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Structural variability and composition of fish communities in the northern continental shelf of the Bay of Bengal, Bangladesh

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ABSTRACT

The structural variability and composition of fish communities in the northern continental shelf of the Bay of Bengal, Bangladesh were assessed from monsoon 2014 to pre-monsoon 2015. A total of 73 species belonging to 43 orders, comprising 61 species of finfishes and 12 species of shellfishes were identified from estuarine set bag net (ESBN) fisheries. Of these, sixty species were commonly found throughout the study period and while nine species were dominant with higher contribution to the total communities. Community parameters and abundance were higher in monsoon and lower in winter. Multivariate analysis revealed a clear structural and compositional variation in fish communities. Furthermore, RELATE (coefficient of correlation between the fisheries communities and environmental parameters) and BIOENV/BEST (Biota-environment best matching) analyses showed that these variations were driven by both single (transparency) and multi-stressors [transparency in combination with associated factors such as salinity, total dissolved solids (TDS), total suspended solids (TSS), phosphate-phosphorus (PO_4-P) and nitrite-nitrogen (NO_2-N)]. Community parameters showed significant positive correlation with transparency, salinity and PO_4-P which indicated that structure of fish communities is shaped by ecological conditions in this coastal habitat.

Keywords: Bay of Bengal, Community structure, Ecological conditions, Estuarine set bag net fishery, Multivariate analysis

Introduction

The northern continental shelf of the Bay of Bengal (BoB) is blessed with diversified faunal and floral communities due to its strategic location of the deltaic areas of Ganga-Barmophotra-Megna rivers (Kamal, 2000; Islam, 2005; Hossain *et al*., 2007; Abu Hena and Khan, 2009). Studies reported that throughout the Bangladesh coast, the estuarine and marine channels are enriched with fisheries resources (Kamal, 2000; Islam, 2005; Hossain *et al*., 2007; Abu Hena and Khan, 2009; Chowdhury *et al*., 2011; Rashed-Un-Nabi *et al*., 2011; Hossain *et al*., 2012). These estuarine and marine fish communities showed seasonal and spatial variations in their abundance and these variations are influenced by monsoonal activities with fluctuations of ecological parameters of the Bay of Bengal (Rashed-Un-Nabi *et al*., 2011; Hossain *et al*., 2012). Among the ecological parameters, salinity, transparency, temperature, dissolved oxygen and water nutrients can significantly shape the global and regional fisheries diversity of fish (Blaber and Blaber, 1980; Cyrus and Blaber, 1987; Peterson and Ross, 1991; Thiel *et al*., 1995; Marshall and Elliott, 1998; Whitfield, 1999; Hyndes *et al*., 1999; Griffiths, 2001; Castillo-Rivera *et al*., 2002; Martino and Able, 2003; Moyle, 2004; Jaureguizar *et al*., 2003, 2004; Harrison and Whitfield, 2006; Chowdhury *et al*., 2011; Hossain *et al*., 2012). Investigations have clearly indicated that recent climate changes and anthropogenic stresses may also have significant effects on aquatic habitats including fish communities (Kuo *et al*., 1999; Bonecker *et al*., 2009; Lo *et al*., 2010).

Fisheries population dynamics in coastal habitats are compacting in both temporal and spatial spectra because of intra-annual environmental variations. The tidal cycle of the day can affect the interactions of fish communities with ecological condition which can also change behavioural activities among them *i.e.,* predator-prey relationship (Bonecker *et al*., 2009; Ooi and Chong, 2011). Moreover,

the complex and dynamic habitat structure of open channels are more suitable for most euryhaline fishes, because post-larval/juvenile stages of most fish/shellfish prefer this ecological condition for performing their lifecycle (Ooi and Chong, 2011). Blaber (2000) has reported that Gobiid species prefer estuarine habitat as so-called permanent residents and spent whole life within this ecosystem. However, it has also been reported that some marine fishes such as ariids, sciaenids, grey mullets, clupeids, ambassids and centropomids may prefer the channel systems as spawning ground (Kuo *et al*., 1999; Bonecker *et al.,* 2009; Lo *et al.,* 2010) but the factors affecting fish assemblages in these habitats is unclear yet. Therefore, in order to understand the causes of changing the fisheries communities, regional heterogeneity and the link of environmental processes must be studied.

Studies have reported that south-eastern coastal zone of Bangladesh including marine channels are diversified with artisanal fishers (Chowdhury *et al.,* 2011; Hossain *et. al.,* 2012) where they are engaged in fishing as the only way of their livelihoods. The Kohelia Channel placed in the continental shelf of the northern Bay of Bengal, has supported diverse aquatic resources with multitudes of different plant species (*i.e.,* mangroves and sub-tropical salt marshes), fish/shellfish and other organisms. These resources generate employment opportunities (*i.e.,* fishing, farming and cattle rearing) for coastal dwellers which support blue economic development of the country.

In this study, a one-year baseline research was carried out in the coastal waters of the northern Bay of Bengal, Bangladesh from monsoon 2014 to pre-monsoon 2015 to document the composition and structural variability of fish communities in this marine channel ecosystem as well as to demonstrate the impact of environmental changes on fish community variation.

To do so, we analysed ESBN (estuarine set bag net) fisheries data across four seasons at three different stations located in the northern Bay of Bengal continental shelf region and estimated their structural and community variability. Then, we combined environmental parameters to identify the key drivers of these variations. Our approach is based on the hypothesis that community structure and composition should be triggered by a single or a combination of drivers directly related to the intensity of environmental/anthropogenic stress on these ecosystems with consequences on the structuring and functioning of fish communities.

Materials and methods

Study area description and data collection

Samples were collected from the coastal waters of the northern Bay of Bengal in Kohelia Channel, Bangladesh (21º38.87′ N to 21º44.18′ N and 91º52.93′ E to 91º54.56′E) (Fig. 1). Monthly, samples were collected considering the accessibility of the ESBN during one low and one high tide period (2 times in a day). A total of 24 samplings (12 during high tide and 12 during low tide) were carried out at the three stations from monsoon 2014 to pre-monsoon 2015 from local ESBN fishers (Fig.1). Stations for the study were selected based on anthropogenic stress and human activities, *i.e.,* station 1 (St 1) was far from human activities and pollution free in the continental shelf of the Bay of Bengal, station 2 (St 2) was placed in area of active human pressure (fish/shrimp farms) and station 3 (St 3) was located in area heavily polluted due to anthropogenic stress (untreated sewage discharges). Subsequently, related ecological parameters of these three stations such as temperature, salinity, pH and water transparency were estimated *in situ* using appropriate sensors (WTW multi 3500i sensor). Simultaneously, 1 l of subsurface water was preserved in refrigerated box under dark condition, and analysed for measuring dissolved oxygen (DO), total dissolved solids (TDS), total suspended solids (TSS), nitrite-nitrogen(NO_2-N) and phosphate-phosphorus(PO_4-P) following standard methods (APHA, 1989).

Species identification of collected fish samples was carried out based on morphological characteristics following Howlader (1976); Shafi and Quddus (1982); and Ahmed *et al.* (2008, 2009). The number of species was calculated by counting total number from each haul while abundance was calculated from the number of individuals present in each haul that was expressed as catch per haul.

Data analysis

Fisheries diversity indices were measured as Shannon-Wiener Index (*H'*), species richness (*d)* (Margalef) and species evenness (*J'*) (Pielou). These three indices were calculated using the following formulae in PRIMER v.7.0.13 software program:

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

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

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

where, H' = observed diversity index; P_i = proportion of the total count arising from the i^{th} species; S = total number of species and N = total number of individuals.

The species contribution as rank contributor to the average Bray-Curtis similarity among the three stations during four seasons was analysed using SIMPER (similarity percentage analysis) (Anderson *et al*., 2008; Clarke and Gorley, 2015). The community variations at

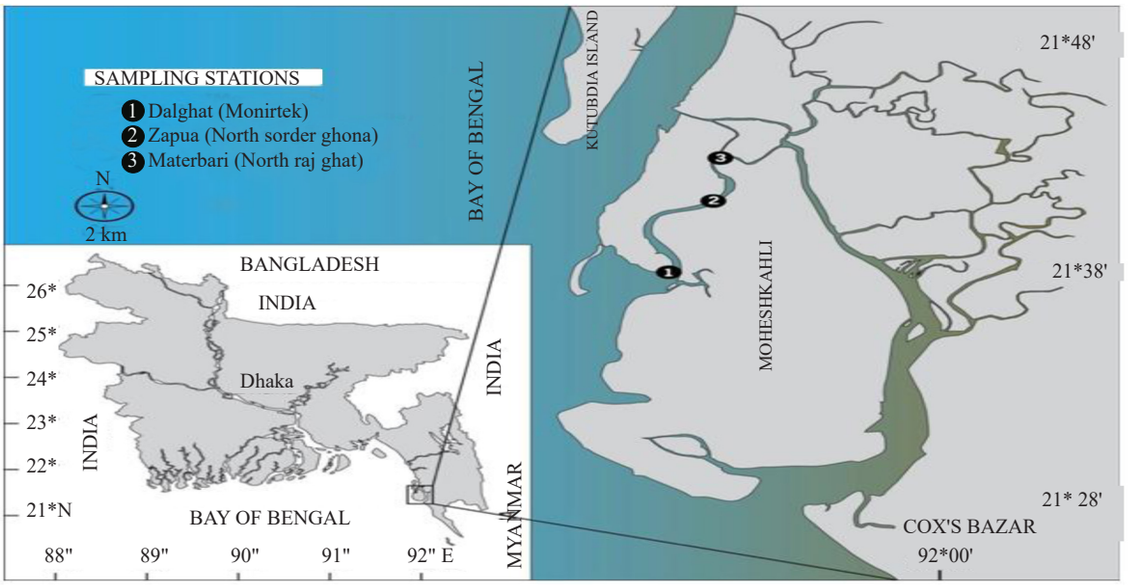


Fig. 1. Sampling stations (St 1 to 3) in Kohelia Channel, in the northern continental shelf of the Bengal Bay, Bangladesh.

three stations during the four seasons were analysed using the submodule of CLUSTER of Bray-Curtis similarities from species abundance while changes of environmental parameters were summarised by Principal component analysis (PCoA) of PREMANOVA (Clark and Gorley, 2015). RELATE (coefficient of correlation between the fisheries communities and environmental parameters) and BIOENV (best matching analysis) were analysed to identify existing correlation between them and the potential ecological factors influencing the variation in fish communities (Anderson *et al.,* 2008; Clarke and Gorley 2015). All these multivariate analyses including diversity indices were conducted using PRIMER v7.0.13 (Anderson *et al.*, 2008; Clarke and Gorley, 2015). A simple Pearson correlation analysis was conducted to identify existing correlation among the environmental parameters and community parameters of fisheries using SPSS program.

Results and discussion

Ecological condition of the Kohelia Channel

Among the ecological parameters measured in the present study, water temperature, transparency and PO_4-P levels were found higher during pre-monsoon. Salinity, NO_2-N and TSS varied significantly with seasons and higher peaks were observed in winter while TDS, DO and pH were found higher during post-monsoon (Fig. 2). Seasonal variations in ecological parameters were predominant in the study area which is the case for the entire coastal area of Bay of Bengal, Bangladesh. Generally, in the northern continental shelf of the Bay of Bengal, the hydrological condition is dynamic due to the strong influence of the monsoonal activities with heavy rainfall and terrestrial runoff that can significantly reduce water salinity and transparency (Rashed-Un-Nabi *et al*., 2011). This results imply that seasonal variation of environmental parameters of the Kohelia Channel is directly or indirectly driven by monsoonal activities of the Bay of Bengal. Furthermore, coastal upwelling process and terrestrial freshwater fluxes can carry bulk amount of nutrients during monsoon period, which can significantly provide favourable ecological niche for aquatic organisms (Chowdhury *et al*., 2011; Hossain *et al*., 2012).

Variation in species composition

A total of 73 species from 43 orders, comprising of 61 species of finfishes, 12 species of shellfishes (*i.e.,* shrimps, lobsters and crabs) were recorded during the study period. Of these, 60 species were common and were present throughout the study period, while 9 species (*Corica soborna*, *Cynoglossus cynoglossus*, *Dussumieria acuta*, *Mugil cephalus*, *Liza parsia*, *Penaeus indicus*, *Penaeus merguiensis*, *Palaemon styliferus* and *Coilia ramcarati*) were found to be higher contributors to the total fisheries communities (Table 1). Kamal (2000) reported 46 species of fish and later Rashed-Un-Nabi *et al*. (2011) reported 35 species of fish and 10 species of shrimps from Moheshkhali Channel, in the south-eastern coastal waters of Bangladesh. Further,

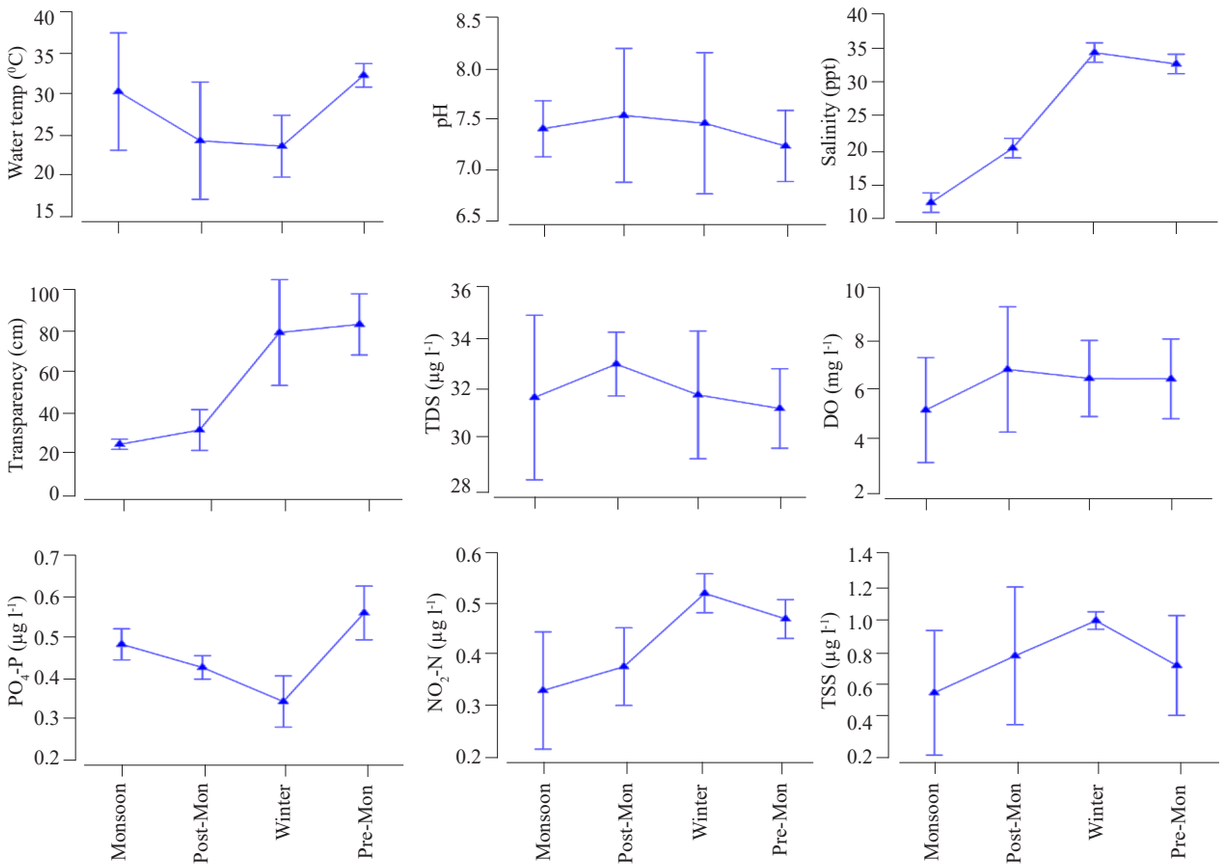


Fig. 2. Variation in nine environmental parameters during the study period in Kohelia Channel, in the northern continental shelf of Bengal Bay, Bangladesh (Post-Mon = Post-monsoon; Pre-mon = Pre-monsoon)

Table 1. Top nine species contributing to ESBN fishery during the study period based on SIMPER analysis

Species	Monsoon	Post-monsoon	Winter	Pre -monsoon
Corica soborna	8.42	9.77	8.24	9.11
Cynoglossus cynoglossus	3.14	4.08	–	–
Dussumieria acuta	–	–	10.75	9.76
Mugil cephalus	7.48	8.55	12.11	10.98
Liza parsia	–	–	4.13	–
Penaeus indicus	4.15	4.21	4.53	4.27
Penaeus merguiensis	3.19	–	3.60	4.06
Palaemon styliferus	–	–	–	3.81
Coilia ramcarati	–	–	–	3.79

Hossain *et al*. (2012) found 53 species of fish in the south-eastern coast of Bangladesh. As per previous reports, 161 to 185 fish species are commonly found in coastal and estuarine waters along the northern continental shelf of the Bay of Bengal, Bangladesh (Hossain *et al*., 2007; Chowdhury *et al*., 2011). Compared to the previous research findings, the number of fish species recorded during the present study was lower, which could probably be attributed to the different types of fishing gear used, sampling time and location.

Variation in fish community structure

Both the species number and abundance showed higher values with lower variability in monsoon and lower values with higher variability in winter (Fig. 3). In this study, the species number and abundance were found higher in monsoon and lower in winter. The number of species and abundance in the Kohelia Channel were higher than in the Moheshkhali Channel (Rashed-Un-Nabi *et al*., 2011), however it was found to be lower than those

reported in other studies in the Bay of Bengal probably due to the gear selectivity, different habitat characteristics and monsoonal impacts with heavy freshwater runoff. Studies have stated that marine channels and estuaries of the Bay of Bengal have a significant positive relation with tidal ranges, freshwater runoff and coastal upwelling, which create favourable ecological niche for biotic communities (Hossain *et al*., 2007, 2012; Chowdhury *et al*., 2011; Rashed-Un-Nabi *et al*., 2011). Moreover, the coastal habitats with mangrove vegetation from productive regions owing to the abundant sources of food, nursery grounds and shelter zones for fish communities (Alongi, 2009; Abu Hena and Khan, 2009).

Cluster analysis revealed that there was a clear structural variation in fish communities among the four seasons at three stations (Fig. 4). Based on 73% similarity level, community structure, during monsoon and post-monsoon (cluster group 1) were clearly separated

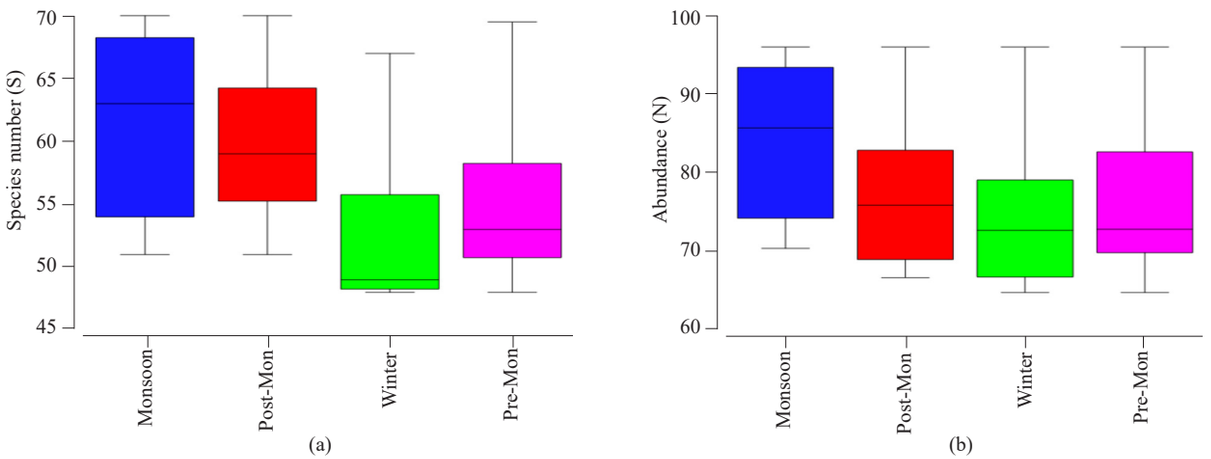


Fig. 3. Variation in (a) species number (*S*) and (b) abundance (*N*) of fisheries communities during the study period

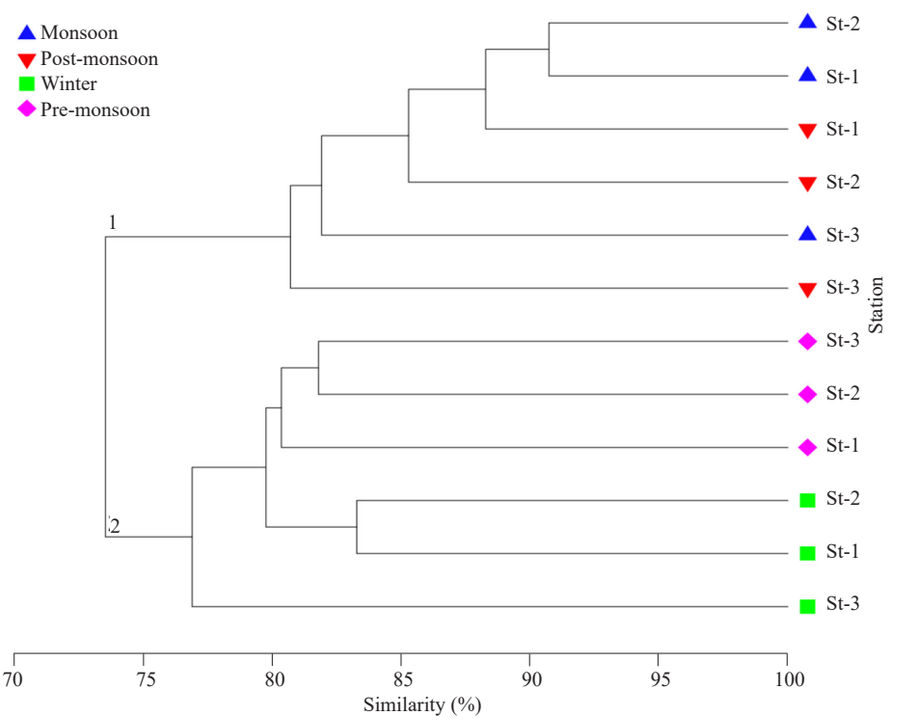


Fig. 4. Cluster analysis among the four seasons at the three stations showing structural variability of the fish communities.

from those of the other two seasons *i.e.*, winter and pre-monsoon (cluster group 2) (Fig. 4).

The species richness, species evenness and species diversity indices showed similar patterns that higher values with lower variability was found in monsoon and lower values with higher variability was observed in winter (Fig. 5). All the three indices estimated in this study, showed higher values than reported in previous studies in coastal waters of the Bay of Bengal, Bangladesh (Hossain *et al*., 2007, 2011; Rashed-Un-Nabi *et al*., 2011), probably be due to the differences in the location of the study area as well as in the fishing gear.

Influence of ecological conditions on fish community composition

Multivariate analysis of PCoA (principal component analysis) for ecological parameters is shown in Fig. 6. The vector coordination of these parameters revealed that water transparency, salinity, DO, NO_2-N and TSS were the most significant factors contributing to structural variation and community composition in winter, while the most significant contributing factors, in post-monsoon were TDS and pH and in pre-monsoon water temperature and PO_4-P.

Coefficient of correlation between environmental parameters and fish communities using RELATE analysis showed that structural variability of fisheries communities significantly correlated with ecological conditions ($p=0.782$, $p<0.05$). Further, BEST analysis (Biota-environment best matching analyses) revealed that structural variation in fisheries communities was mainly driven by water salinity, transparency, PO_4-P and NO_2-N (Table 2).

Pearson correlation showed that community parameters significantly correlated with ecological parameters (Table 3).

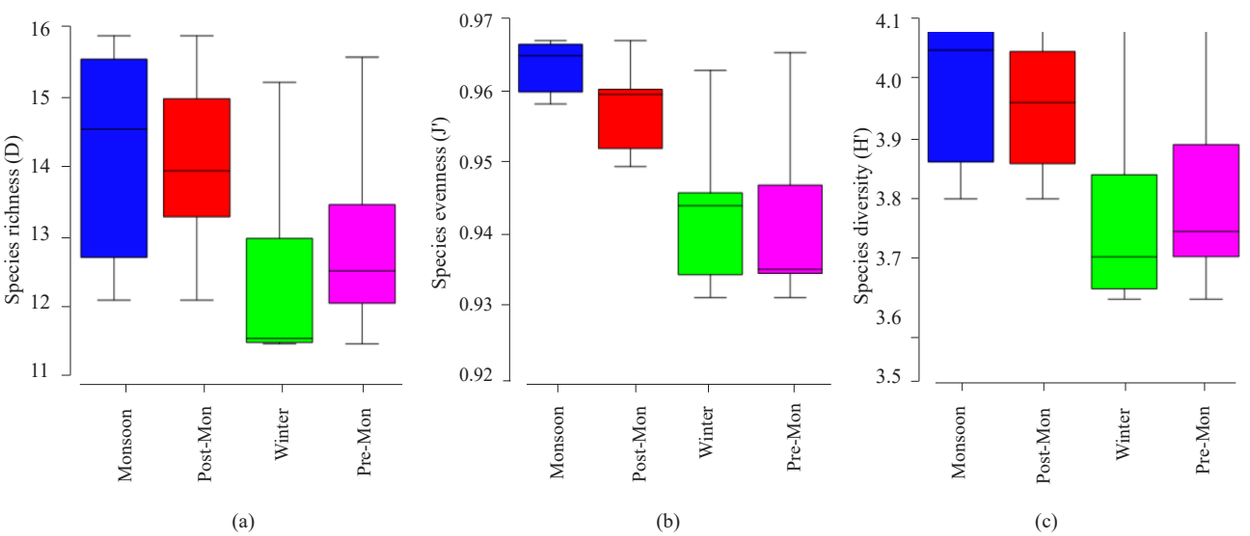


Fig. 5. Variation in species richness (*D*), species evenness (*J'*) and species diversity (*H'*) of fish communities during study period

Table 2. Summary of results of BEST matching (BIOENV) analysis showing the 10 best matches of environmental parameters with fish communities

Rank	Environmental parameters	*p* value	p value
1	Salinity, Transparency, PO_4-P, NO_2-N	0.718	<0.01
2	Transparency, NO_2-N	0.710	<0.01
3	Transparency	0.708	<0.05
4	Salinity, Transparency, PO_4-P	0.706	<0.05
5	Salinity, Transparency	0.696	<0.01
6	Salinity, Transparency, NO_2-N	0.693	<0.01
7	Salinity, Transparency, TDS, PO_4-P, NO_2-N	0.688	<0.01
8	Salinity, PO_4-P, NO_2-N	0.671	<0.05
9	Salinity, NO_2-N	0.664	<0.05
10	Salinity, Transparency, PO_4-P, NO_2-N, TSS	0.663	<0.05

p value: Spearman correlation coefficient; P value: statistical significance level.

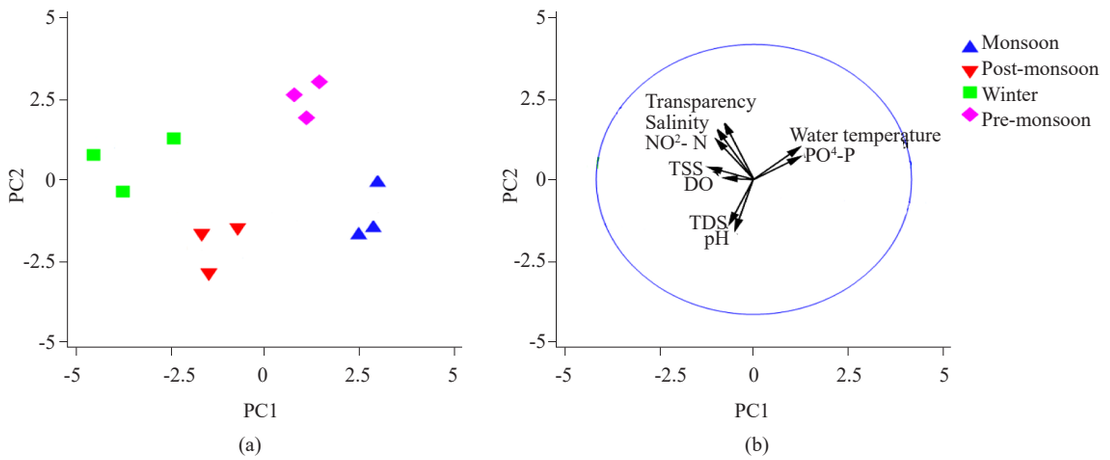


Fig. 6. Principal component analysis (PCA) for environmental parameters showing their seasonal variation at the three stations

For example, water salinity showed significant positive correlation with species number (r=0.771) ($p<0.01$), species richness (r=0.644) ($p<0.05$) and diversity (r=0.879) ($p<0.01$) while negative significant correlation with evenness (r=-0.299) ($p<0.05$). Water transparency showed positive significant correlation with species number (r=0.855) ($p<0.05$), richness (r=0.859) ($p<0.01$) and species diversity (r=0.872) ($p<0.01$). However, PO_4-P showed significant positive correlation with species number (r=0.899) ($p<0.05$), richness (r=0.886) ($p<0.05$) and diversity (r=0.899) ($p<0.01$) (Table 3). It has been reported that the community composition of coastal and estuarine habitats is driven by combination of ecological parameters where temperature, salinity and dissolved oxygen can significantly change the abundance and composition of fisheries communities due to their strong integration with life history patterns of fisheries communities (Thompson, 1966; Hotos and Vlahos, 1998), which are consistent with our findings.

In this study, the multivariate and univariate analyses of both fisheries data and environmental parameters revealed that many interacting influencing factors like salinity, transparency, water temperature, dissolved oxygen and PO_4-P played important role on composition and diversity of the fisheries communities in the study area. The regular or irregular fluctuations of environmental parameters lead the primary productivity in the aquatic ecosystem, which ultimately affect the structural variations in the fish communities (Rozengurt and Hedgepeth, 1989; Arthington and Welcome, 1995; Cyrus and Mclean, 1996; Whitfield, 1999; Maes *et al*., 2004). The findings of the study suggest that ecological conditions can significantly influence structural and compositional variations of fish communities in marine ecosystems.

In conclusion, the fish communities in Kohelia Channel in the northern continental shelf of the Bay of Bengal, Bangladesh showed significant structural variability among the four seasons. Species number and abundance showed similar patterns that were found higher in monsoon and lower in winter. Fisheries community was significantly correlated with ecological conditions suggesting that diversity and composition of fisheries communities are shaped by ecological conditions in this coastal ecosystem. However, further studies are needed to justify this conclusion.

Table 3. Pearson correlations between environmental and community parameters of the fisheries communities during the study period

Parameters	WT	pH	Sal	Trans	TDS	DO	TSS	PO_4-P	NO_2-N
Species number (S)	.397	.3513	.771**	.855*	.331	-.584	.398	.899*	-.899
Abundance (N)	.251	-.180	-.573	-.522	-.442	-.180	.322	-732	-.818
Evenness (J')	.360	.536	-.299*	-.739	.668	-.621	.223	-.743	-.962
Richness (D)	.211	.479	-.644	.859**	.233	-.137	.260	.886*	-.836
Diversity (H')	.435	.237	.879**	.872*	.565	-.580	.298	.899**	-.899

*Significance level $p<0.05$ and **significance level $p<0.01$. WT - Water temperature; pH - Hydrogen ion concentration; Sal - Salinity; Trans - Transparency; TDS - Total dissolved solids; DO - Dissolved oxygen; TSS - Total suspended solids; PO_4-P - Phosphate phosphorus; NO_2-N - Nitrite nitrogen

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