Available online at: www.mbai.org.in

doi: 10.6024/jmbai.2017.59.1.1954-06

Assessing multiple stressors on macrofaunal benthic communities along the coastal ecosystem of southern Kerala

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Received: 24 Nov 2016, Accepted: 17 Mar 2017, Published: 10 June 2017

Original Article

Abstract

This paper explores the multiple stressors on benthic macro invertebrate communities of three environmentally disturbed stations along the coast of Kerala, southwest coast of India. Seasonal sampling (pre-monsoon, monsoon, and post-monsoon) was done for a period of one year (2013-2014). The benthic fauna comprised of Gastropods (G), Bivalves (B), Polychaetes (P), Nematodes (N) and Scaphopods (S). Hydrological (Temperature, pH, Salinity, Dissolved Oxygen, Total Dissolved Solids, Nutrients, Chlorophyll a, Heavy metals (HM), Poly Aromatic Hydrocarbons (PAHs)) and sedimentological parameters (Temperature, Sediment texture, Organic Carbon, Organic matter) were determined. The temporal and spatial distribution of benthos at the four sites were identified in the order S1: G>P>B, S2: G>B>P>N>S, S3: G>B>P>N and S4: G>B>N>P. Principle Component Analysis (PCA) revealed the correlation between sedimentological parameters and macrofaunal assemblages, with most significant variation occurring at site 1 (50.50%) and 3 (43.40%), moderate at site 2 (33.34%) and site 4 (33.40%). Agglomerative hierarchical clustering (AHC) reflected the ecological distances of hydrological parameters between sites. The study, thus relates to the temporal and spatial distribution of macrobenthic invertebrate communities and the prevailing coastal pollution.

Keywords: *Kerala coast, multiple stressors, anthropogenic impact, macrobenthos, coastal pollution*

Introduction

Climate change associated with a variety of anthropogenic stressors interact with each other to produce combined impacts on biodiversity and ecosystem functioning (Cardoso *et al*., 2008). India, with a coastline of approximately 7,500 km (Chandramohan *et al*., 2001) has 250 million people thriving along the coast within a distance of 50 km (Areti *et al*., 2012). The tiny south Indian state of Kerala is found to be one of the most thickly populated regions in the world with a growth rate rise of 14% per decade. Anthropogenic activities are exerting tremendous pressure on fragile coastal environment of Kerala.

Contaminated environment influence diversity and structure of the benthic communities. Although considerable related work has been carried out globally (Warwick and Clarke, 2009; George *et al*., 2009; Blake, 2011; Nourinezhad *et al*., 2013). In India, previous studies mainly concentrated on mangrove and backwater ecosystems. Anjana Mohan *et al.* (2008) studied macro and mega faunal communities of Tamil Nadu coast in relation to post-tsunami with varying degrees of human disturbances. Ingole *et al.* (2009) carried out a comparative study of macro and meiobenthos of Kakinada backwaters by correlating its temporal and spatial diversity with sediment grain size and depth. Ramkumar *et al.* (2010) also studied benthic macroinvertebrate communities in relation to pollution of three different sites in Tuticorin coastal waters. Water pressure and heavy metals Co, Hg has significantly affected macrofauna of the southeast continental shelf of India (Manokaran *et al.*, 2014). Musale and Desai (2010) opined that sediment characteristics (sand, silt, and clay) organic carbon and dissolved oxygen were important factors influencing the benthic abundance and species diversity. Hence in the present study, an attempt was made to identify the seasonal variation and abundance of benthic assemblages along the Coast of Kerala and identify the probable bio-indicators of stress, and elucidation of the impact of multiple stressors (HM, PAHs and Nutrients) on benthic community structure. The study also correlated the temporal and spatial distribution of macrobenthic invertebrate communities with prevailing environmental coastal pollution.

Fig.1.Map of Kerala showing the study sites

Material and methods

Study Area

Four sampling sites (Fig.1) were selected for the study representing different anthropogenic stressors that could potentially affect sediment quality, water quality, and macrobenthic diversity.

Site 1 - Varkala (8° 43' N latitude & 76° 43' E longitude): characterized by foot traffic and pilgrimage, resulting in sewage and organic pollution. Site 2 -Neendakara (8° 56' N latitude & 76° 32' E longitude): characterized by oil pollution as a fishing harbour and port with large scale motor boat/trawler movements. Site 3- Chavara (9° 07' N latitude & 76° 31' E longitude): characterized by inorganic pollution of heavy metals, trace metals, polycyclic aromatic hydrocarbons and organochlorine by release of effluents from the Kerala Minerals and Metals Ltd, Titanium dioxide factory and Site 4 - Alappad (9° 05' N latitude & 76° 29' E longitude): characterized as a control site lacking any industrial /agricultural enterprise in the vicinity were considered for the present study.

Duration of the study

The study was carried out seasonally (pre-monsoon, monsoon, and post-monsoon) for a period of one year (March 2013-February 2014).

Sampling Protocol

Triplicate samples were collected using a van Veen grab having mouth area $0.1 m^2$, along the four transects off Varkala, Neendakara, Chavara and Alappad from the near shore region (1 km from the shoreline). Samples were passed through a 0.5 mm mesh sieve and benthic fauna retained on the sieve were fixed in neutral formalin Rose-Bengal mixture, preserved in 70% ethanol for laboratory analysis and further identification. Both sediment and bottom water samples were collected using Grab and Nessler's bottom water sampler (Tagliapietra and Sigovini, 2010).

Environmental variables: Hydrological and Sedimentological Parameters

Temperature: Temperature of overlying sediment and water were recorded with a thermometer, pH, and Salinity were recorded at the field itself using a hand held refractometer and digital pH pen, Dissolved Oxygen (DO) and Total Dissolved Solids (TDS): were recorded by water - analyser (Systronics-model 371), Nutrients (nitrate, nitrite, phosphate, and silicate) were estimated by the method of Grasshoff *et al.* (1983), Chlorophyll a in water was estimated spectrophotometrically (Dere *et al.*, 1998). Heavy metals (Pb, Cd, Cr, Ni, Zn, Fe) were determined with the help of ICP-AES and Hg was determined by direct

Hg analyser (Teledyne Leeman /Hydra IIc). Polycyclic Aromatic Hydrocarbons (PAHs) were determined using GC-FID. Sediment Texture was determined by Pipette Analysis (Krumbein and John, 1938), Organic Carbon was estimated by wet organic carbon method (El-Wakeel and Riley, 1957) which was later converted to Organic matter (Trask, 1939).

Laboratory Analysis

Analysis of Fauna: Preserved fauna was identified up to major taxonomic groups using appropriate keys (Pennak, 1978; Olomukoro, 1996; Day, 1967; Fauchald, 1977).

Data Analysis - Principal Component Analysis

Statistical analysis such as Principal Component Analysis (PCA) extraction and Rotation Method (Promax with Kaiser Normalization) was conducted by detecting trends of variation of sedimentological parameters with benthos across the study sites using SPSS version 24. Agglomerative hierarchical clustering (AHC) similarity was computed by complete linkage and correlation of hydrological parameters (http://www.addinsoft.com).

Results

Macrobenthic diversity

Five groups represented the benthic macrofauna at the study sites viz., Gastropods, Bivalves, Polychaetes, Nematodes, and Scaphopods totalling 3,479 individuals representing 62 taxa. Gastropods (70%) were the most dominant, followed by Bivalves (15%), Polychaetes (10%), Nematodes (3%) and Scaphopods (2%). The temporal and spatial distribution of benthos at the four sites were in the order S1: G> B>P>N>S; S2: G>B>P>N>S; S3: P>G>B>N=S and S4: G>B>P>N>S (Fig. 2).

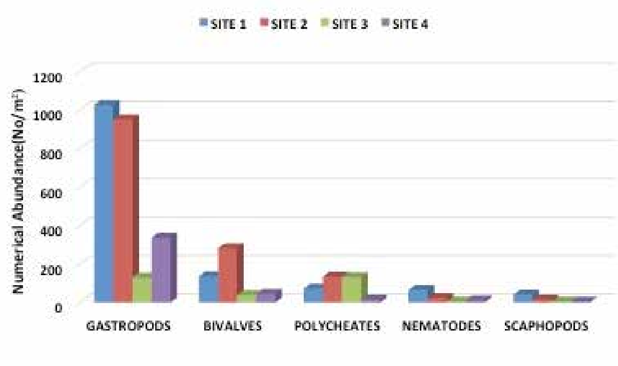

Fig. 2. Numerical abundance of benthic communities along the study sites

Statistical results

The data matrix was treated with multivariate techniques such as Hierarchical Agglomerative Cluster analysis (HAC) and Principal Component Analysis (PCA) in which cluster analysis rendered significant variations between sites (Fig 3. a-d). The proximity measurement used was Euclidian distance with different groups of similarity between sampling sites and variables. Dendrogram revealed four meaningful clusters, site 1 (Varkala - organic pollution) and site 4 (Alappad - Natural disturbances) which evince positive correlation in pH, Dissolved Oxygen, Salinity, No_3, Chlorophyll *a*, Fe, Pb and Cd, while at site 2 (Neendakara - organic & inorganic pollution) and site 3 (Chavara - inorganic pollution) reveal a positive correlation between Temperature, TDS, NO_2 (indicator for presence of organic pollutants), PAHs, Hg and Cr (indicator for presence of inorganic pollutants).

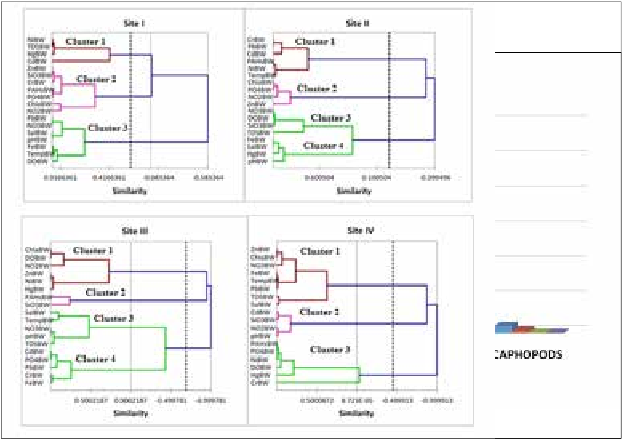

Fig. 3. a-d. Cluster Analysis showing classification of hydrological parameters along study sites

In general, PCA analysis - component matrix correlation coefficients greater than 0.6 are taken for interpretation (Orloci *et al.*, 1967). At site 1 (Varkala), PCA was identified at four factors, explaining 50.50 % of the total variance of the data set (Table 3a). PC1 revealed the silty nature of sediment, it may be due to the strong positive correlation of Nematodes and less correlation of Scaphopods in the area. PC2 contributed more sand, clay and least influence of sediment temperature are the factors incorporated into the strong correlation to polychaetes with less correlation to bivalves and Scaphopods. PC3 bring about the importance of sand and clay in the high abundance of bivalves, the moderate abundance of Scaphopods and least abundance of Gastropods in the area disclose, being an intertidal zone where sediments remain damp without the tide. PC4 incorporated importance of sediment organic carbon, organic matter and sand in the strong positive correlation of Scaphopods and moderate with polychaetes and gastropods.

Site 2 (Neendakara) explained 33.34 % of the total variance of data set, (Table 3b). PC1 highly contributed to factors such as organic carbon (OC) and organic matter (OM), and their high correlation with bivalves, indicating the input of harbour originated organic wastes in the area, while in PC2, clay revealed the high correlation with gastropods and moderate with polychaetes. PC3 integrate sediment

Table 1. The benthic assemblages along the study sites

Taxa	Site 1 (Varkala)			Site 2 (Neendakara)			Site 3 (Chavara)			Site 4 (Alappad)		
	Pre-M	Mon	Post- M	Pre-M	Mon	Post-M	Pre-M	Mon	Post-M	Pre-M	Mon	Post-M
GASTROPODS												
Architectonica perdix	52	-	148	-	-	-	-	-	75	-	-	35
Babylonia spirata	135	-	-	-		-	-	-	-	-	-	-
Balcis martini	140	-		70	50	-	-	-	-	62	-	-
Brachiodontes sp	-	8	-	75	-	70	-	-	15	20	45	20
Bullia ampulla	-	-	-	-	50	-	-	-	-	-	-	-
Bullia melenoides	-	-	20	50	-	60	-	-	-	45	30	20
Bullia sp	-	50	-	-	-	-	-	-	-	-	-	-
Bullia vitata	-	-	-	5	-	-	-	-	-	-	-	-
Bursa bufonia	-	20	-	40	50	35	-	-	-	-	-	-
Diodora lima	-	41	-	50	-	-	-	-	-	-	-	-
Littorina sp	-	-	-	-	-	-	-	-	-	5	-	-
Murex tribulus	-	-	-	-	25	60	-	-	-	-	-	-
Murex virgineus	-	-	-	-	10	10	-	-	-	-	-	-
Nassarius dorsatus	-	35	-	22	-	20	-	-	-	10	-	-
Oliva reticulata	-	5	45	-	-	-	-	-	-	5	-	-
Oliva tricolor	-	-	-	-	-	-	-	-	-	-	15	
Oliva annulata	-	-	-	-	-	-	-	-	-	-	5	
Oliva oliva	-	-	-	-	-	-	-	-	-	-	20	-
Paphia sp	-	-	-	45	5	-	-	-	-	-	-	-
Telescopium telescopium		25										
Terebra palustris	-	75	73	-	-	-	-	-	-	-	-	-
Trochus stellatus	55	-	35	-	-	-	-	-	-	-	-	-
Turitella terebra Linne	-	-	40	25	25	-	-	-	5	-	-	-
Turitella javanica	25	-	-	25	75	-	-	-	35	-	-	-
BIVALVES												
Anadara sp	-	-	-	10	-	10	-	-	-	-	-	-
Anadara formosa	30	-	10	-	20	-	-	-	-	-	-	-
Anadara granosa	-	15	-	-	10	-	-	-	5	-	-	-
Anodontia sp	-	-	-	10	-	5	-	-	-	-	-	-
Cardium sp	-	-	-	5	-	7	-	-	-	-	-	-
Anodontia edenticula	-	-	-	-	10	-	-	5	5	-	-	-
Donax scortum	-	-	-	-	20	-	-	-	-	-	-	-
Mactra luzonica Reeve	5	-	-	25	-	-	-	-	-	-	-	-
Mactra sp	10	-	-	-	-	5	-	-	-	-	-	-
Papilonis sp		-	-	10	-	15	-	-	-	-	-	-
Pinctada sp	20	-	-	-	-	-	-	-	-	-	10	-
Semele radiata	-	-	-	33	-	10	-	-	-	-	-	-
Tellina sinuata Spengler	12	-	-	-	8	-	-	-	-	-	-	-
Trisidos sp	-	-	-	-	-	-	-	-	-	-	10	-
Vepricardium coronatum	-	-	-	-	20	-	-	-	13	-	-	-
Umbonium sp	10	25	-	-	50	-	-	5	5	25	-	-
NEMATODES												
Desmodara sp	20	5	10	10	-	10	5	-	-	5	-	2
Desmoscolex	21	10	-	-	-	5	-	-	-	-	5	-
SCAPHOPODS												
Dentalium bisexangulum	31	-	10	-	-	15	-	5	-	5	-	-

POLYCHAETES												
Ceratonereis sp	-	-	-	25		20	-	-	10	-	10	-
Cheatopterus sp	-	-	-	-	-	-	-	-	13	-	-	-
Cirratulus africanus	-	-	-	-	-	5	10	-	5	-	-	-
Nephtys dibranchis	-	-	8	35	-	20	-	-	10	-	-	-
Nereis capensis	9	-	5	-	-	-	15	-	9	-	-	-
Polydorid sp	10	10	-	-	-	-	-	-	-	-	-	-
Phyllodoce castanea	-	-	11	-	-	-	-	-	10	-	-	-
Scolelepis squamata	-	-	-	5	-	-	-	-	14	-	-	-
Scolelepis ruba	-	20	-	-	5	-	-	-	10	-	15	-
Cassura sp	-	-	-	-	12	8	-	-	-	-	-	-
Glycera sp	-	-	-	-	-	-	7	5	5	-	-	-

temperature, organic carbon, organic matter and sand which showed influence on the abundance of Polychaetes in the area. The high abundance of polychaetes in the area can be attributed to the heterogeneous sediments, with high sand content (Jaleel, 2012). PC4 explains sediment temperature, organic carbon, organic matter, silt and clay, and showed that such factors strongly influence the highest abundance of scaphopods, the moderate abundance of polychaetes and least abundance of bivalves.

Site 3 (Chavara) explained 43.40 % of the total variance of data set, (Table 3c). Sediment organic carbon, organic matter, and temperature were the prime factors in PC1 revealed strong positive correlation to bivalves and moderate correlation with gastropods. PC2 highly contributed sand moderately contributed organic carbon and organic matter with favourably moderate correlation to gastropods and polychaetes. PC3 include only one factor is sand, which revealed the moderate correlation with gastropods and polychaetes. PC4 is highly contributed to the factor silt which highly correlated the presence of scaphopods and moderately influences the presence of bivalves and polychaetes in the area.

Site 4 (Alappad) explained 33.40 % of the total variance of data set, (Table - 3d). PC1 revealed that Sed T, Sed OM, Sed OC highly influenced bivalves of the area. PC2 revealed the significant correlation with gastropods due to the influence of sand in the area with less correlation to polychaetes since polychaetes prefer organic rich environment. PC3 revealed the strong correlation with gastropods and less correlation to bivalves, PC2 & PC3 confirm that sand is an important factor for the survival of gastropods. The high correlation of scaphopods was found in PC3 and PC4, revealing the importance of clay in the assemblages of scaphopod community. The presence of clay in the area reflects an increase in fine particles, compounded by organic constituents bringing an increase in the benthic metabolism (Meksumpun and Meksumpun, 1999).

Diversity Indices of macro fauna

Diversity indices for macrobenthic fauna are given in table 2. Shannon-Wiener index showed the highest value at site 2 (H= 3.25) with the lowest value at site 3 (H=2.21), while Simpson Index was highest at site 2 (λ'=0.76) and least at site 4 (λ'=0.48). Margalef's index showed the highest value at site 3 (R= 3.33) and its lowest value at site 4 (R= 1) with Pielou's evenness values, greatest at site 4 (J=2.11) and lowest at site 3 (J=1.01).

Table 2. Diversity Indices

Sites	Shannon index(H)	Simpson Index(λ)	Margalef's richness Index(R)	Pielou's Evenness index(J)
Site 1	3.09	0.58	2.00	1.91
Site 2	3.25	0.76	2.33	1.72
Site 3	2.21	0.74	3.33	1.01
Site 4	2.71	0.48	1.00	2.11

Discussion

In our study, the presence of several bio-indicators revealed the existence of various stressors in the ecosystem. Among Gastropods, *Architectonica perdix* was exclusively found at site 1 and site 3 during post-monsoon, whereas *Babylonia spirata* was found at site 1 only during pre-monsoon. *Oliva oliva, O. tricolor,* and *O. annulate* were found only at site 4 during monsoon. The IUCN red listed major threatened species, *Telescopium telescopium* was also exclusively found only at site 1 during monsoon which indicates that this species is impacted locally due to loss of habitat by the increased sewage load (Mumthas and Miranda, 2016).

High species diversity of molluscs found at site 2 raises the possibility of using them as bio-indicators of aquatic pollution. The greater abundance of gastropods at site 2 can be correlated to increase in alkalinity and sandy silt sediments. *Bullia ampulla* and *Bursa bufonia* - established bio-indicator species at site 2 are the most important indicator species which can be utilized in Coastal Environment Risk Assessment Programs as bio-monitoring agents signaling coastal marine pollution. Bivalves, the second dominant group in numerical abundance at site 2 represented by *Anadara* sp, *Anodontia* sp, *Papilionis* sp, *Semele rdiata* and *Cardium* sp were found only during pre-and post-monsoon. These bivalves are well known for their affinity in increased salinity in the area which is considered as one of the main reason for their presence at site 2.

Polychaetes, the third dominant group in numerical abundance at site 3 and represented by *Cirratulus africanus, Nephtys dibranchis, Phyllodoce castanea, Scololepis squamata, S. ruba, Nereis capensis* and *Chaetopterus* sp. were recorded only during post monsoon, while *Ceratonereis* sp. was found only at site 2 during post and pre-monsoon and at site 4 during post monsoon. *S. squamata* was the least abundant species found at site 3 due to the increasing industrial pollution which has negatively affected its survival in the area. Similar observations were made by Devassy *et al.* (1987) who stated increased sewage and industrial pollution as the main cause of benthic community decline. *C. africanus* was present only at site 2 during post-monsoon and at site 3 during post and pre-monsoon. *N. capensis* was present only at site 1 and at site 3 during pre-and post-monsoon. Among nematodes, *Desmodara* sp. and *Desmoscolex* sp. was found the maximum in numerical abundance at site 1 during pre-monsoon and minimum at site 4 during post-monsoon. Scaphopods such as *Dentalium bisexangulum* (Tusk shells) were found the maximum in numerical abundance at site 1 during pre-monsoon which shows reveals that they are possible indicators of early social stratification.

The mean water temperature (30.51 °C ± 0.61) and TDS (16.43 ppt ± 0.37) were found to be maximum at site 1 and 2 indicating fast growth rates of bacteria and phytoplankton, contributing to increased water turbidity, macrophytic growth and algal blooms (Chapman, 1992). In site 3, bottom water showed high variations in pH (5.3 ± 0.6) compared to other sites due to the presence of effluents and atmospheric decomposition of acid forming substances. A major source of metals in the marine environment is often derived from mining activities. Site 3 shows the destructive consequences of industrial mining and effluent discharge. At site 1, dissolved oxygen concentrations ranged from 2.6 - 3.36 mg/l, dissolved oxygen levels below 4 mg/l are considered unhealthy to many aquatic inhabitants. Several resident marine organisms are subjected to physiological stress resulting in high biotic mortality rates (Domínguez and Reaka, 1988).

Benthic animals play an important role in releasing nutrients back to the water column aiding in the stability of sediments. The macrofaunal distribution of species at the bottom is

Table 3. a-d. Rotated Component matrix extracted using PCA and their % contribution to explaine the variance in sedimentological parameters with Macrofaunal Assemblages along study sites

Component Matrix[a]				
a) Site 1	Component			
PC1	PC2	PC3	PC4	
SedT	0.919	0.007	0.043	-0.21
SedOC	-0.901	-0.267	-0.22	0.092
SedOM	-0.901	-0.28	-0.213	0.098
Sand	-0.956	0.178	0.074	0.051
Silt	0.952	-0.203	-0.032	-0.051
Clay	0.111	0.442	-0.753	-0.01
Gastropods	0.385	-0.735	0.063	0.393
Bivalves	-0.223	0.282	0.734	-0.455
Polychaetes	0.488	0.669	-0.169	0.371
Nematodes	0.901	-0.19	-0.042	0.01
Scaphopods	0.026	0.267	0.521	0.785
Component Matrix[a]				
b) Site 2	Component			
PC1	PC2	PC3	PC4	
SedT	-0.281	-0.66	0.56	0.194
SedOC	0.936	-0.2	0.111	0.227
SedOM	0.933	-0.207	0.117	0.23
Sand	-0.966	0.085	0.155	-0.113
Silt	0.963	-0.116	-0.164	0.104
Clay	0.125	0.849	0.269	0.258
Gastropods	0.116	0.738	-0.545	0.064
Bivalves	-0.6	-0.398	-0.372	0.376
Polychaetes	-0.206	0.527	0.646	0.448
Scaphopods	-0.433	-0.156	-0.444	0.7
Component Matrix[a]				
c) Site 3	Component			
PC1	PC2	PC3	PC4	
SedT	0.723	0.045	-0.136	-0.424
SedOC	0.874	0.445	0.011	-0.065
SedOM	0.878	0.445	0.013	-0.061
Sand	-0.605	0.653	0.387	-0.123
Silt	0.211	0.282	-0.633	0.569
Clay	0.488	-0.795	-0.05	-0.179
Gastropods	0.369	0.544	0.675	-0.035
Bivalves	0.703	-0.438	0.323	0.404
Polychaetes	0.052	0.467	-0.378	0.483
Scaphopods	0.021	-0.266	0.629	0.666
Component Matrix[a]				
d) Site 4	Component			
PC1	PC2	PC3	PC4	
SedT	0.723	0.045	-0.136	-0.424
SedOC	0.874	0.445	0.011	-0.065
SedOM	0.878	0.445	0.013	-0.061
Sand	-0.605	0.653	0.387	-0.123
Silt	0.211	0.282	-0.633	0.569
Clay	0.488	-0.795	-0.05	-0.179
Gastropods	0.369	0.544	0.675	-0.035
Bivalves	0.703	-0.438	0.323	0.404
Polychaetes	0.052	0.467	-0.378	0.483
Scaphopods	0.021	-0.266	0.629	0.666

closely related to salinity, water movement, sediment grain size and organic content of the sediment (Duineveld *et al*., 1991). Organic rich sediment found at site 2 during pre-and post-monsoon has contributed to opportunistic species at the harbour (site 2). Increased harbour activities after monsoon have led to a rise in sediment load and release of contaminants (hydrocarbons and metals) into the environment causing considerable stress to dwelling organisms making only the tolerant species to survive these unfavourable conditions (Anbuchezhian *et al*., 2009).

At site 4, low pH levels were found during monsoon (7.33 ± 0.24), which may be due to the influence of fresh water and release of metabolites (Rajesh *et al*., 2014). High amounts of clay in the area revealed an increase in fine particles (silt & clay) compounded with organic constituents elevating benthic metabolism (Meksumpun, 1999) and marking decline in sediment O^2 content (Pearson, 1980) leading to anoxic conditions, the main reason for low species richness at site 4 (Table 2). Macrofaunal communities respond differently to flooding events, depending on ecology and feeding habits of species (Norkko *et al*., 2002; Picard *et al*., 2003).

At site 2, maximum species diversity was recorded in spite of high nutrient load (eutrophication) resulting in the conducive environment for macrobenthos. Multiple stressors including pollutants, excessive nutrient altered habitat, and hydrological regimes impact the resources by single, cumulative or synergistic processes, lowering overall system stability (Dolbeth *et al*., 2007). Responses of biota to environmental stressors, integrated as a result of both direct and indirect processes reflect changes in abundance, diversity, and hardiness of individuals, populations, and communities (Adams, 2005). Benthic communities are dynamic in nature and their presence or absence change environment variations with great complexity and any attempts at the recognition of species will be able to act as robust indicators of low diversity. The present work is a reiteration that environmental variables play an important role in structuring macrofauna of coastal ecosystems. Stringent bio-monitoring of coastal waters of Kerala is recommended.

Acknowledgements

We express our sincere thanks to the management and the Principal of Fatima Mata National College, Kollam, Kerala for providing facilities to carry out this work. The first author is also thankful to the University of Kerala for the award of a Research Fellowship.

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