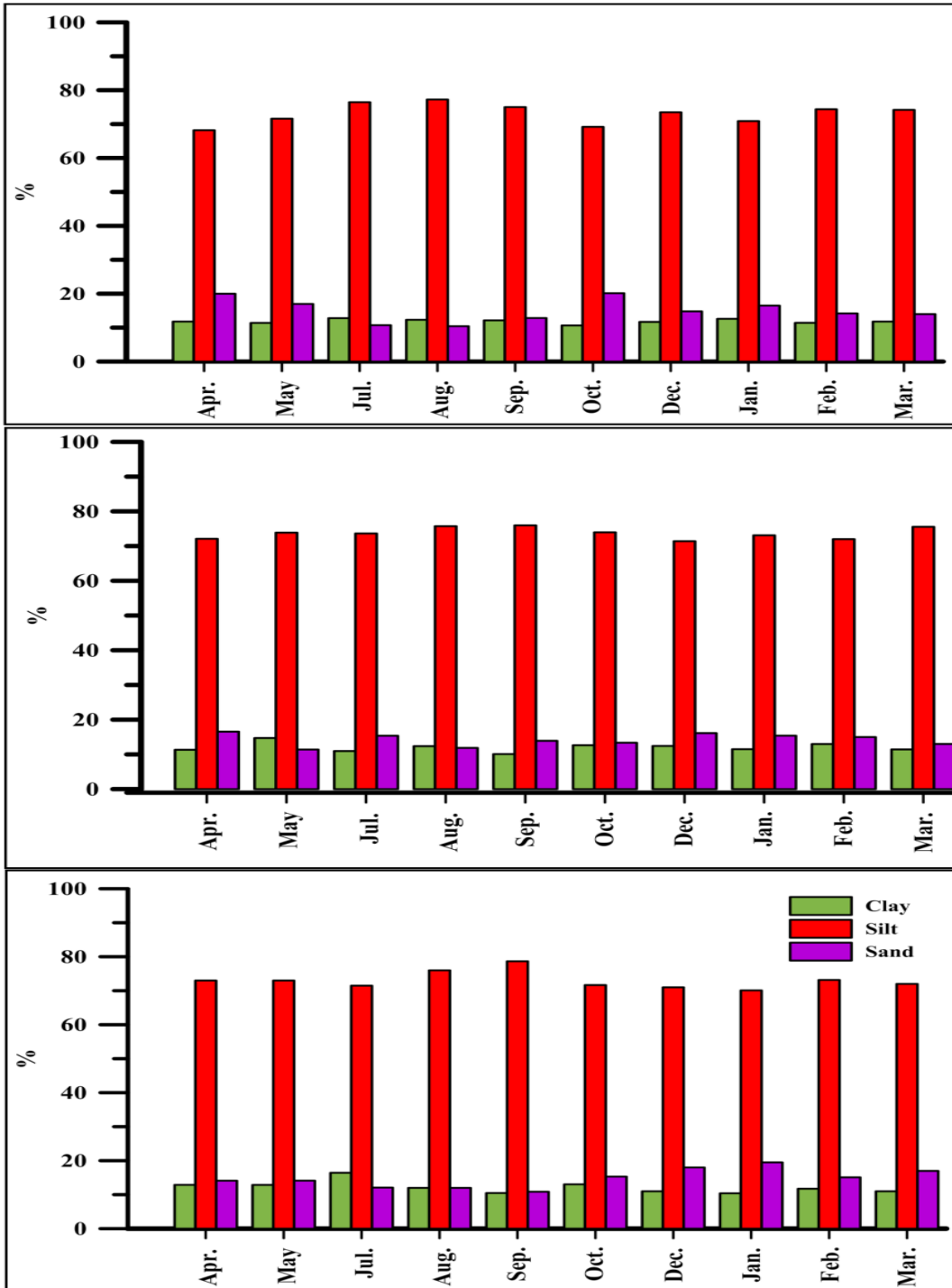


Figure 6

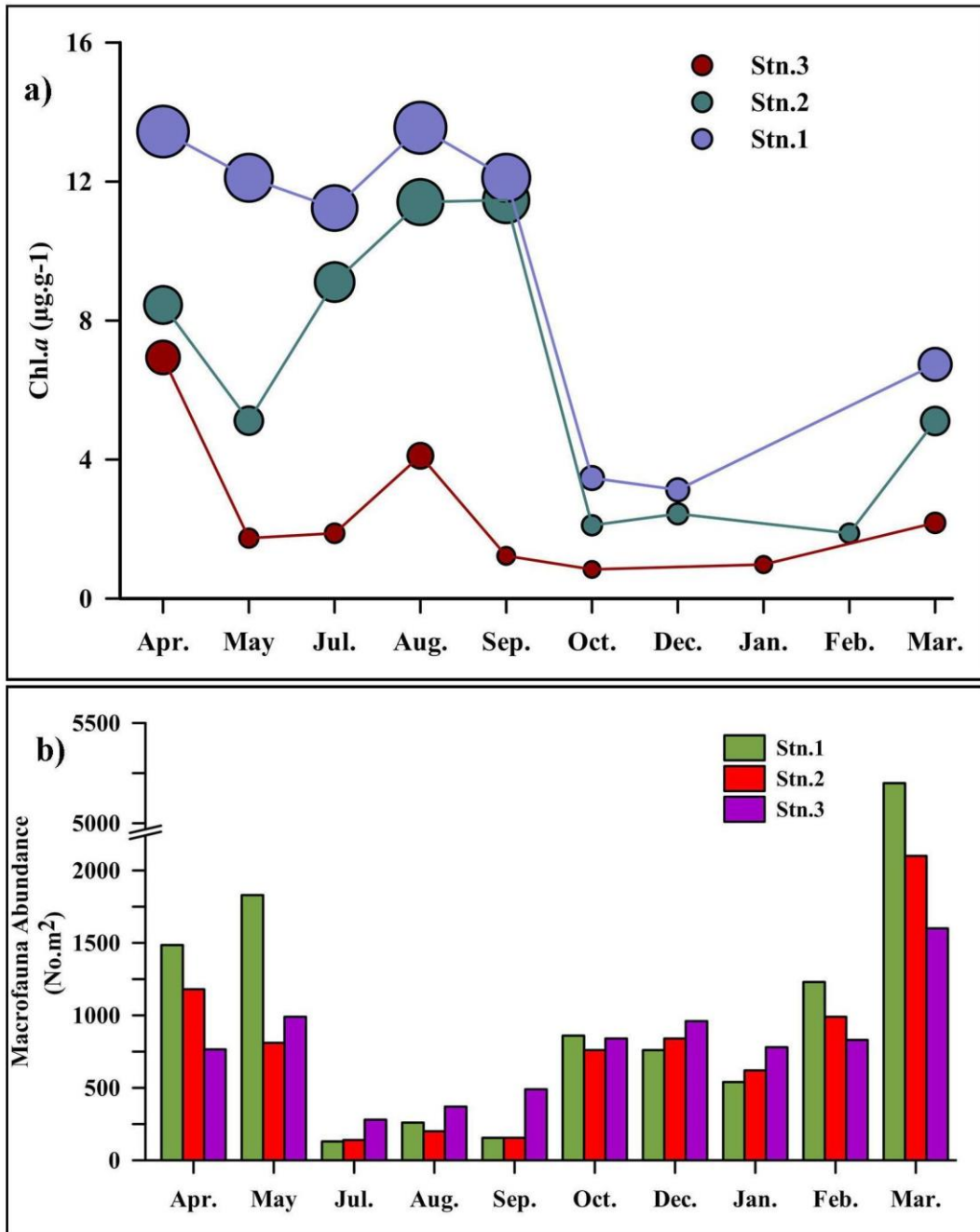


Figure 7

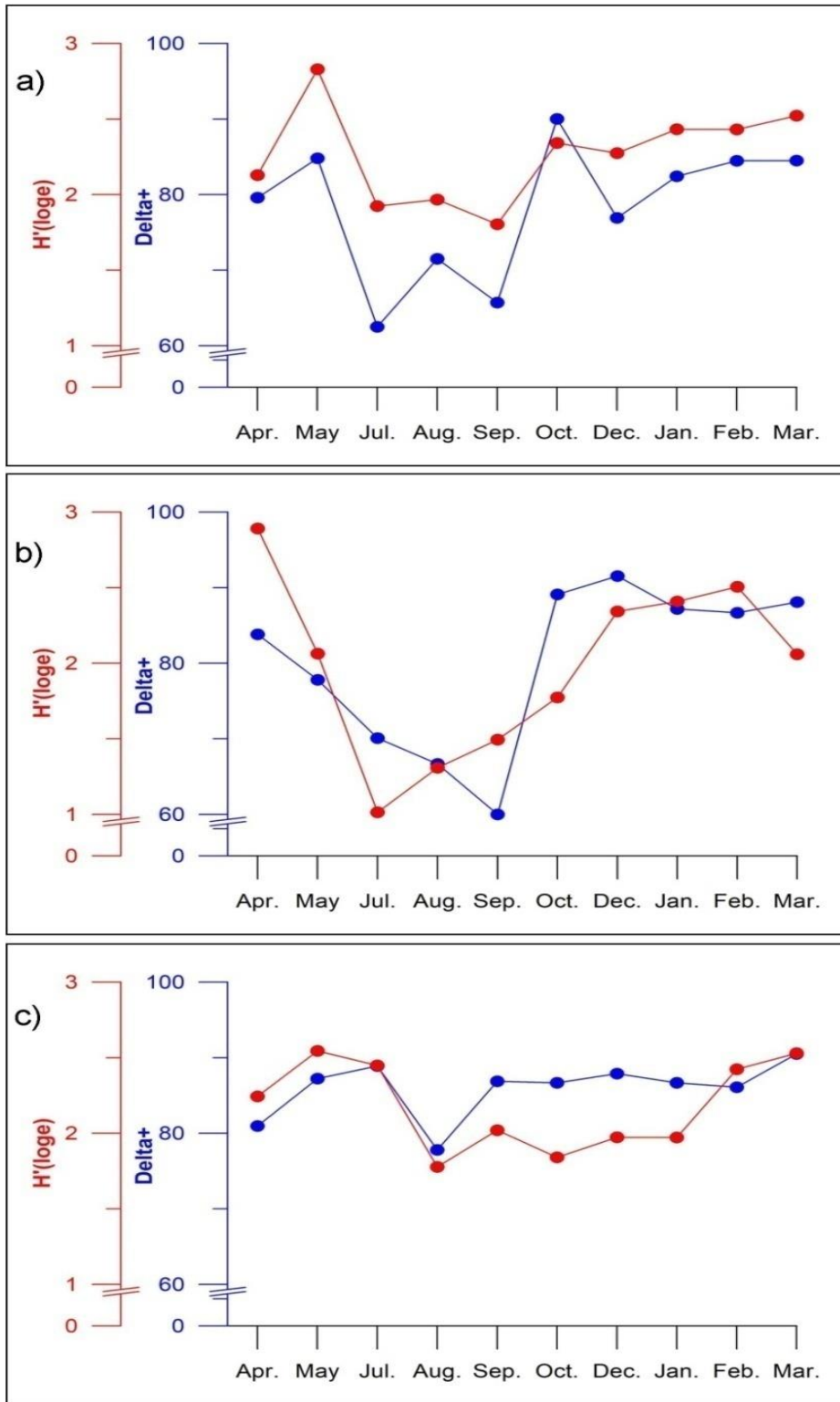


Figure 8

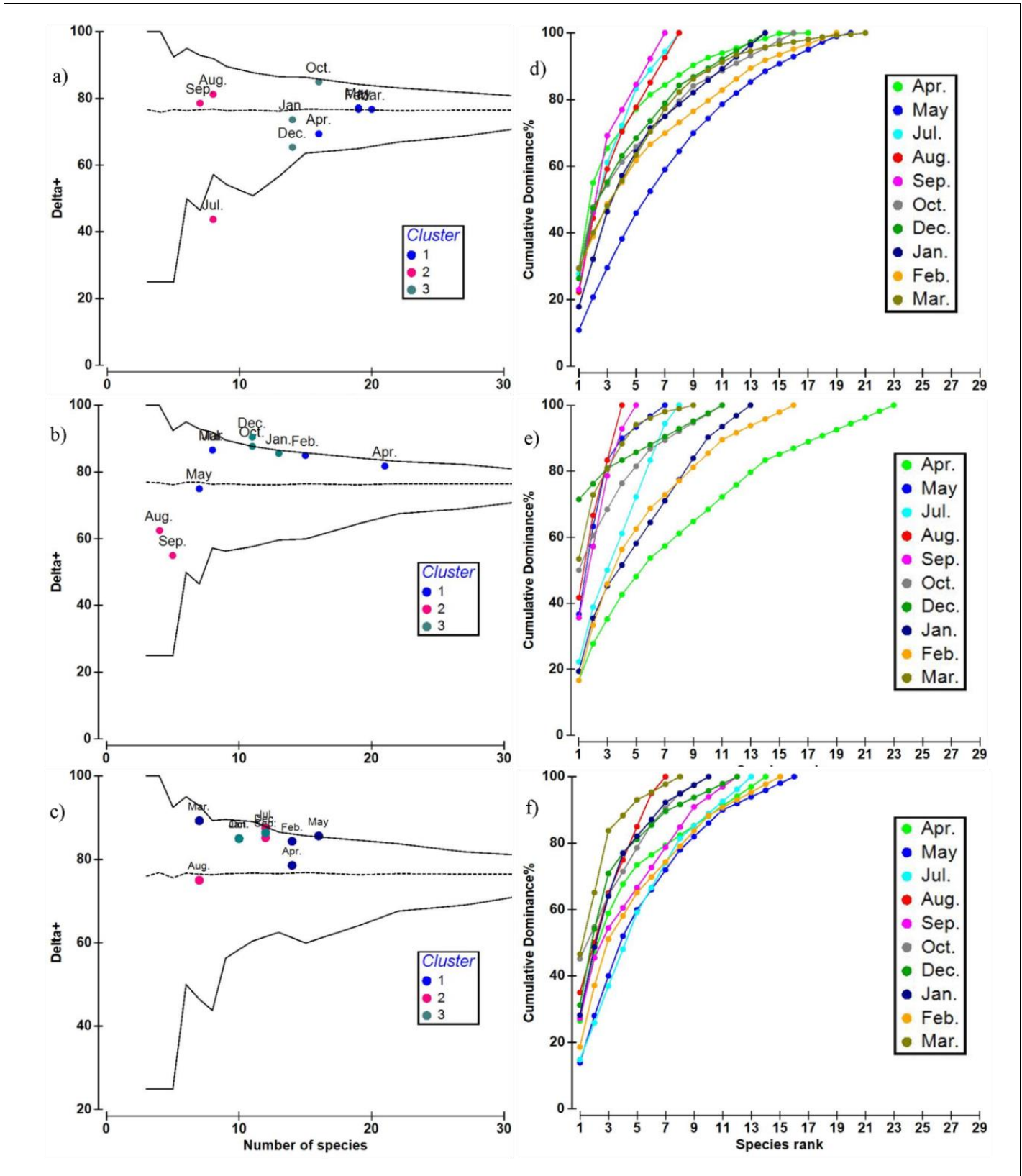


Figure 9

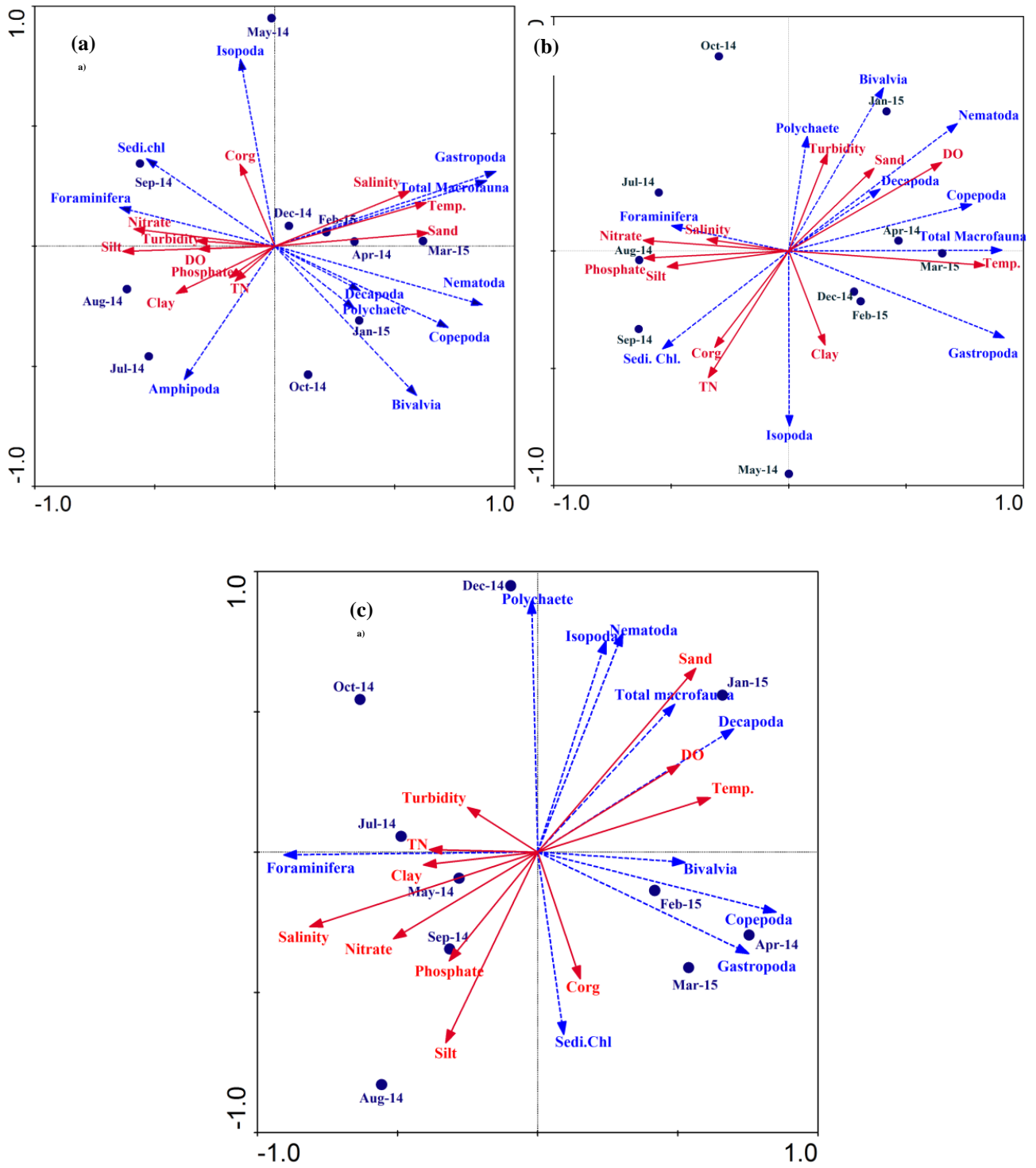


Figure 10

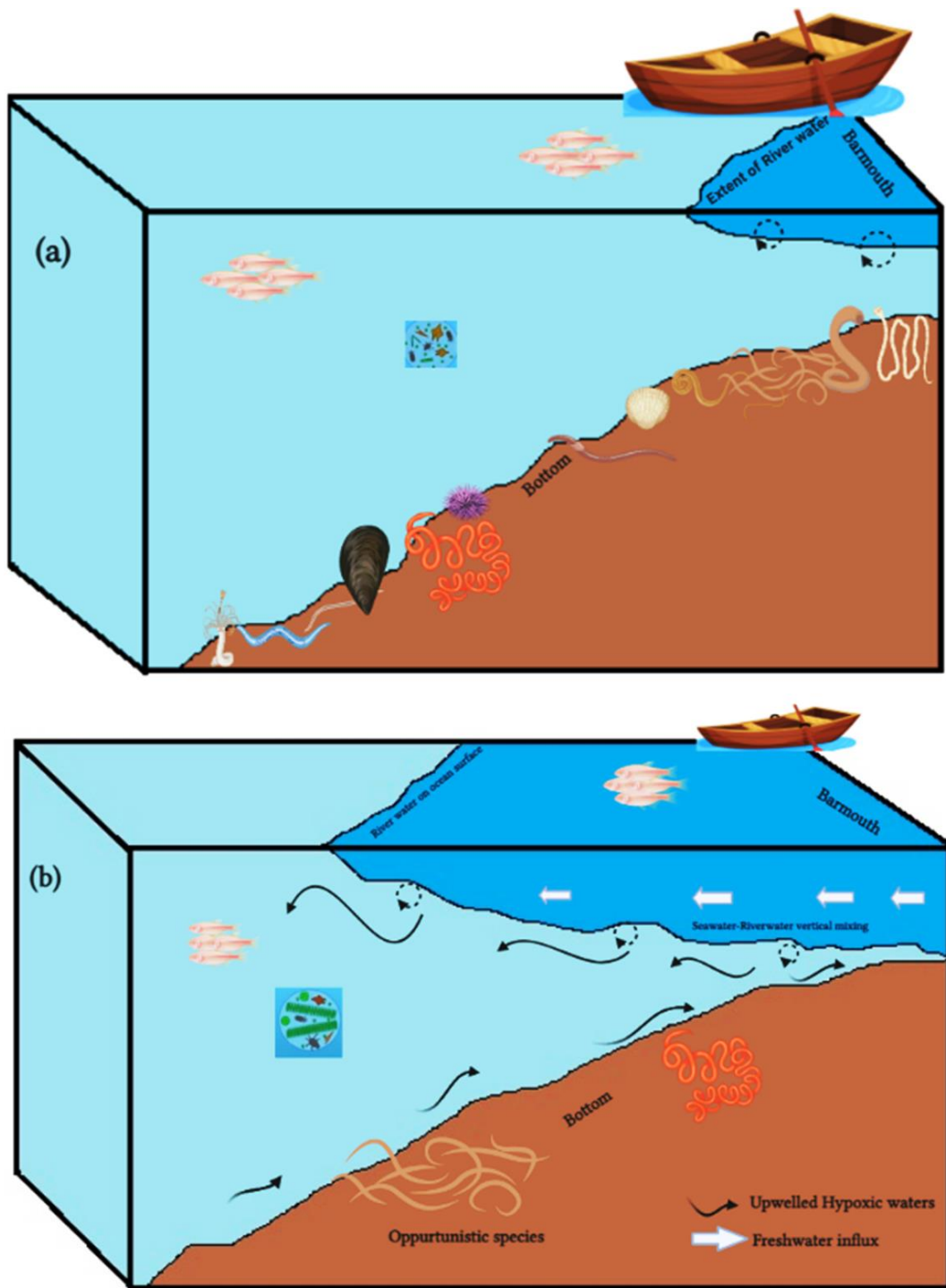


Figure 11

Table 1 - Environmental parameters in the coastal waters off Kochi from the monthly sampling. Mean and standard deviations are presented. Abbreviations. S - Surface; B - Bottom.

Parameters	Station 1			Station 2			Station 3		
	SWM	NEM	PRM	SWM	NEM	PRE	SWM	NEM	PRM
Salinity S	24.69±14.02	30.79±1.09	31.91±4.43	29.35±7.55	31.95±0.33	32.79±5.35	29.24±7.10	32.33±2.07	33.91±0.40
Salinity B	32.19±6.14	31.20±0.35	31.728±1.41	34.54±0.87	34.38±0.25	34.39±0.84	35.18±0.39	34.68±0.85	34.52±0.46
Temperature B	26.20±0.49	30.34±0.71	29.30±0.96	25.51±1.86	29.90±0.81	28.55±0.40	22.42±1.61	28.37±0.42	29.28±0.50
Turbidity B	25.91±10.92	23.40±10.27	16.50±6.89	8.16±6.22	7.00±1.04	12.57±3.11	9.84±14.77	3.47±2.72	2.28±1.12
DO (B)	1.35±0.15	7.45±1.06	4.51±0.72	1.55±1.09	4.33±1.78	6.77±1.65	0.41±0.17	5.29±1.61	5.63±1.08
NO3 (B)	6.45±4.97	1.96±1.15	1.35±1.41	14.05±11.40	1.63±1.09	1.02±0.62	12.91±3.73	1.73±0.43	1.05±0.60
PO4 (B)	1.54±1.00	0.96±0.63	0.75±0.47	2.27±1.63	1.38±0.08	0.33±0.10	1.90±0.84	0.37±0.06	0.04±0.02
Clay(%)	12.42±0.34	11.61±0.23	11.65±0.97	11.15±1.15	13.99±2.26	14.97±1.43	12.97±3.10	11.48±1.38	12.12±0.92
Silt(%)	76.25±1.13	72.10±2.89	71.20±2.17	75.12±1.29	72.83±3.74	73.38±4.68	75.38±3.63	70.92±0.78	72.79±0.53
Sand(%)	11.33±1.31	16.30±2.82	17.15±2.73	13.73±1.76	14.97±0.34	13.99±0.16	11.65±0.68	17.60±2.12	15.09±1.36
Chl <i>a</i>	12.30±1.17	9.11±4.40	3.25±0.19	10.66±1.35	5.14±2.68	2.28±0.23	1.41±0.51	0.91±0.10	3.62±2.88
SOC (%)	0.58 ±0.24	0.54± 0.25	0.98± 0.14	0.68±0.14	1.15±0.19	1.20±0.45	1.10±0.24	1.31±0.10	1.33±0.31
TN(%)	0.08± 0.05	0.07 ±0.01	0.06±0.01	0.08±0.04	0.04±0.01	0.05±0.01	0.07±0.02	0.05±0.02	0.02±0.01

Table 2 - Macrobenthos abundance in the coastal waters off Kochi during different seasons. Mean and standard deviations are presented. Macrobenthic abundance (No./ m²). Abbreviations: SWM - Southwest Monsoon; NEM – Northeast Monsoon; PRM – Premonsoon.

Groups	Station 1			Station 2			Station 3		
	SWM	NEM	PRM	SWM	NEM	PRM	SWM	NEM	PRM
Polychaete	126± 41	373 ±11	85± 22	75± 17	333 ± 134	75± 24	173±61	160± 74	110± 36
Bivalvia	16 ±7	52 ± 8	20± 6	46± 26	56± 11	47± 20	20± 7	18± 7	87± 20
Gastropods	0 ±0	140 ± 21	2146± 250	0± 0	26± 3	1065± 320	30± 4	13± 4	90± 25
Nematoda	0 ±0	57 ± 10	65± 25	0± 0	103± 22	0± 0	10± 2	108± 34	90± 14
Foraminifera	111± 27	60 ± 13	50± 12	80 ± 20	67± 22	50± 27	110± 30	27± 11	55± 8
others	0±0	20 ± 5	40± 12	0± 0	40± 20	20 ± 15	20± 4	235± 52	241 ± 25
Unidentified	0±0	18 ± 5	30± 12	0± 0	115± 20	12± 5	17± 4	300± 50	200± 20
Total Macrofauna	253± 69	720 ± 69	2436± 550	201± 30	740± 90	1269± 173	380 ± 105	860± 92	871± 96

Table 3 - Macrobenthos based on the AMBI index of pollution of ecological groups.

S.No	Species	Ecological Groups	S.No	Species	Ecological Groups
1	<i>Minuspio cirrifera</i>	IV	21	<i>Dendronereis aestuarina</i>	III
2	<i>Capitella capitata</i>	V	22	<i>Grandidierella sp.</i>	II
3	<i>Lepidonotus sp.</i>	II	23	<i>Ampelisca sp.</i>	I
4	<i>Amphicteis sp.</i>	III	24	<i>Cirrolinia sp.</i>	IV
5	<i>Prionospio pinnata</i>	IV	25	Cyclopoida	I
6	<i>Prionospio cirrifera</i>	IV	26	<i>Rhabditis sp.</i>	III
7	<i>Prionospio polybranchiata</i>	IV	27	<i>Mesorhabditis sp.</i>	III
8	<i>Cossurida costa</i>	IV	28	<i>Desmocolex sp.</i>	III
9	<i>Glycera longipinnis</i>	IV	29	<i>Daptonema sp.</i>	III
10	<i>Glycera alba</i>	IV	30	<i>Desmodora sp.</i>	III
11	<i>Mediomastus sp.</i>	III			
12	<i>Ancistrosyllis parva</i>	III			
13	<i>Terebellides sp.</i>	I			
14	<i>Lumbrineris impatiens</i>	II			
15	<i>Nereis sp.</i>	III			
16	<i>Nephtys sp.</i>	II			
17	<i>Cossura sp.</i>	IV			
18	<i>Amphicteis sp.</i>	III			
19	Onuphidae	II			
20	<i>Platynereis sp.</i>	III			

Table 4 - Temporal variations of biodiversity indices of macrobenthos in the study area

Parameters	Ranges (Min – Max)	Temporal differences within locations		
		PRM	SWM	NEM
Station 1				
Species Richness	07 - 21	19.25 ± 1.70	7.66 ± 0.58	14.67 ± 1.15
Shannon Diversity H'(loge)	1.80 - 2.83	2.47 ± 0.29	1.89 ± 0.08	2.34 ± 0.08
Total taxonomic distinctness (sDelta+)	500 - 1690	1544 ± 185	600 ± 100	1223 ± 191
Station 2				
Species Richness	4-23	13.75 ± 7.34	5.67 ± 2.08	11.67 ± 1.15
Shannon Diversity H'(loge)	1.01 – 2.89	2.37 ± 0.40	1.34 ± 0.14	2.17 ± 0.35
Total taxonomic distinctness (sDelta+)	266 - 1760	1077 ± 560	423 ± 243	1040 ± 82
Station 3				
Species Richness	7-16	13.25 ± 3.6	10.67 ± 3.21	10.66 ± 1.15
Shannon Diversity H'(loge)	1.78 – 2.54	2.44 ± 0.14	1.81 ± 0.39	2.14 ± 0.27
Total taxonomic distinctness (sDelta+)	542 - 1396	1092 ± 325	717 ± 302	929 ± 108

Table 5 - ANOVA results

Parameters	Spatial differences between locations	Temporal differences within locations		
		Station 1	Station 2	Station 3
Total Macrofauna	F=0.97; P =39	F=4.52 P=0.04*	F=6.806 P=0.02*	F=6.854 P=0.02*
Species Richness	F=1.64; P=0.22 (NS)	F=66.71 P<0.01**	F=5.02 P=0.044*	F=9.12 P=0.01*
Shannon Diversity H'(loge)	F=1.21; P=0.32 (NS)	F=7.688; P=0.01*	F=9.05; P=0.01*	F=5.211; P=0.04*
Total taxonomic distinctness (sDelta+)	F=1.24; P=0.34 (NS)	F=27.6; P=0.0004**	F=5.76; P=0.033*	F=4.973; P=0.04*