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Seasonal shift in soft bottom-dwelling community structure in coastal waters of the northern Bay of Bengal, Indian Ocean

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Benthic invertebrate communities play an important role in functioning of benthic food webs and commonly used as potential biomarkers in environmental monitoring programs. The seasonal variation in community structures of macro benthos was studied in northern Bay of Bengal, Bangladesh from summer 2015 to spring 2016. A total of 45 species belonging to 35 families, 25 orders and 5 classes were identified. Of these species, 14 were commonly distributed and 10 were highest contributors. The species number, total abundance and species richness peaked in summer and sharply dropped in winter whereas evenness and diversity were highest in spring and both were lowest in winter. Multivariate analysis (CAP and RELATE) revealed a clear significant seasonal shift in community patterns of the benthic communities with relation to environmental variables. Further, BIOENV signified that water temperature, salinity, dissolved oxygen and water nutrients were the main drivers to shape the community structure. These finding suggest that seasonal shift in benthic communities in response to environmental changes might be used as bio indicators for discriminating environmental quality status in coastal ecosystems.

[Keywords: Macro benthos; Seasonal shift; Community structure; Environmental monitoring; Coastal ecosystem]

Introduction

Benthic invertebrate communities are mobile or sessile aquatic organisms living in the bottom sediments or on the substratums[1,2]. They play an important role in transitional ecosystems by filtering planktonic and microbial organisms acting as a food source for larger benthic organisms in the food web, thereby they link primary producers with higher trophic levels in aquatic food chain[1]. Furthermore, they oxygenate the bottom deposits by reworking sediments and play a fundamental role in breaking down organic material before bacterial decomposition and remineralisation[1,2]. The seasonal variation in community structure of soft bottom dwelling macro invertebrate communities depends on environmental parameters i.e. surface area, water salinity, habitat structure[3-5]. Therefore, these factors can actually be considered the key limiting dimensions defining the environmental niche for benthic invertebrates in coastal ecosystems[5-7]. Thus, we hypothesize that distribution and diversity patterns are linked to those environmental variables, basically water nutrients and sediment features.

Organisms that show instant reaction with the change of certain environmental conditions, which also gives early warning focussing on rapid and sensitive response, are defined as bio-indicators[8]. In contrast, benthic communities like filter feeding mollusc (e.g. bivalves & gastropods), polychaete (*Capitella capitata*), oligochaete (*Tubifex tubifex*), amphipod and chironomid species have widely been used as bio-monitoring indicators for bioassessment and eco-toxicological tests, due to their strong sensibilities to pollutants both organic or inorganic and either natural or anthropogenic[9-17]. Therefore, recent anthropogenic activities and climate changes have negative impacts on the environment and ecosystem while use of benthic communities will be an effective tool for discriminating the environmental status and water quality [7,18]. Although research on benthic invertebrate community structure and relative hydrological resources are prime necessary in Bangladesh for sustainable ecosystem health management, however as regards, a few research works have been conducted very recently which significantly limited for community based bio assessment in coastal ecosystems[19-22].

On the basis of environmental health status monitoring, a 1-year baseline survey of macro benthos communities was conducted in coastal waters of the Bay of Bengal (BoB), Bangladesh. The main objectives of this study were; (1) to document the taxonomic composition and community structure of macro benthic communities; and (2) to evaluate the environmental quality status based on the benthic community structure and related environmental variability in the coastal area.

Materials and Methods

Three sampling sites were selected in the subtidal area of Kohelia channel in coast waters of the northern Bengal Bay, Bangladesh (Figure 1). These three sites were selected based on pollution gradients: Site 1 (St–1) is slightly polluted near Dalghata Monirtek; site 2 (St–2) is moderately polluted from aquaculture/agriculture discharges in the middle part of the channel near Jhapua; and site 3 (St–3) is heavily polluted by anthropogenic contaminants from domestic sewages and oil spilled (shipping) in Matarbari north Rajghat in the northern Bengal Bay eco-region. A total of 60 samples were collected in summer (March 2015), autumn (July 2015), winter (November 2016) and spring (January 2016).

Sediment, water and benthic faunal samples were collected using transect method[23]. For benthic faunal sampling 5 sediment cores samples (using Van-Veen grab sampler, up to 20 centimetres deep within a sampling area of 1×1 m^2) were taken randomly from the quadrant of 5 × 5 m^2 placing at each of transect in all stations. Samples were sieved using a sieve plate (a mesh size of 0.5 mm) and preserved with 8% formalin and kept overnight with Rose Bengal stain for sorting and taxonomic identification described by Tagliapietra & Near[11]. Identification was carried out on the basis of morphological characteristics according to the published literatures[19, 22, 24-33].

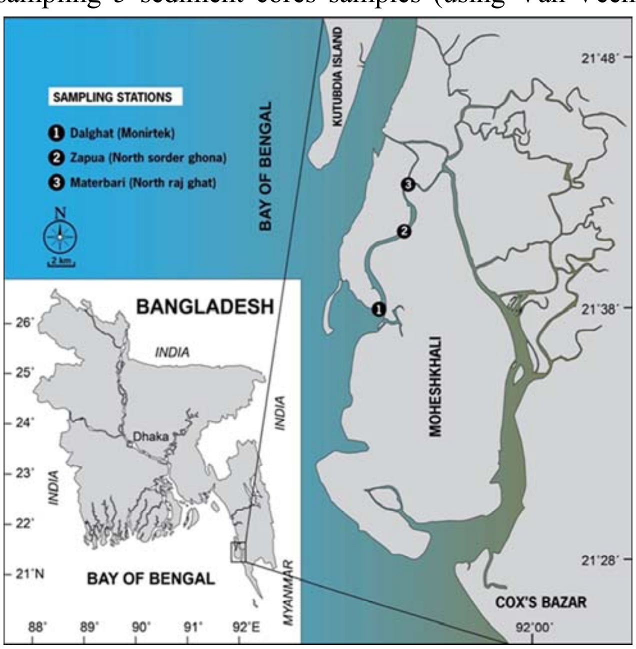

Fig. 1 — Sampling sites (St--1, 2, 3) in coastal waters of the Bay of Bengal, Bangladesh.

Water temperature (ºC), salinity (psu), pH, and water transparency (cm) were estimated *in situ* using centigrade thermometer, refractometer (TANAKA New S-100, Japan), digital pen pH meter (HANNA instruments, model HI 98107) and secchi disk, respectively. Subsurface water samples below ~1 m were collected in a pre-marked plastic bottle for measuring dissolved oxygen (DO), total dissolved solid (TDS), total suspended solid (TSS), nitrate-nitrogen (NO_2-N) and soluble reactive phosphorus (PO_4-P) following APHA[34] and Huq & Alam[35].

The abundances of species were expressed with the number of individuals per square meter (individuals/m^2) according to Welch[36]. Diversity of species indices Shannon-Wiener Index (H'), species richness (d) and species evenness (J') were used to summarize the biodiversity[37-39]. They were calculated according to the following formulae:

$$H' = -\sum_{i=1}^{s} P_i(\ln P_i)$$

$$J' = H' / \ln S$$

$$d = (S - 1) / \ln N$$

where H'= observed diversity index; P_i = proportion of the total count arising from the ith species; S = total number of species; and N = total number of individuals.

Multivariate analysis on seasonal variations in the benthos communities were conducted using the PRIMER v7.0.13 + PREMANOVA add on[40,41]. Bray-Curtis similarity and Euclidean distance matrices were computed on square root transformed biotic data and on log-transformed/normalized environmental data, respectively. The species distribution among four seasons was analysed by the sub-module of CLUSTER on Bray-Curtis similarities from the standardized/transformed species abundance data. The significance of differences of samples tested using the routine of ANOSIM (analysis of similarities) which is a permutation/randomization based test[41]. Species contribution (rank) to the average Bray-Curtis similarity among the four seasons, as well as to the similarity within one season was analysed using the SIMPER (similarity percentage ayh vnalysis) program[41]. The seasonal variations in community patterns were ordinated using the sub-module of CAP (canonical analysis of principle coordinate) of PREMANOVA, while the seasonal pattern of environmental variables was ordinated using the routine PCA (principle component analysis)[40,41]. The significance of biota and environment correlations was tested using the routine of RELATE, while the routine BIOENV (biota-environmental correlation analysis) was used to explore potential relationship between community structure with the environmental parameters[41]. Pearson correlation was carried out using the IBM-SPSS v.22 to determine the relationships between the ecological parameters of benthic communities and environmental variables[42].

Results

Water temperature ranged from 18.33 to 32.33 ^{o}C during monsoon to pre-monsoon. The average values of pH ranged from 7.24 to 7.54. Salinity ranged around 12.33 to 34.33 psu. Transparency varied from 17 to 75.67 cm. The values of TDS varied from 30.93 to 32.67 mgl^{-1}, and those of TSS varied from 0.58 to 1.00 mgl^{-1}. The concentrations of DO were fluctuated from 4.76 to 6.35 mgl^{-1}. The values of NO_2–N varied from 0.34 to 0.53 µmol l^{-1}, and those of PO_4–P varied from 0.33 to 0.55 µmoll^{-1} (Table 1)

A mean plotted analysis was summarized for seasonal variability of these 9 environmental variables. All these nine variables showed three different variabilities (1) water transparency, salinity, TSS and NO_2-N was higher in winter while found lower in summer (Figures 2c, d, h and i); (2) pH, TDS and DO maximum in autumn while minimum in spring (Figures 2b, e and f); and (3) other two parameters water temperature and PO_4-P were peaked in spring however, dropped in winter (Figures 2a and g).

A total of 45 species belonging to 35 families, 25 orders and 5 classes were identified during the study period (Table 2). Of these species, 14 forms (*Tanaissus lilljeborgi, Nephtys hombergii, Heteromastus filiformis, Dasybranchus caducas, Neanthes chingrighattensis, Micronephtys oligobranchia, Gammarus roeseli, Notomastus hemipodus, Nephthys oligobranchin, Liguas fasciatus, Pomacea insularum, Gesaneris malayensis* and *Scolelepsis squamata*) occurring in all four seasons were defined as 'common species', while species of the top 10 ranked contributors at each season were defined as 'dominant species' (Table 2).

A dendrogram for species distribution among four seasons showed that total 45 species were divided into six groups at 30% similarity level (Figure 3). Regarding these six groups, group-1 represented 32 species including common/dominant species with bulk of contribution. The others five groups showed relatively rare assemblages with lower abundance. It was noteworthy that six species (e.g., *Bullia vittata, Pharella javanica* and *Polyodontes maxillosus*) occurred in specific seasons, and defined as endemic species with season (Figure 3 & Table 2).

The abundances peaked in summer and dropped in autumn (Figure 4a). In terms of relative abundances, *Tanaissus lilljeborgi* was the most dominant species in all four seasons, with maximum in winter and minimum in spring compared to the other nine dominant species (Figure 4b).

The species number and total abundance peaked in the summer while species number dropped in winter while minimum abundance was in autumn (Figures 5a and b).

Table 1— Average values (±SD) of environmental variables for each seasons monitored at three stations in coastal waters in the northern Bay of Bengal, Bangladesh during the study period.

Parameters	Spring	Summer	Autumn	Winter
WT	32.33±3.51	29±3.39	26.67±3.32	18.33±2.96
pH	7.24±2.11	7.41±2.13	7.54±2.14	7.46±2.13
Sal	30±3.43	10.33±2.43	20.33±3.06	31.33±3.48
Trans	75.67±4.34	17±2.89	24±3.21	71.67±4.28
TDS	30.93±3.46	31.36±3.48	32.67±3.52	31.46±3.48
DO	6.64±2.03	6.42±2.00	7.01±2.08	6.66±2.03
W PO_4-P	0.55±0.44	0.47±0.39	0.42±0.35	0.33±0.29
W NO_2-N	0.48±0.39	0.34±0.29	0.38±0.32	0.53±0.42
TSS	0.74±0.55	0.58±0.45	0.80±0.58	1.00±0.69

WT=water temperature, Sal=salinity, Trans=transparency, TDS= total dissolved solid, TSS= total suspended solid, DO=dissolved oxygen, W NO_2-N= water nitrite nitrogen, W PO_4-P= water soluble reactive phosphorus; ±SD, standard deviation.

Table 2 — Species list with average abundance (ind.m^{-2}), contributions of top 10 ranks (based on SIMPER analysis) at each seasons of the benthic communities in coastal waters of the northern Bay of Bengal, Bangladesh

Species name	Spring		Summer		Autumn		Winter	
	N	R	*N*	R	*N*	R	*N*	R
Allonais paraguayensis	+	….	+	….	+	….	-	….
Amphicteis gunneri	-	….	+	….	-	….	-	….
Arenicola marina	-	….	-	….	+	….	+	….
Aricidea simplex	+	….	+	….	+	….	-	….
Aulodrilus pigueti	+	….	+	….	-	….	-	….
Brachiopods laevae	+	….	+	….	-	5	+	….
Branchiodrilus semperi	-	….	+	….	+	….	-	….
Branchiodrilus semperi	+	….	+	….	-	….	+	….
Bullia vittata	++	….	+	….	+	….	-	….
Capitella capitata	**-**	**3**	**+**	**….**	**-**	**….**	**-**	**….**
Cirratulus cirratus	++++	….	+	….	+	….	-	….
Cyathura carinata	**+**	**….**	**+**	**7**	**-**	**….**	**+**	**3**
Dasybranchus caducus	**+**	**….**	**++**	**3**	**-**	**….**	**++**	**….**
Dero digitata	**++**	**….**	**+++**	**….**	**+**	**7**	**+**	**….**
Enigmonia aenigmatica	+	….	+	….	-	….	-	….
Euzonus flabelligerus	-	….	+	….	+	….	-	….
Gammarus roeseli	**++**	**7**	**++**	**4**	**+++**	**2**	**++**	**2**
Gesaneris malayensis	**+++**	**5**	**+**	**9**	**++**	**3**	**+**	**8**
Heteromastus filiformis	+	….	+	….	+	….	+	….
Heterospio catalinensis	+	….	-	….	-	….	+	….
Hypereteone foliosa	**+**	**….**	**+**	**….**	**-**	**….**	**+**	**7**
Lanice conchilega	**+++**	**6**	**+**	**….**	**-**	**….**	**+**	**4**
Liguas fasciatus	+	….	+	….	+	….	+	….
Limnodrilus hoffmeisteri	-	….	+	….	+	….	+	….
Lopadorhynchus henseni	-	….	+	….	+	….	-	….
Lumbrineris blainville	**++**	**8**	**+**	**….**	**-**	**….**	**+**	**….**
Micronephtys oligobranchia	**++**	**9**	**+**	**….**	**+**	**….**	**+**	**6**
Neanthes chingrighattensis	**++**	**….**	**++**	**8**	**+**	**8**	**+**	**9**
Nephthys oligobranchia	**+**	**….**	**+**	**….**	**+**	**9**	**+**	**5**
Nephtys hombergii	**++++**	**2**	**++**	**5**	**+**	**4**	**+**	**….**
Nereis zonata	**-**	**….**	**+++**	**2**	**+**	**….**	**-**	**….**
Notomastus hemipodus	**++**	**….**	**++**	**6**	**+**	**6**	**+**	**10**
Pharella javanica	-	….	+	….	-	….	-	….
Polyodontes maxillosus	-	….	+	….	-	….	-	….
Pomacea insularum	+	….	+	….	+	….	+	….
Sabella spallanzanii	**+++**	**4**	**+**	**….**	**-**	**….**	**-**	**….**
Scolelepis squamata	**++**	**10**	**+**	**….**	**+**	**10**	**+**	**….**
Scylle serrata	+	….	+	….	-	….	-	….
Stygocapitella subterranea	+	….	+	….	+	….	+	….
Tanaissus lilljeborgi	**+++++**	**1**	**+++++**	**1**	**+++++**	**1**	**+++++**	**1**
Telescopium telescopium	**+**	**….**	**+**	**10**	**+**	**….**	**-**	**….**
Trachycardium asiaticum	-	….	-	….	+	….	-	….
Tubifex tubifex	+	….	+	….	+	….	-	….
Turris crispa	+	….	+	….	-	….	+	….
Umbonium vestiarium	-	….	-	….	+	….	-	….

N, average abundance (ind.m^{-2}): +=0–1; ++=2-10; +++=11-20; ++++=21–30; and +++++=over 40; R= Rank contributors; Text bold, dominant species at each season.

The analysis of similarity (ANOSIM) revealed a significant difference in the benthos community structure among the four seasons (Global R=0.623, $P < 0.001$).

The pair-wise comparison showed that three species (*Tanaissus lilljeborgi, Cyat*hura carinata and Gammarus roeseli) highly contributed in total population however, only one species *Tanaissus*

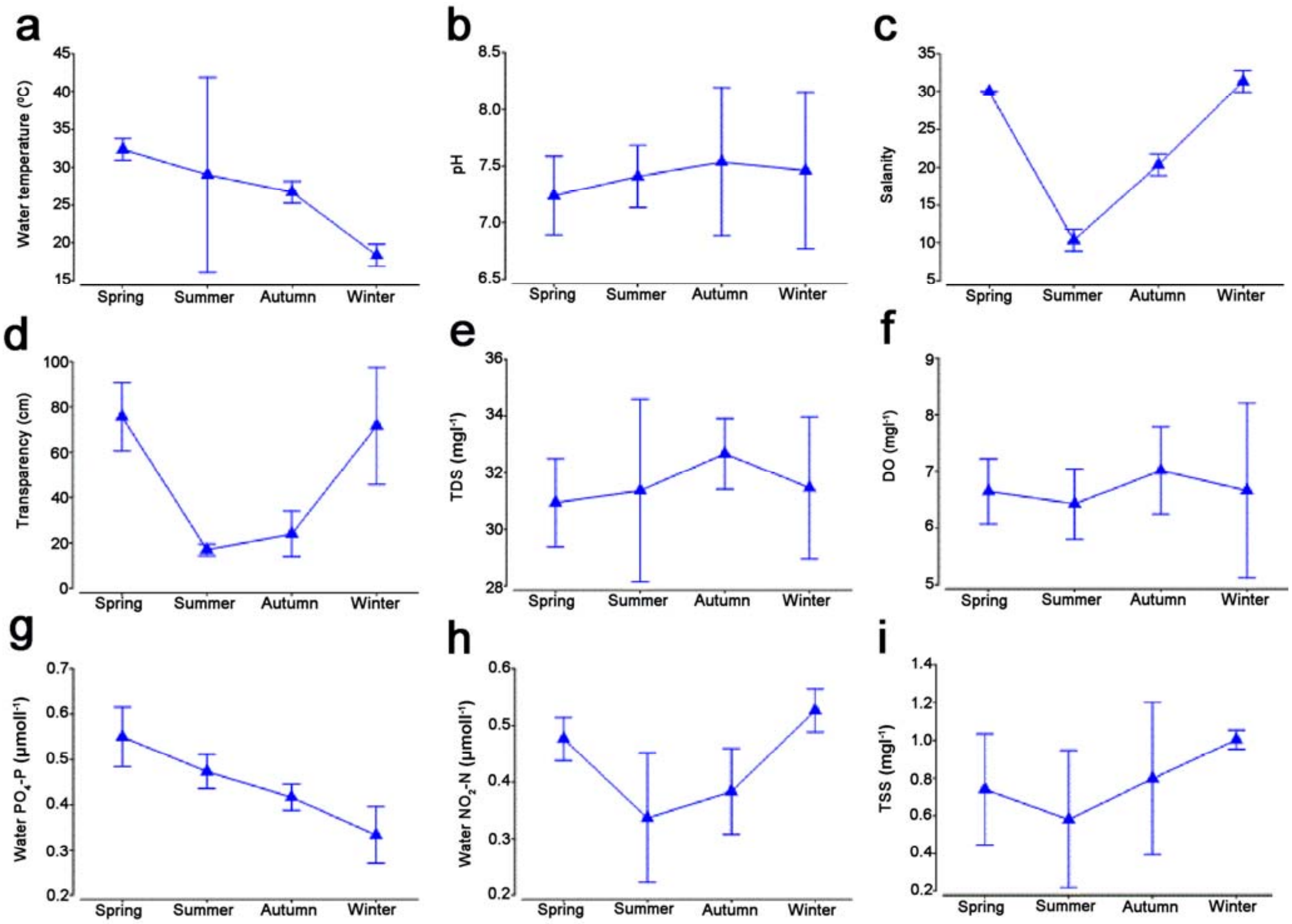

Fig. 2 — Seasonal variation in environmental variables of coastal water in the BoB, Bangladesh during the study period.

Table 3 — Summary of results from biota-environment (BIOENV) analysis showing the 10 best matches of environmental variables with seasonal variations of the benthic communities during the study period.

Rank	Environmental variables	ρ value	P value
1	WT, DO, W PO_4-P	0.674	<0.05
2	WT, DO, W PO_4-P, W NO_2-N	0.669	<0.05
3	DO, W PO_4-P, W NO_2-N	0.665	<0.05
4	WT, DO, pH, W PO_4-P	0.640	<0.05
5	WT, DO, W PO_4-P, W NO_2-N, TSS	0.611	<0.05
6	WT, DO, W NO_2-N	0.610	<0.05
7	WT, DO, pH, W PO_4-P	0.609	<0.05
8	pH, DO, W PO_4-P, W NO_2-N	0.608	<0.05
9	WT, Trans, DO, W PO_4-P	0.606	<0.05
10	DO, W PO_4-P	0.605	<0.05

ρ value: Spearman correlation coefficient; P value: statistical significance level. See Table 1 for other abbreviations.

lilljeborgi was driven the variations of whole communities in all four seasons during study period.

The species richness peaked in the summer and dropped in the winter (Figure 5c) whereas the species evenness and diversity were peaked in the spring and both were dropped in winter (Figures 5d and e).

CAP (canonical analysis of principal coordinates) analysis demonstrated that the first canonical axis (CAP 1) separated the samples in spring from those of winter (on the left) and those in summer and autumn (on the right), while the second canonical axis (CAP 2) discriminated the samples in spring and

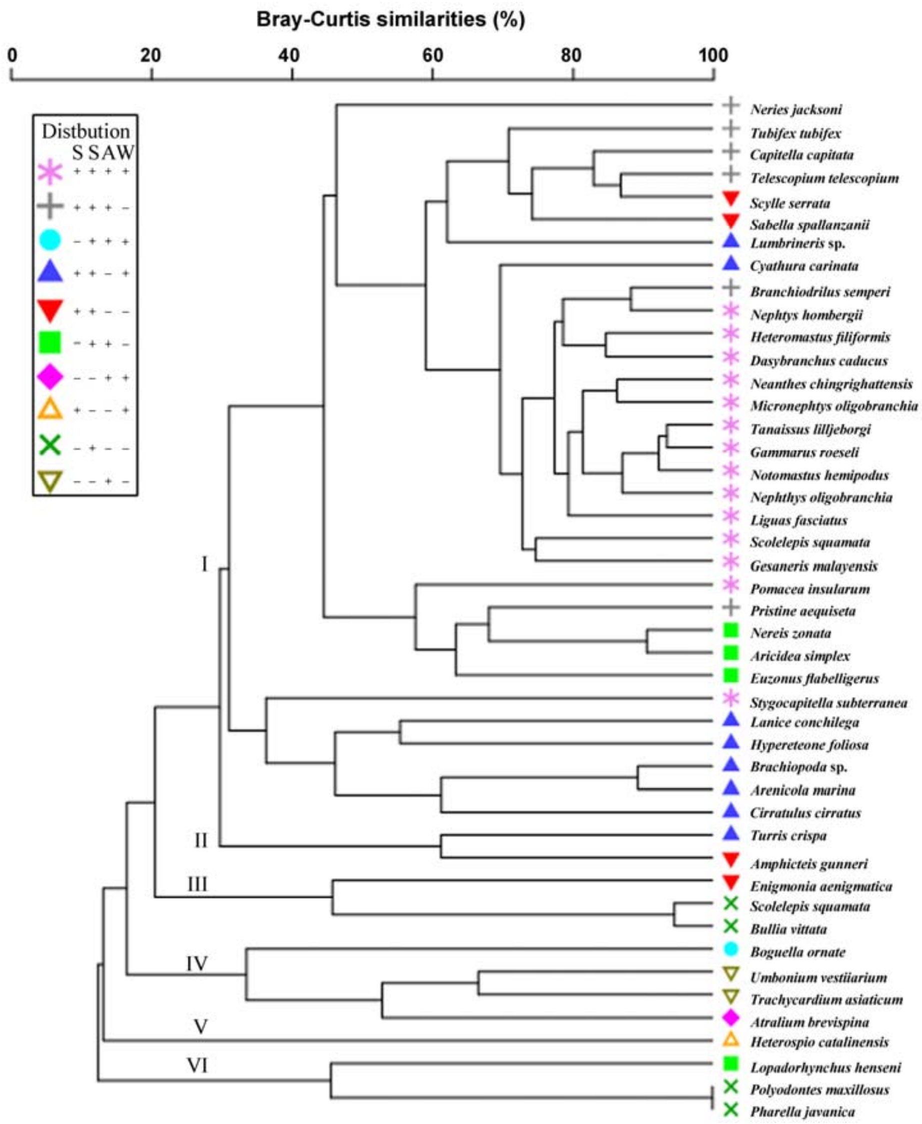

Fig. 3 — Dendrogram of the species distribution during four seasons using group average clustering based on Bray-Curtis similarities from square root transformed species abundance data of each species in coastal waters of the Bay of Bengal, Bangladesh during study period. (+, presence; –, absence; SSAW, S: summer, S: spring; A: autumn and W: winter)

summer (upper) from those at autumn and winter (lower) (Figure 6a).

Vector overlay of 10 dominant species with the CAP axis revealed vectors for six species (*Capitella capitata, Gesaneris malayensis, Lanice conchilega, Nephtys hombergii, Notomastus hemipodus* and *Sabella spallanzanii*) pointed towards the sample clouds in the spring (upper left), two (*Tanaissus lilljeborgi* and *Cyathura carinata*) toward that in winter (lower left), one (*Dasybranchus caducus*) towards that in summer (upper right), and one (*Gammarus roeseli*) toward that in autumn (lower right) (Figure 6b).

The seasonal changes in environmental variables were summarized by principle component analysis (Figure 6). The first axis (PC 1) separated the environmental variables in summer and autumn (on the right) from those in spring and winter (on the left), while the second axis (PC 2) discriminated the parameters in spring and summer (upper) from those in winter and autumn (lower) (Figure 6c).

Vector overlay of Pearson correlations of the 9 variables with the PCA axis vector for three variables (pH, TSS and TSS) toward that in summer (upper right), two (water temperature and water PO_4-P) toward that in winter (lower left) and the other four

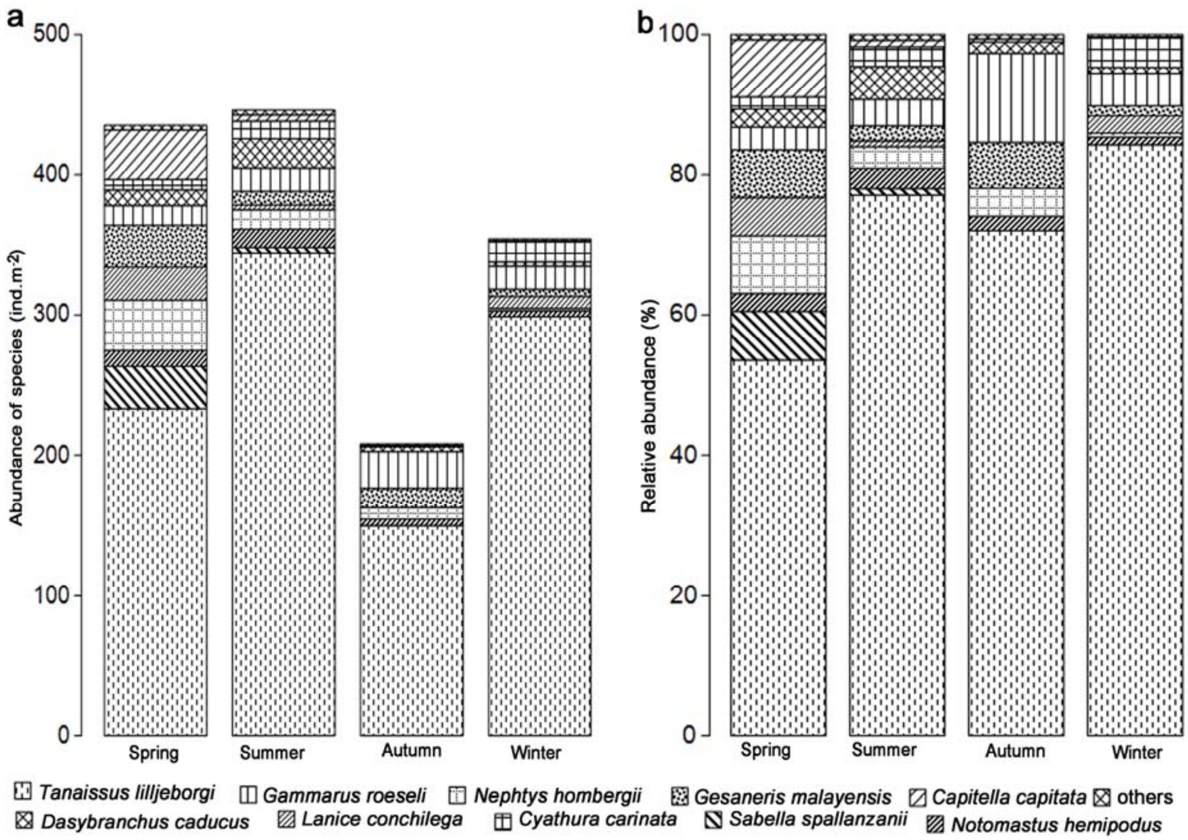

Fig. 4 — Variation in abundances (a) and relative abundances (b) of the dominant species during the four seasons at three stations.

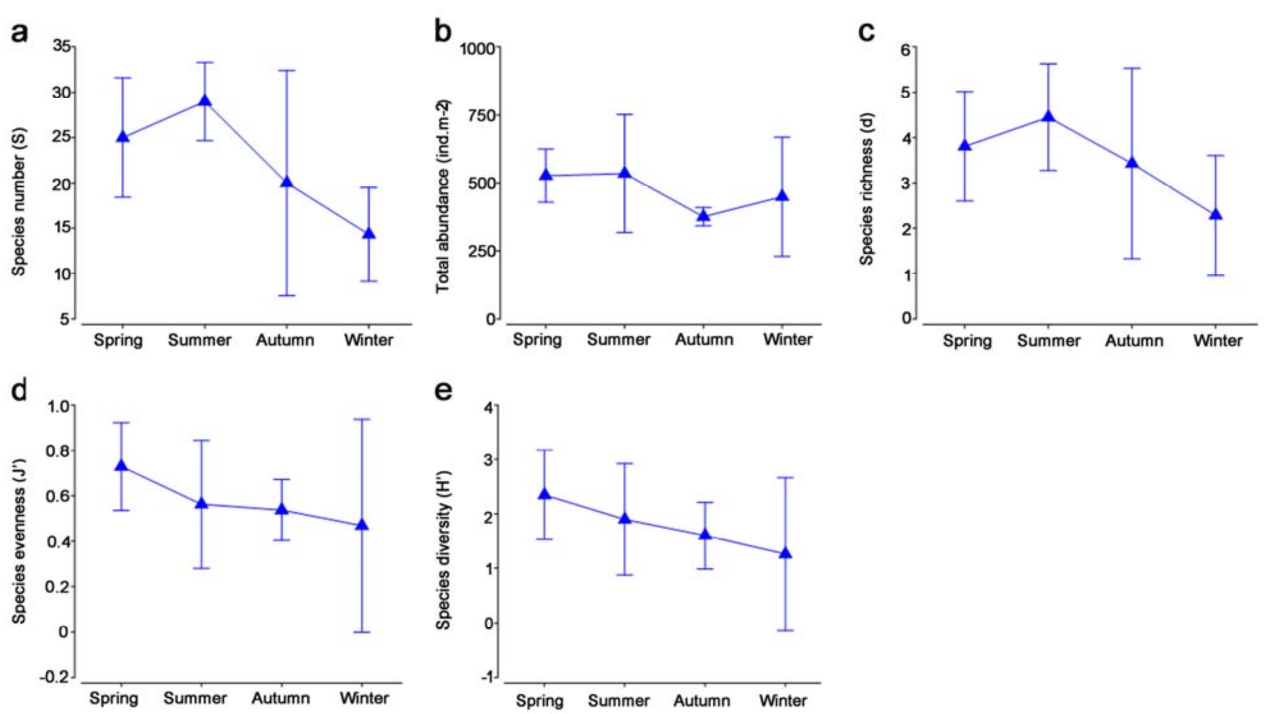

Fig. 5 — Variation in species number (*S*), total abundance (*N*), species richness (*D*), species evenness (*J*') and species diversity (*H*') during study period.

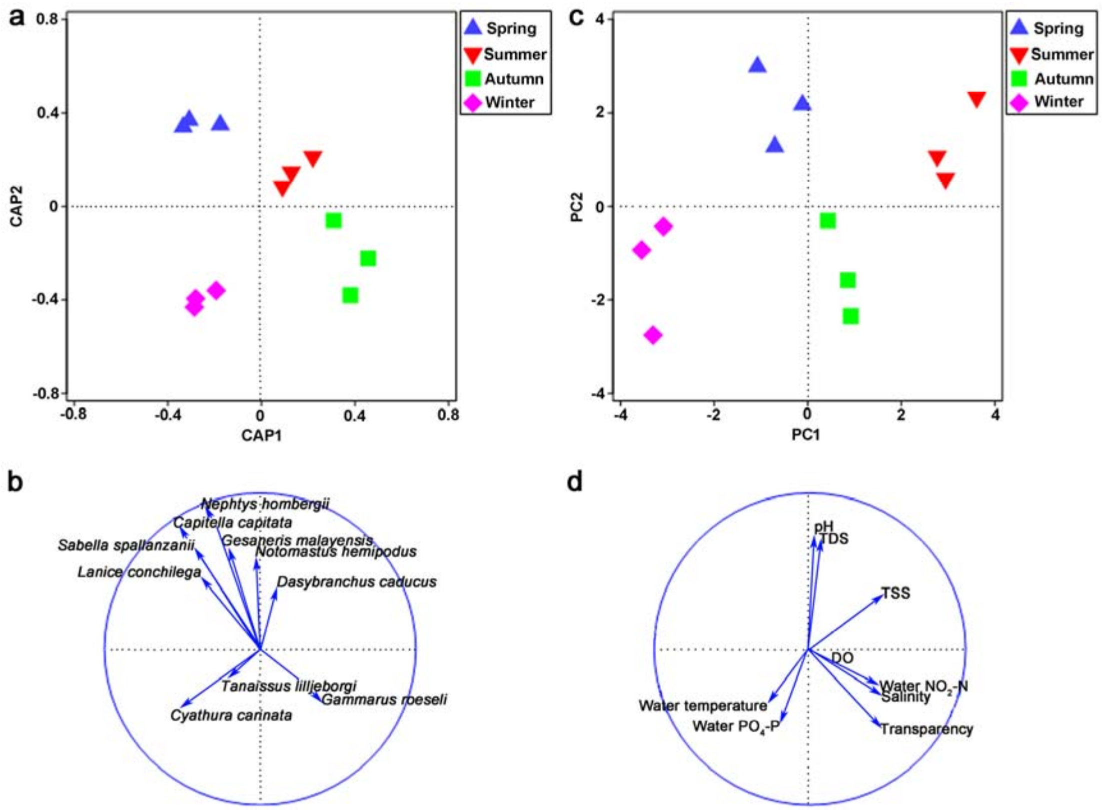

Fig. 6 — Canonical analysis of principal coordinates (CAP) for the benthic communities with correlation of 10 dominant species with CAP axis (a, b) and principle component analysis (PCA) for the environmental parameters with correlations of benthic communities in PC axis (c, d) with required data transformed from four seasons.

(DO, water NO_2-N, salinity and transparency) toward that in autumn (lower right) (Figure 6d).

RELATE analysis showed that the seasonal variations in benthic communities were significantly correlated with the change of environmental variables ($\rho = 0.403$, $P < 0.05$). Furthermore, BIOENV analyses conformed that this variation was mainly driven by water temperature, DO and water nutrients (Table 3).

Pearson correlation analysis showed that benthos communities and biodiversity indices were significantly correlated with these variables where water temperature, TDS and water soluble phosphate showed positively except pH, salinity, TSS and water nitrate which showed negatively (Table 4). Among 10 dominant species, for example, seven forms (e.g., *Nephtys hombergii, Capitella capitate, Lanice conchilege, Tanaissus lilljeborgi, Dasybranchus caducus, Sabella spallanzanii* and *Notomastus hemipodus*) were significantly correlated with water temperature, pH, TSS and water PO_4-P (Table 4).

Discussion

So far there has been little understanding of the macro benthic community patterns in the Bay of Bengal ecoregion of Bangladesh, although a few studies on abundances and composition have been caries out in this area[19-22]. In our study, a total of 45 species representing 35 families, 25 orders and 5 classes, were identified during one-year study period in the Bay of Bengal Bay, south eastern coast of Bangladesh. This result is comparable with the previous reports studied by Islam et al[21] that found 33 species; Abu Hena et al[20] recorded 25 species and 5 major groups using same methods over one-year study period, and Muir & Hossain[19] recorded 7 species (5 were newly recorded from Bangladesh continent).

Based on our data, the 45 species represented a clear seasonal variation in species composition and distribution. Species number was peaked in summer and dropped in winter, while the maximum value occurred in summer but the minimum in autumn, which is in consistent with the previous reports[43-48].

Multivariate analysis revealed a significant seasonal shift in community structure of the macrobenthos. Best matching analysis demonstrated that this seasonal variability was significantly

Table 4 — Pearson correlations between average values of the 10 dominants species and community parameters (biodiversity indices) with average environmental variables in coastal waters of the northern Bengal Bay, Bangladesh during study period.

Species name	WT	pH	Sal	Trans	TDS	DO	TSS	PO_4-P	NO_2-N
Tanaissus lilljeborgi	-0.062	-0.509	-0.169	0.049	**-.713****	-0.290	-0.185	-0.106	0.012
Gammarus roeseli	-0.105	-0.188	-0.141	-0.259	0.073	0.563	-0.286	-0.136	-0.072
Nephtys hombergii	**0.769****	-0.507	.155	.346	-.487	-.111	-.416	**.850****	.037
Gesaneris malayensis	.440	.042	.176	.231	-.164	-.041	-.245	.512	.136
Capitella capitata	**.651***	-.512	.375	.530	-.433	-.123	-.175	**.826****	.248
Dasybranchus caducus	.369	-.247	-.539	-.303	-.525	-.438	**-.735****	.503	-.391
Lanice conchilega	.318	**-.584***	.479	.562	-.554	.337	.016	.492	.378
Cyathura carinata	-.355	-.077	.088	.258	-.408	-.391	.168	-.249	.330
Sabella spallanzanii	.564	-.395	.315	.439	-.447	-.188	-.275	**.617***	.208
Notomastus hemipodus	**.655***	-.407	-.407	-.170	-.412	-.223	**-.594***	**.712****	-.427
Biodiversity parameters									
S	**.700***	**-.602***	**-.602***	-.424	-.044	-.347	**-.586***	**.786****	**-.657***
N	.351	-.142	-.142	.169	**.842****	-.358	-.435	.434	-.016
D	**.665***	**-.611***	**-.611***	-.499	.167	-.291	-.505	**.722****	**-.709****
J	.541	.117	.117	.173	.137	-.115	-.181	**.718****	-.037
H'	**.653***	-.057	-.057	.045	.087	-.182	-.301	**.823****	-.198

*Significant level at 0.05 (*P*<0.05); *Significant level at 0.01 (*P*<0.01); text bold, significant values; *S*, species number; *N*, abundance; *D*, species richness; *J*, species evenness; *H'*, species diversity; See table 1 for other elaboration.

correlated with water temperature, salinity, and DO either alone or combined with water nutrients. Of 10 dominant species, 7 forms (e.g., *Nephtys hombergii, Capitella capitate, Lanice conchilege, Tanaissus lilljeborgi, Dasybranchus caducus, Sabella spallanzanii* and *Notomastus hemipodus*) were significantly correlated with the water temperature, pH, TDS, TSS and water nutrients. This might be explained by the hypothesis that these environmental drivers may significantly change the types of food supply available, and thus indirectly shape the seasonal dynamics of species composition of the benthic communities[6, 20,21, 49-53].

Biodiversity indices have been widely used for community research and monitoring programs. Generally, higher indices values indicate better environmental/ecological quality status (David & Kirsty, 2006). In the present study, species richness was highest in summer whereas the species diversity and evenness observed in spring and all three indices were lowest in winter. These indicated that summer and spring seasons were more favorable for most of the dominant species (e.g., *Tanaissus lilljeborgi, Cyathura carinata* and *Capitella capitata*) may be due to favorable ecological parameters of the environment, e.g., water transparency, DO, salinity and nutrients as reported elsewhere[4,43,47,54-58]. Based on these findings, we suggest that the benthic community may reflected environmental quality and has a potentiality to use for bio-assessment in coastal ecosystems.

Conclusion

Macro benthic communities showed a clear seasonal variation among the four seasons although they were more significant differences between summer and autumn rather than spring and winter. The species number and abundance both peaked in summer however lower in winter and autumn respectively. The community structure of benthic communities represented significant differences among the four seasons which significantly correlated with changing environmental parameters especially, water temperature, DO and water nutrients. Based on our research, seasonality of macro benthic community structure with relation to environmental conditions indicting that the usefulness of community based bioassessment of coastal ecosystem where macro benthic communities might be used as a potential biomarker. However, future investigation on a range of marine habitats and over extended time periods should be needed to justify this conclusion.

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