

Structural patterns of fisheries communities with relation to ecological condition in subtropical coastal waters of the northern Bay of Bengal, Bangladesh

Muhammed Forruq Rahman^{1,2}, Mamun Abdullah Al^{1,3*}, Aysha Akhtar¹, Mohammad Nesarul Hoque⁴,
Md. Shafiqul Islam¹, Mohammad Nurul Azim Sikder¹, & Partho Protim Barman²

¹Institute of Marine Sciences, University of Chittagong, Chittagong-4331, Bangladesh

²College of Fisheries, Department of Marine Fisheries, Ocean University of China, Qingdao 266003, China

³College of Marine Life Sciences, Ocean University of China, Qingdao 266003, China

⁴Department of Oceanography, University of Chittagong, Chittagong 4331, Bangladesh

*[E-mail: mamun.imsfcu16@gmail.com]

Received 02 May 2018; revised 20 June 2018

Fisheries assemblages with notes on the ecological conditions in coastal waters of the northern Bay of Bengal, Bangladesh, were investigated based on beach seine fishing net data from a one-year cycle (2015-2016) data collected by beach seine net. A total of 75 species comprising of 61 finfishes, 7 shrimps, 2 cephalopods, 2 lobsters and 3 crab species were identified. Among them, 58 species were commonly distributed in all four seasons, while 16 species were found dominant to the total communities. The species number, richness, evenness, and species diversity peaked in the monsoon and fell in the winter. Multivariate analysis of CAP and dbRDA revealed that there were clear temporal and spatial variations in fisheries assemblages in the Kohelia channel. RELATE analysis showed a significant correlation between fisheries communities with environmental variables. Furthermore, best matching analysis (BEST/BIOENV) confirmed that these temporal and spatial variations were driven by changing salinity, transparency and nutrients either alone or combined with soil nutrients. Thus, these findings suggest that fisheries community structure is shaped by the ecological condition in this marine channel system.

[Keywords: Bay of Bengal, Beach seine net, Community patterns, Coastal habitat, Ecological condition]

Introduction

The complex and diversified geography of Bangladesh has formed it as the greatest deltaic plain at the confluence of Ganges-Brahmaputra-Meghna rivers and their tributaries. Besides, it has been endowed with more than 710 square kilometers long coast in the northern continental shelf of the Bay of Bengal. The marine and coastal water of Bangladesh is blessed with diverse aquatic resources of both flora and fauna¹. In particular, the south-eastern coasts of Bangladesh (i.e., Chittagong and Cox's Bazar) are regular and unbroken and mostly covered by a complex dynamic estuarine ecosystem with strong interactions between abiotic and biotic factors^{1,2}. Thus, we hypothesized that biotic and abiotic factors might influence the assemblage of fisheries communities. Chowdhury et al.³ reported that the rich fisheries resources in the southeastern coasts play an important role in sustaining the small-scale multi-gear fishing communities.

The coastal and marine fisheries of Bangladesh consist of 490 species of fishes, 28 species of shrimps,

16 species of crabs and 30 species of sharks and 39 species of rays where 139 species of bony fish, 15 species of penaeid shrimp, 2 species of solenoceroid shrimp, 10 species of caridean prawn, 3 species of lobster and 15 species of crab reported by Shafi and Quddus⁴. It has been reported that there are about 20 estuarine and 3 maritime open channel ecosystems along the Bangladesh coast characterized by a complex hydrologic phenomenon, tidal forest, and rich aquatic biodiversity^{1,2}. However, these coastal ecosystems have been poorly explored with a limited empirical investigation on different aspects¹⁻⁸.

The marine and estuarine fisheries community structure are shaped by various environmental factors exhibiting a wide range of significant variations in species composition. This variation occurs mainly because of constant seasonal fluctuations of the environmental and hydrologic factors in the ecosystems, which might have a direct influence on the fisheries communities⁹⁻¹³. These variations most probably are driven by the dominant abiotic variables

such as salinity, depths, temperature, turbidity, freshwater flow, hydrology of latitudinal gradient areas, size, habitat structure and bottom configuration which acting as a physiological sieve for distributing of the fisheries communities on global or regional/local scale¹⁴⁻²². In addition, recent anthropogenic activities such as untreated industrial runoff, including water quality alternations, dams/impoundments, habitats degradation and urbanization have major effects on aquatic habitats and fisheries assemblages. Therefore, understanding the role of environmental parameters in structuring fish assemblages has been an important prerequisite for successful biodiversity conservation in the ecosystem.

In the south-eastern coastal waters of Bangladesh, especially in the Kohelia channel, a little information on aquatic resources (e.g., zooplanktons²³ and benthic organisms⁴⁰) has been documented. However, few scattered works were done on different biological aspects in estuarine habitats in northern continental shelf of the Bay of Bengal^{2,3,5}. Given the above linkage, environmental impact on the structure and composition of fish assemblages in subtropical coastal waters has been paid prime importance to take the initiative for sustainable coastal fisheries biodiversity assessment and proper management.

This study was designed for a one-year baseline survey of fisheries resources and relative environmental parameters in the Kohelia channel,

southeastern coast of Bangladesh from monsoon (July) 2015 to pre-monsoon (May) 2016. The main objects of this study were: (1) to document the taxonomic composition and community structure of fisheries communities in this area; (2) to assess the seasonal patterns of the fisheries communities and environmental parameters in the Kohelia Channel; (3) to characterize the interaction of changing environmental parameters on fisheries community structure in coastal waters in the Bay of Bengal.

Materials and Methods

Study area and dataset collection

The sampling site is located in the northern continental shelf of the Bay of Bengal, Kohelia channel in the south-eastern coastal zone of Bangladesh (21°38.87'N to 21°44.18' N and 91°52.93'E to 91°54.56' E) (Germin, GPS 60). The funnel-shaped channel is created from tidal activities of the Bay of Bengal in the Moheshkhali Island joining with the other two channels Moheshkhali and Kutubdia in the north (Fig. 1). The approximate length of this channel is ~28 km long, and the average depth is ~7 m during low tide, but the depth gradually increased north to south direction, and the deepest depth was found 15 m at the mouth. The semidiurnal tidal systems occurring two high and two low tide in a day (2.5~3m tidal variation) and monsoonal activities of the Bay water provides permanent water bodies

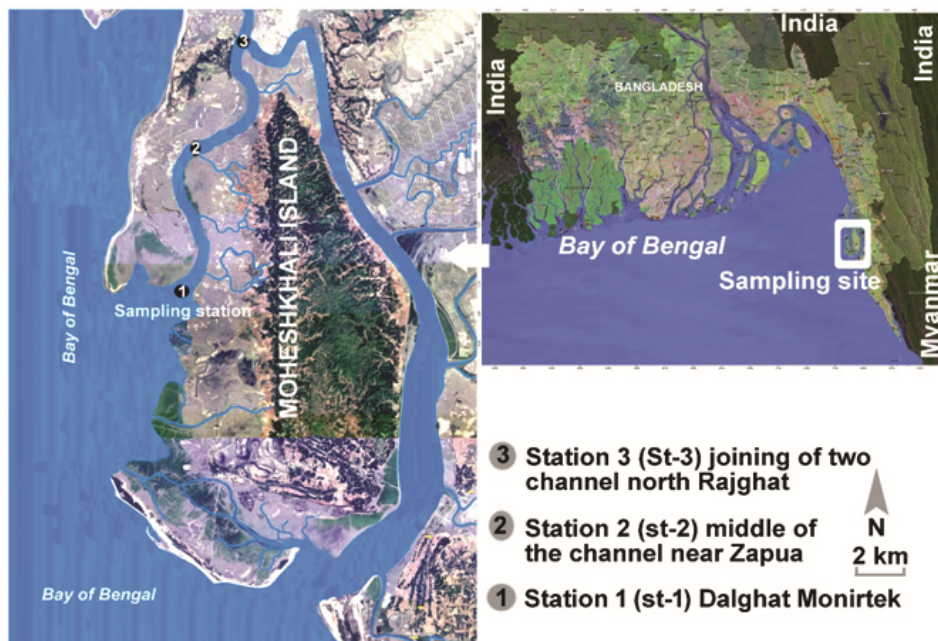


Fig. 1 — Location of the sampling stations (1–3) in the northern continental shelf of the Bengal Bay, southeastern coastal zone of Bangladesh.

and creates suitable ecological niches for different aquatic species both fish and shellfish and enrich nutrient content of sediments beds create prospects for massive growth of the mangroves and salt marshes in both sides along the coast in this channel²³. During the monsoon period, especially June to September, this channel system acts as an open water estuary habitat by taking a flash of freshwater runoff from Moheshkhali hills by adjacent canals/creeks and also from Chakoria Sundarbans region via Matamohory river systems together with Moheshkhali channel systems. Due to geographical location and stable salinity (>30 psu) during summer to winter period (e.g., November to April), Kohelia channel based flood plain areas are more suitable for natural salt production in summer (~30-40 % in total salt production in Bangladesh). In addition, during pre to post-monsoon periods, i.e. May to September are suitable for semi-intensive and extensive coastal aquacultures, where culture ponds feed water from this channel acting as inlets and outlets systems²³.

Three sampling stations were selected in the coastal waters of the Kohelia channel in the Bay of Bengal, Bangladesh. These three stations were selected by considering the accessibilities of the beach seine net operation and anthropogenic activities/human interferences. Station 1 (St-1) was located the site free from anthropogenic activities/human interference in the mouthparts of the channel near Dalghata Monirtek while station 2 (St-2) was slightly polluted site by aquaculture discharges in the middle part of the channel. Station 3 (St-3) was mostly polluted site by anthropogenic activities (untreated sewage discharges/oil exiled from boat and Jetty) Matarbari, north Rajghat and (Fig. 1)²³.

A total of 12 samples were carried out seasonally at these three stations from monsoon 2015 to pre-monsoon 2016 during the full moon and new moon (based on tide chart for Cox's Bazar, Bangladesh), as during these time fishes and shrimp abundances and catches are higher than others period according to Kohelia channel fishermen with their direct observation. Local fishermen usually used ESNB (Estuarine set beg net) and beach seine nets for fishing from this channel. In the present study, we used fisheries data collected only by beach seine net. The details of the structure and application of this net have been reported by Tietze et al.²⁴. Fisheries samples were identified using taxonomic literature following Shafi and Quddus⁴; Howlader²⁵; Ahmed,

Ahmed, and Kabir^{26,27} based on their morphological characteristics. In the case of unknown species found then rapidly iced and brought to the laboratory of Faculty of Marine Sciences and Fisheries, University of Chittagong, Bangladesh for identification.

Environmental parameters temperature (°C), 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, i.e. ~1m samples, were collected for measuring dissolved oxygen (DO) instant preserved with iodine solution, alkalinity, total dissolved solids (TDS), total suspended solids (TSS), nitrite-nitrogen (NO₂-N) and soluble reactive phosphorus (PO₄-P). Soil samples were collected for assessing soil organic matter, soil organic carbon, soil PO₄-P, and soil NO₂-N were determined, followed by standard method.

Data analysis

Biodiversity indices such as species diversity (H'), species richness (d) and species evenness (J') were used for summarizing the fisheries diversity status, which was calculated according to the following formula:

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

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

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

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.

Both multivariate and univariate analyses were performed to identify seasonal variations in the fisheries communities using PRIMER v7.0.13 and IBMSPSS v.22. The species distribution during the study period was analyzed by the sub-module of CLUSTER coordinating with the nMDS (non-metric multidimensional scaling) on Bray-Curtis similarities from square root transformed species abundance data. The contribution of each species to the average Bray-Curtis similarity among the four seasons and three stations was analyzed using SIMPER (similarity percentage analysis) program, and the significant

differences among the seasons were tested using the sub-module of ANOSIM (analysis of similarity)^{28,29}. The seasonal variations in community structure of the fisheries communities were analysed by coordinating the submodule of CAP axis (canonical analysis of principal coordinates) on using Bray–Curtis similarity matrix from square root transformed species abundance data while the significant differences among the three stations were tested by SIMPROF and ordinate using the routine dbRDA (distance-based redundancy analysis). The coefficient of correlation among the biotic and abiotic parameters RELATE and the submodule of BIO-ENV (biota–environment correlation analysis) was tested to identify the potential relationship between environmental parameters with the fisheries communities^{28,29}.

Pearson correlation matrix was performed for identifying any correlation/existences of variation between the environmental parameters and the fisheries communities. All data were log-transformed before performing the analysis.

Results

Changing of environmental variables

The average values of 15 environmental variables were summarized in Table 1. Environmental parameters showed a clear seasonal variation, where air and water temperature ranging from 22.33 to 35.33°C and 23.67 to 32.33°C from monsoon to pre-monsoon, respectively. 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. TDS varied from 30.93 to 32.67 mg l⁻¹. TSS varied from 0.58 to 1.00 mg l⁻¹. DO was fluctuated from 4.76 to 6.35 mg l⁻¹. NO₂-N varied from 0.34 to 0.53 mg l⁻¹. PO₄-P varied from 0.33 to 0.55 mg l⁻¹. Alkalinity was 40.10 to 61.66 mg l⁻¹. Soil organic matter was 4.33 to 5.75 %. Soil organic carbon was 2.41 to 3.03 %. Soil PO₄-P varied from 1.69 to 6.69 µg kg⁻¹. Soil NO₂-N was ranging from 2.75 to 3.61 µg kg⁻¹ (Table 1).

Taxonomic composition and species distribution

A list of species with their average abundances, composition and the ranks of the top 10 contributors in each season summarized in Table 2. A total of 75 species belonging to 61 of finfishes, 7 of shrimps, 2 of lobster, 2 of cephalopods and 3 species of crabs, were identified during the study period. Among these species, 58 species occurred in all four seasons and were defined as ‘common’, while 16 species that occurred within the top 10 ranked contributors in each season were defined as ‘dominant’ (Table 2). It was noteworthy that some species were endemic to seasons such as *Argyrops spinifer* occurred only in monsoon. Due to its occurrence in the specific season, it can be represented as endemic with the season.

The dendrogram for species distribution showed 58 species were commonly distributed in all four seasons, while 72 species occurred in monsoon, 71 were in post-monsoon, 68 were in winter, and 69 species occurred in pre-monsoon (Fig. 2a). Based

Table 1 — Average values of environmental variables for each season monitored at three stations in the Kohelia channel, northern Bay of Bengal during the study period.

Parameters	Monsoon	Post-Mon	Winter	Pre-Mon
AT (°C)	29.67	26.67	22.33	35.33
WT (°C)	30.33	24.33	23.67	32.33
pH	7.41	7.54	7.46	7.24
Sal (psu)	12.33	20.33	34.33	32.67
Trans (cm)	17	24	71.67	75.67
TDS (µg l ⁻¹)	31.36	32.67	31.46	30.93
TSS (µg l ⁻¹)	0.58	0.80	1.00	0.74
DO (mg l ⁻¹)	4.76	6.35	5.99	5.98
WNO ₂ -N (mg l ⁻¹)	0.34	0.38	0.53	0.48
WPO ₄ -P (mg l ⁻¹)	0.47	0.42	0.33	0.55
AL (mg l ⁻¹)	47.73	59.59	61.66	40.10
SOM (%)	5.75	4.58	4.33	5.29
SOC (%)	3.03	2.41	2.28	2.54
SPO ₄ -P (µg kg ⁻¹)	3.69	3.06	1.69	3.02
SNO ₂ -N (µg kg ⁻¹)	3.51	3.61	2.75	3.06

AT= air temperature, WT= water temperature, Sal= salinity, Trans= transparency, TDS= total dissolved solid, TSS= total suspended solid, DO= dissolved oxygen, WNO₂-N= water nitrite nitrogen, WPO₄-P= water soluble reactive phosphorus, AL= alkalinity, SOM= soil organic matter, SOC= soil organic carbon, SPO₄-P= soil phosphate-phosphorus, SNO₂-N= soil nitrite nitrogen.

Table 2 — Species list with number of individual (N/haul), contribution (%) and rank of top 10 contributors in each season by SIMPER result of the fisheries communities during the study period.

Species name	Total individual	Abundance (average)	Monsoon		Post-Mon		Winter		Pre-Mon	
			%	R	%	R	%	R	%	R
<i>Acentrogobius caninus</i>	24	0.17	0.23	—	0.24	—	0.12	—	0.14	—
<i>Acentrogobius viridipunctatus</i>	20	0.14	0.19	—	0.24	—	0.10	—	0.10	—
<i>Apocryptes bato</i>	21	0.15	0.23	—	0.32	—	0.06	—	0.10	—
<i>Argyrops spinifer</i>	2	0.01	0.08	—	0	—	0	—	0	—
<i>Ariomma indica</i>	15	0.10	0.19	—	0.08	—	0.08	—	0.10	—
<i>Awaous guamensis</i>	19	0.13	0.23	—	0.16	—	0.10	—	0.10	—
<i>Carangoides malabaricus</i>	4	0.03	0.08	—	0.08	—	0	—	0	—
Chanda nama	50	0.35	0.58	—	0.47	—	0.28	9	0.21	—
<i>Chelonodon patoca</i>	13	0.09	0.12	—	0.04	—	0.06	—	0.14	—
<i>Chirocentrus dorab</i>	6	0.04	0.08	—	0.08	—	0.02	—	0.02	—
Coilia ramcarati	82	0.57	0.92	6	0.71	7	0.10	—	0.83	6
<i>Congresox talabonides</i>	9	0.06	0.15	—	0.08	—	0.02	—	0.05	—
Corica soborna	4009	27.86	53.40	1	55.63	1	7.65	3	19.68	2
<i>Cynoglossus bilineata</i>	18	0.13	0.27	—	0.12	—	0.08	—	0.10	—
<i>Cynoglossus cynoglossus</i>	93	0.65	1.15	5	1.82	4	0.14	—	0.24	—
<i>Dasyatidae bennettii</i>	8	0.06	0.08	—	0.16	—	0	—	0.05	—
<i>Dussumieria acuta</i>	953	6.62	0	—	0	—	10.75	—	9.76	—
Eleotris fusca	21	0.15	0.19	—	0.24	—	0.08	2	0.14	3
<i>Eleotris lutea</i>	28	0.19	0.31	—	0.36	—	0.10	—	0.14	—
<i>Eleutheronema tetradactylus</i>	27	0.19	0.27	—	0.28	—	0.14	—	0.14	—
<i>Gerres filamentosus</i>	7	0.05	0.12	—	0.04	—	0.04	—	0.02	—
<i>Glossogobius giuris</i>	18	0.13	0.23	—	0.18	—	0.08	—	0.07	—
<i>Gymnothorax punctatus</i>	6	0.04	0.08	—	0.04	—	0.02	—	0.05	—
<i>Harpodon nehereus</i>	9	0.06	0.12	—	0.20	—	0	—	0.02	—
Hemirhamphus georgii	29	0.20	0.12	—	0.20	—	0.20	—	0.26	10
<i>Ilisha megalopteran</i>	7	0.05	0.08	—	0.12	—	0.02	—	0.02	—
<i>Johinus belangeri</i>	13	0.09	0.23	—	0.08	—	0.04	—	0.07	—
<i>Lates calcarifer</i>	16	0.11	0.15	—	0.20	—	0.04	—	0.12	—
Leander styliferus	109	0.76	0.88	8	0.99	5	0.55	6	0.79	7
<i>Leiognathus fasciatus</i>	17	0.12	0.31	—	0.16	—	0.02	—	0.10	—
<i>Lepturacanthus savala</i>	16	0.11	0.15	—	0.16	—	0.06	—	0.12	—
<i>Limulus Polyphemus</i>	16	0.11	0.15	—	0.32	—	0.06	—	0.02	—
<i>Loligo edulis</i>	6	0.04	0.08	—	0.08	—	0.02	—	0.02	—
<i>Lutjanus johnii</i>	12	0.08	0.19	—	0.16	—	0.04	—	0.02	—
<i>Macrobrachium rosenbergii</i>	18	0.13	0.23	—	0.16	—	0.10	—	0.07	—
<i>Macrobrachium birmanicus</i>	78	0.54	0.92	7	0.63	8	0.36	—	0.48	9
<i>Metapenaeus monoceros</i>	17	0.12	0.19	—	0.16	—	0.06	—	0.12	—
<i>Monopterusuchia</i>	15	0.10	0.15	—	0.16	—	0.08	—	0.07	—
<i>Mugil cascasia</i>	23	0.16	0.19	—	0.20	—	0.12	—	0.17	—
Mugil cephalus	7517	52.24	25.32	2	25.70	2	73.35	1	59.54	1
<i>Mugil corsula</i>	26	0.18	0.23	—	0.28	—	0.12	—	0.17	—
Mugil Persia	60	0.42	0.15	—	0.16	—	0.83	5	0.24	—
<i>Mystus bleekeri</i>	31	0.22	0.54	—	0.43	—	0.06	—	0.07	—
<i>Naptunus pelegicus</i>	9	0.06	0.23	—	0.08	—	0.02	—	0	—
<i>Odontamblyopus rubicundus</i>	15	0.10	0.15	—	0.08	—	0.06	—	0.14	—
<i>Oxyurichthys microlepis</i>	23	0.16	0.27	—	0.24	—	0.08	—	0.14	—
<i>Panna macrophthalmus</i>	23	0.16	0.35	—	0.20	—	0.14	—	0.05	—
<i>Panna microdon</i>	15	0.10	0.08	—	0.08	—	0	—	0.26	8
<i>Panulirus polyphagus</i>	21	0.15	0.19	—	0.24	—	0.10	—	0.12	—

(Contd.)

Table 2 — Species list with number of individual (N/haul), contribution (%) and rank of top 10 contributors in each season by SIMPER result of the fisheries communities during the study period. (Contd.)

Species name	Total individual	Abundance (average)	Monsoon		Post-Mon		Winter		Pre-Mon	
			%	R	%	R	%	R	%	R
<i>Panulirus versicolor</i>	9	0.06	0.08	—	0.08	—	0.04	—	0.07	—
<i>Parambasis thomassi</i>	61	0.42	0.73	10	0.55	9	0.38	—	0.21	—
<i>Penaeus indicus</i>	213	1.48	2.50	3	2.02	3	0.87	4	1.26	4
<i>Penaeus merguensis</i>	120	0.83	1.19	4	0.75	6	0.53	7	1.03	5
<i>Penaeus monodon</i>	30	0.21	0.46	—	0.28	—	0.14	—	0.10	—
<i>Pisodonophis boro</i>	7	0.49	0.08	—	0.16	—	0.02	—	0	—
<i>Pomadasys hasta</i>	22	0.15	0.27	—	0.24	—	0.06	—	0.14	—
<i>Pomadasys maculatus</i>	9	0.06	0.08	—	0.04	—	0.04	—	0.10	—
<i>Psedapocryptes elongates</i>	22	0.15	0.54	—	0.20	—	0.04	—	0.02	—
<i>Pseudambassis baculis</i>	53	0.37	0.81	9	0.55	10	0.24	10	0.14	—
<i>Rhinobatus granulatus</i>	11	0.08	0.12	—	0.08	—	0.08	—	0.05	—
<i>Saurida tumbil</i>	11	0.08	0.15	—	0.08	—	0.04	—	0.07	—
<i>Scatophagus argus</i>	27	0.19	0.19	—	0.24	—	0.14	—	0.21	—
<i>Scoliodon sorrakowah</i>	2	0.01	0.04	—	0	—	0.02	—	0	—
<i>Scomberomorus guttatus</i>	7	0.05	0.11	—	0.08	—	0	—	0.05	—
<i>Scylla serrata</i>	40	0.28	0.54	—	0.32	—	0.20	—	0.19	—
<i>Sepia esculenta</i>	3	0.02	0.04	—	0.04	—	0.02	—	0	—
<i>Sillago domina</i>	23	0.16	0.23	—	0.28	—	0.10	—	0.12	—
<i>Tenualosa ilisha</i>	14	0.10	0	—	0.24	—	0.10	—	0.07	—
<i>Tenualosa toil</i>	8	0.06	0	—	0.08	—	0.04	—	0.10	—
<i>Terapon jarbua</i>	35	0.24	0.38	—	0.28	—	0.16	—	0.24	—
<i>Thalamita crenata</i>	22	0.15	0.23	—	0.24	—	0.10	—	0.12	—
<i>Thryssa hamiltoni</i>	12	0.08	0.23	—	0.12	—	0	—	0.07	—
<i>Thryssa purava</i>	13	0.09	0.12	—	0.12	—	0.12	—	0.02	—
<i>Triacanthus brevirostris</i>	14	0.10	0.08	—	0.16	—	0.02	—	0.17	—
<i>Xenotodon cancila</i>	8	0.06	0.19	—	0	—	0.02	—	0.05	—
Total number of taxa	73		70		69		66		67	
Total number of individuals	14390		2608		2529		5061		4192	

Text bold, top 10 rank contributors species; R, rank; %, contribution in each season, pre-mon, pre monsoon; post-mon, post monsoon.

on clustering analysis, 75 species were categorized into nine groups at 65 % similarity level where group 1 (G1) consisted of 49 species, including most of the common/dominant species with their higher occurrence and contribution to the total fisheries communities (Fig. 2a). However, other groups were represented relatively rare assemblages with lower abundances and composition.

The seasonal variation in species distribution was representing the coordination of non-metric multidimensional scaling (nMDS) while each cluster group formed with taking the similar distribution patterns of species among four seasons (Fig. 2b). The similarity analysis (ANOSIM) showed a significant variation in species distribution of the fisheries communities among the four seasons ($R=0.759$, $P<0.01$).

In terms of the relative abundances of dominant species, *Corica soborna*, *Mugil cephalus*, and

Penaeus indicus were predominant in monsoon and post-monsoon while *Mugil cephalus*, *Corica soborna* and *Dussumieria acuta* were the primary contributors in winter and pre-monsoon in the fisheries communities (Fig. 2c).

Structural patterns of fisheries communities

In terms of average values, the species number was peaked in monsoon and gradually decreased and dropped to the winter while maximum abundance was recorded in winter, and the minimum was in post-monsoon (Fig. 3a, b). Spatially, the species number and abundance showed similar patterns and both were higher at station 1 and lower at station 3 (Fig. 3c, d).

The analysis of similarity (ANOSIM) revealed that there were significant differences in fisheries assemblage on seasonal scale among the four seasons at three stations (Global $R=0.759$; $P<0.01$). The species assemblage was found highly diversified in

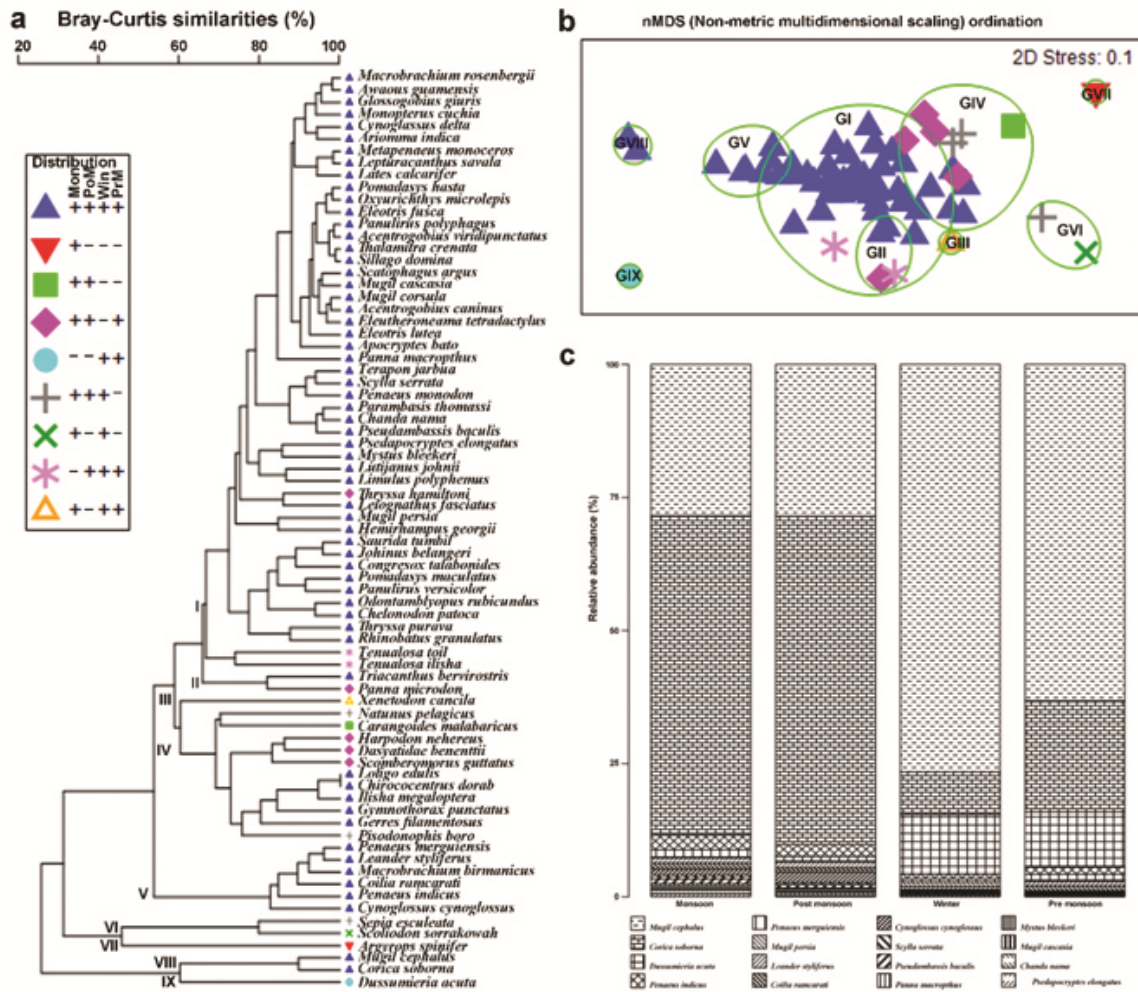


Fig. 2 — Dendrogram of the species distribution during four seasons using group average clustering based on Bray-Curtis similarities coordinating non metric multidimensional scaling (nMDS) from square root transformed species abundance data of each species (a, b) and relative abundances of 16 dominant species for each season during study period. (+, presence; -, absence; Mon= monsoon; PoM= post

the monsoon. The pair-wise comparison of all four seasons, three species showed the highest contribution in the fisheries communities for this seasonal variation and these three species were *Mugil cephalus* (7.48 %, 8.55 %, 12.11 % and 10.98 %), *Corica soborna* (8.42 %, 9.77 %, 8.24 % and 9.16 %) and *Dussumieria acuta* (0 %, 0 %, 8.82 % and 8 %), respectively.

In terms of biodiversity indices, the species richness, evenness and diversity were peaked in the monsoon and dropped in the winter (Figure 4a, b, and c) while all three indices were higher at station 1 and lower at station 3 (Fig. 4c, d and f).

Based on SIMPROF analysis, there was a clear spatial difference among the three stations. Fisheries assemblages at station 1 ($P < 0.05$) were significantly different than those of 2 and 3 ($P > 0.05$) (Fig. 5a). Vector coordination of the dbRDA analysis was

clarified this variation by forming these two stations in the same cluster group (Fig. 5b). CAP analysis summarized the seasonal variations in structural patterns of the fisheries communities (Fig. 5c). The first canonical axis (CAP1) separated the samples in monsoon and post-monsoon (on the left) from those in winter and pre-monsoon (on the right), while the second canonical axis (CAP2) discriminated the samples in post-monsoon and pre-monsoon (upper) from those at the other seasons (lower) (Fig. 5c). Vector overlay of 16 dominant species revealed that vectors for four species (i.e., *Coilia ramcarati*, *Coilia soborna*, *Penaeus indicus* and *Cynoglossus cynoglossus*) pointed towards the sample cloud in the pre monsoon (upper right) whereas three species (i.e., *Penaeus merguensis*, *Mugil cascasi* and *Leander styliferus*) towards that in post monsoon (upper left).

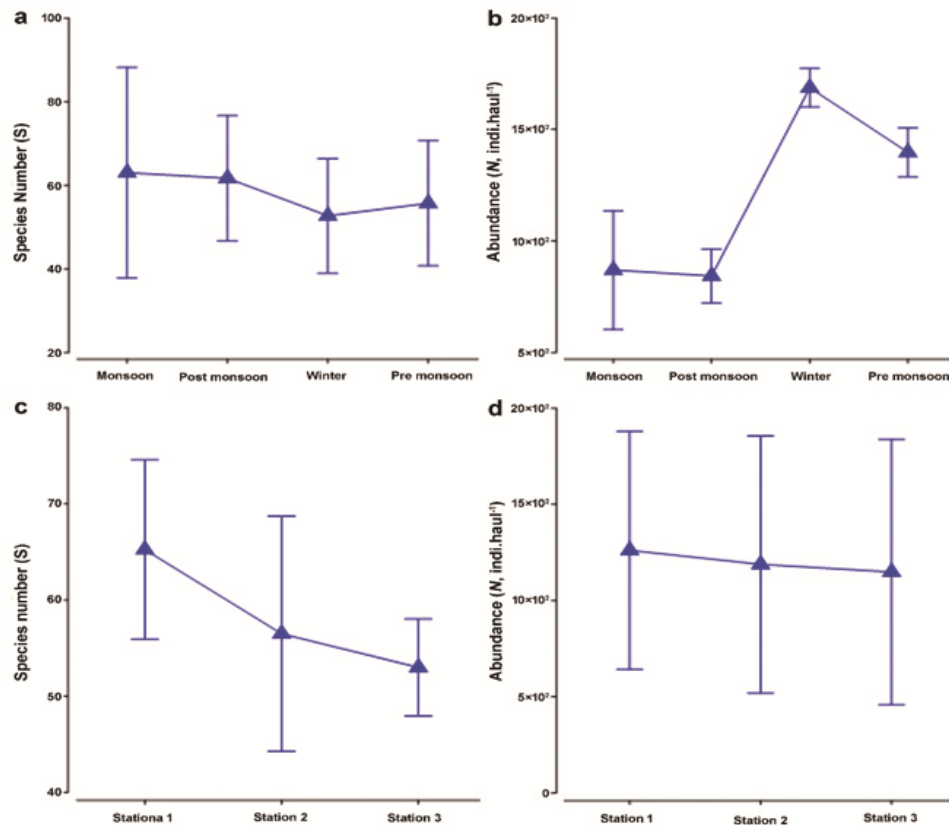


Fig. 3 — Spatio-temporal variation in species number (S) (a, c), total abundance (N) (b, d) fisheries communities during the four seasons and three stations of the study period.

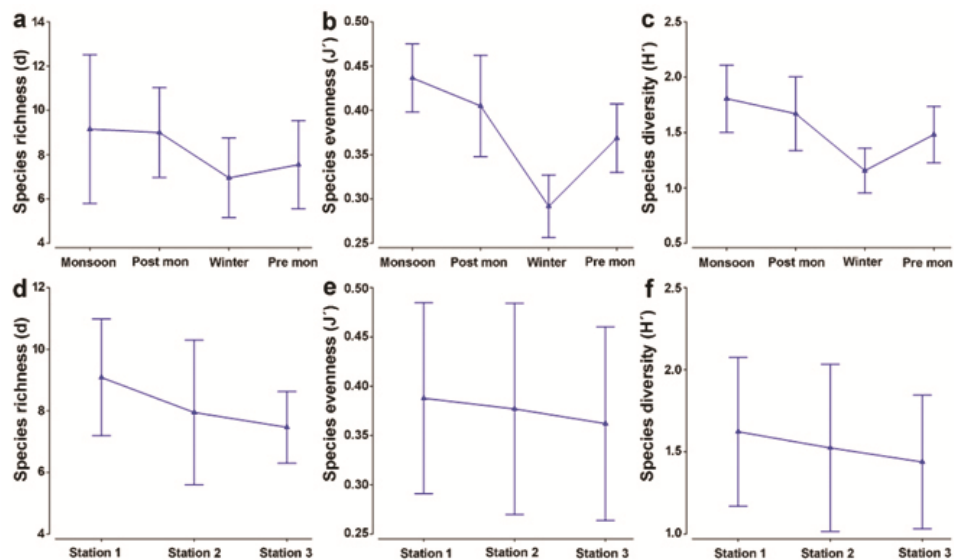


Fig. 4 — Spatio-temporal variation in species richness (D), species evenness (J') and species diversity (H') of fisheries communities during the study period.

Three species (*Mugil cephalus*, *Mugil persia* and *Dussumieria acuta*) toward that in monsoon (lower left) while six species (i.e., *Panna macropterus*,

Chanda nama, *Scylla serrata*, *Myxus bleekeri*, *Pseudapocryptes elongatus* and *Pseudambassis baculis*) toward that in winter (lower right) (Fig. 5d).

Relationship between biotic and abiotic variables

The coefficient of correlation among the biotic and abiotic variables (RELATE) analysis showed that seasonal variations in fisheries communities were correlated with the change of environmental variables ($\rho=0.482$, $P<0.05$). Furthermore, biological-environmental best matching analyses (BEST) demonstrated that the seasonal variations in fisheries

communities were mainly driven by water transparency ($P=0.764$) and salinity ($P=0.743$) either alone or combined with soil and water nutrients (Table 3).

Pearson correlation between environmental parameters and fisheries communities were summarized in Table 4. Among the 16 dominant species, 10 species were significantly correlated with

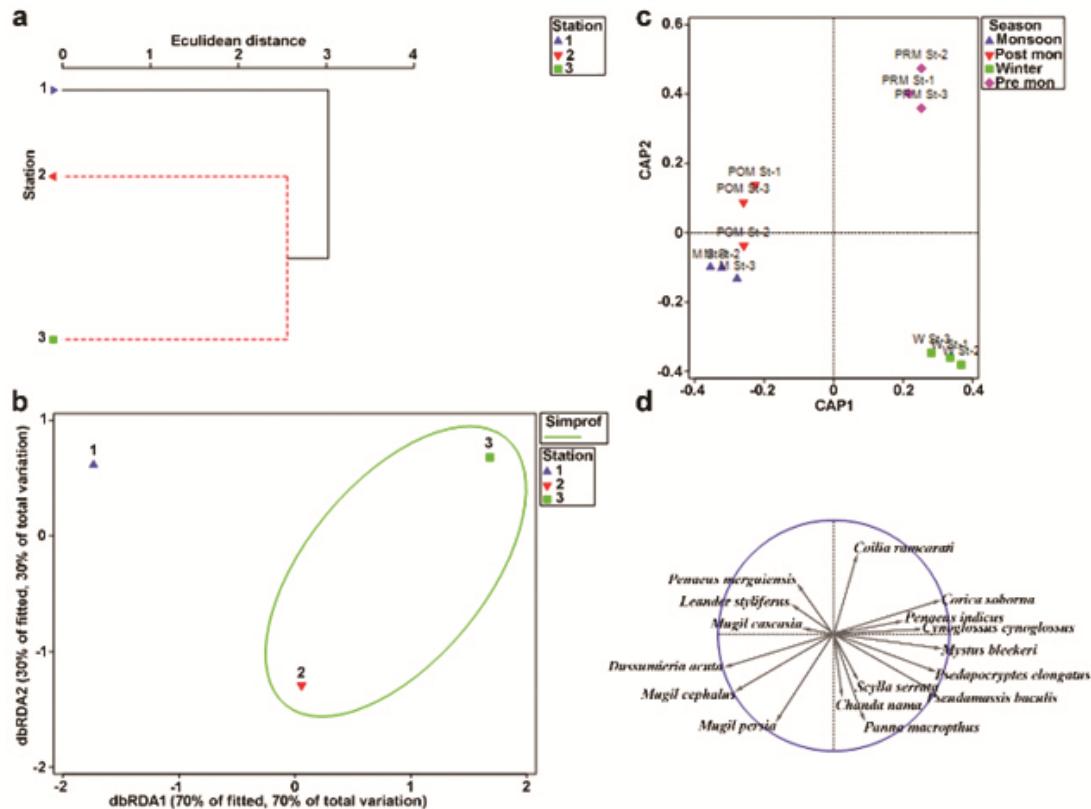


Fig. 5 — Cluster analysis with taking SIMPROF test for significant differences among the stations ordination of distance based redundancy analysis (dbRDA) (a, b) and Canonical analysis of principal coordinates (CAP) for seasonal variations in the fisheries communities with correlation of 16 dominant species with CAP axis (c, d) from four seasons.

Table 3 — Summary of results from biota-environment (BIOENV) analysis showing the 10 best matches of environmental variables with seasonal variation in the fisheries abundances during the study period.

Rank	Environmental variables	ρ value	P value
1	Trans	0.764	<0.05
2	SPO ₄ -p, Sal, Trans	0.743	<0.05
3	SPO ₄ -p, Sal, Trans, TDS, PO ₄ -P	0.742	<0.05
4	Sal, Trans, PO ₄ -P	0.735	<0.05
5	SPO ₄ -p, Sal, Trans, PO ₄ -P	0.730	<0.05
6	SPO ₄ -p, Trans	0.729	<0.05
7	SPO ₄ -p, Sal, Trans, TDS	0.727	<0.05
8	Sal, Trans, TDS, PO ₄ -P	0.727	<0.05
9	Sal, Trans	0.719	<0.05
10	SPO ₄ -p, Sal, Trans, TDS, Alkanity	0.716	<0.05

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

these environmental parameters. For example, *Mugil cephalus* has a positive significant correlation with water PO₄-P but negative with soil NO₂-N; *Corica sobornia* has a negative significant correlation with water PO₄-P but positive with soil NO₂-N. Species evenness showed a significantly negative correlation with salinity while richness showed with transparency and PO₄-P but richness was positively correlated with soil NO₂-N; species diversity was positive significant correlated with soil NO₂-N negatively with salinity, transparency and water PO₄-P (Table 4).

Discussion

The northern continental shelf of the Bay of Bengal (i.e., the southeastern coastal zone of Bangladesh) is a very unpredictable ecological condition due to the strongly influenced of the monsoonal activities^{1-3,5-7}. However, the spatiality of environmental parameters during the present investigation found less significant among the three stations. Among the parameters, only water temperature and dissolved oxygen content were significantly varied with stations that were probably due to the presence of anthropogenic activities i.e., untreated sewage effluents, the fishing harbor,

shipping jetty and agricultural/aquaculture discharge. On the other hand, all studied parameters except pH and soil NO₂-N revealed significant seasonal variations. This result impels that the seasonality of these environmental parameters in this channel might be directly or indirectly influenced by the monsoonal activities of the Bay of Bengal. The nutrients input from upland freshwater fluxes in the monsoon and upwelling process due to the strong current of the Bay waters influenced the variability of the environmental parameters of this area. These findings were consistent with previous reports that significant temporal variations for water temperature, transparency, salinity, and dissolved oxygen in the southeastern coast of Bangladesh shaped mainly monsoonal activities of the Bay of Bengal^{2,3,6}.

Based on the present findings, out of 76 species, 58 were commonly distributed in all four seasons, and 16 were dominant. Rashed-Un-Nabi *et al.*² reported 35 species of fish and 10 were shrimp, where Kamal⁸ reported 46 species of fish in the Moheshkhali channel near to the present study area. In a study by Hossain *et al.*⁶ reported 53 species of finfish in the southeastern coast of Bangladesh. Furthermore, study by Chowdhury *et al.*³ reported 161 species of fish

Table 4 — Pearson correlations between average values of the 16 dominants species with average environmental variables during the study period.

Parameters	AT	pH	Sal	Trans	DO	TSS	PO ₄ -P	NO ₂ -N	SOC	SNO ₂ -N	SPO ₄ -P
<i>Mugilcephalus</i>	-.255	-.303	.915	.920	.337	-.352	.977*	.766	-.621	-.995**	-.873
<i>Coricasoborna</i>	.285	.278	-.902	-.905	-.322	.381	-.971*	-.773	.616	.995**	.882
<i>Coiliamcarati</i>	.993**	-.750	-.168	-.012	-.205	.10**	-.308	-.728	.494	.332	.724
<i>MugilPersia</i>	-.648	.111	.707	.655	.253	-.721	.832	.856	-.613	-.884	-.951*
<i>Cynoglossus cynoglossus</i>	-.08	.632	-.116	-.89	.001	.015	-.838	-.414	.255	.936	.586
<i>Dussumieriacuta</i>	-.07	.569	-.948	-.994**	-.357	.031	-.955*	-.599	.546	.943	.70
<i>Parambasis thomassi</i>	.016	.235	-.929	-.838	-.858	.093	-.845	-.746	.883	.651	.691
<i>Macrobracium birmanicus</i>	.478	-.817	.830	.922	.321	.281	.387	.764	-.356	-.719	-.358
<i>Pannamicrodon</i>	-.654	.637	-.582	-.598	-.586	-.605	-.408	-.087	.381	.216	.023
<i>Chandanama</i>	-.648	.111	.707	.655	.253	-.721	.832	.856	-.613	-.884	-.951*
<i>Pseudambassis baculis</i>	-.337	.539	-.871	-.853	-.712	-.259	-.752	-.472	.662	.577	.441
<i>Penaeusindicus</i>	.512	-.215	-.827	-.663	-.838	.575	-.819	-.972*	.985*	.658	.911
<i>Penaeus merguensis</i>	.785	-.996**	.352	.564	-.255	.727	.308	-.307	.274	-.389	.167
<i>Leanderstyliferus</i>	.476	-.746	.845	.90	.479	.39	.749	.325	-.462	-.646	-.357
<i>Mystusbleekeri</i>	-.019	.464	-.993**	-.991**	-.552	.079	-.972*	-.697	.701	.899	.75
<i>Herirhampus georgii</i>	-.112	.073	-.641	-.503	-.954*	-.074	-.486	-.519	.801	.209	.368
Species number (S)	.20	.313	-.971*	-.955*	-.484	.298	-.999**	-.799	.718	.965*	.872
Abundance (N)	.354	-.085	-.873	-.722	-.89	.422	-.832	-.918	.986*	.646	.848
Evenness (J')	.032	.336	-.99**	-.939	-.721	.123	-.943	-.762	.823	.81	.764
Richness (D)	.163	.379	-.944	-.959*	-.37	.262	-.986*	-.736	.624	.988*	.838
Diversity (H')	.135	.37	-.979*	-.972*	-.481	.298	-.999**	-.799	.718	.965*	.872

Text bold, statistical significant values; *Significant level at 0.05 ($P < 0.05$) and significant level at 0.01 ($P < 0.01$ **). See Table 1 for other abbreviations.

while Hossain et al.^{5,6} reported 185 species of fishes using different nets from Naaf river and Meghna river estuaries in Bangladesh^{3,5,6}. In contrast, the species number was found lower, which might be due to the collection of species from single fishing gear (e.g., beach seine that catches only pelagic and nearshore species). It also might be due to the long-term change of environmental conditions (e.g., temperature, salinity, transparency and soil organic matter) that cause the habitat complexity for fisheries communities because these parameters have a significant correlation with communities.

In comparison to the Moheshkhali channel, another open maritime channel close to the study area species richness and abundance found higher in the Kohelia channel that might be due to differences in habitat characteristics and selection of fishing gear². In addition, due to breeding periodicity of the most dominant species (i.e., *Mugil spp*, *Coilia ramcarati*, *Corica soborna*) during monsoon led higher fisheries abundance in this season. Studies have reported that open maritime channels and estuaries are favorable habitats for most of the commercial species for breeding and nursery ground^{2,3,5,6}. Thus, these channels' habitats structure might shape the community patterns of the fisheries communities. However, a relatively higher number of species and abundance found pollution-free sites at station 1 that is due to absences of human interference, available food supply, and rich aquatic vegetation (e.g., mangroves, seagrass and salt marsh). More so, in the coastal water, mangroves are considered as the most productive area due to shelter zones with adequate sources of food for planktons and fisheries^{23,30,31}. All these observations are in consistence with the higher abundance, and species composition found at station 1.

Biodiversity indices found higher in monsoon while lower in winter. Moreover, all these values were higher than those of the previous reports which might be due to the favorable environmental condition of this channel^{2,5,6}. In the present investigation, biodiversity indices values indicated medium size biodiversity status and this could be due to selectivity of fishing gear because selectivity of gears has highly effective impacts on fisheries biodiversity³². In the case of spatial biodiversity indices, station 1 found higher than station 2 and 3, which indicates that relatively lower disturbances and noises for fisheries communities than the other two stations. Abdullah Al et al²³ reported that i.e. mangroves, seagrasses and salt

marsh areas have higher secondary production that supports relatively higher species diversity than other areas. Therefore, this aquatic vegetation can supply available food and shelter for pelagic fisheries communities. Studies have reported that seasonality of biodiversity is a very common incident in the subtropical coastal ecosystems characterized by strong interaction among environmental factors which is in agreement with this study outcomes^{2,6}.

Multivariate analysis between the fisheries communities and environmental parameters revealed that many interacting influencing factors like dissolved oxygen, salinity, transparency, water temperature, soil organic matter, water, and soil nutrients play an important role in species distribution, abundances, and diversity of the fisheries communities in the study area. It has been argued that seasonal and spatial fluctuations of the environmental parameters lead to the primary productivity in the aquatic ecosystems which ultimately affects the structural variations of the fisheries communities especially pelagic fishes^{31-36,39}. Multivariate approaches of present study results are reflected in those previous studies findings.

Regarding the abundance of dominant species, 16 species were found the highest contributors of the total fisheries communities in the Kohelia channel. According to previous studies, the dominance of the resident species in the coastal and estuarine waters was common due to strong integration with ecological parameters³⁶⁻³⁹. In this study finding, dominant species were significantly correlated with environmental parameters that are consistent with previous judgments. For example, *Coilia ramcarati* has a positive significant correlation with water temperature and TSS, *Mugil cephalus* has a positive significant correlation with water phosphate phosphorus but negative with soil nitrite nitrogen, *Corica soborna* has a significantly positive correlation with water phosphate phosphorus but negative with soil nitrite nitrogen. Thus, these imply that the community structure of the fisheries communities might be shaped by the environmental condition of the channel system.

It has been concluded that monsoonal activities of the Bay of Bengal and channel habitat structure have significant influenced for increasing fisheries diversity in the Kohelia channel, Bangladesh. Species number was higher in the monsoon while abundance was found in the winter. All these three diversity

indices were higher in the monsoon and lower in the winter. The findings of the study suggest that community patterns of the fisheries communities might be shaped by changing the environmental conditions of the Kohelia Channel. However, furthermore and extensive research should be needed to justify this conclusion.

Acknowledgment

This work was supported by the Chinese Government Scholarship Award for Excellent Master's Degree (CSC no.: 2016GXY030) under the Ministry of Education in China.

References

- 1 Abu Hena, M.K., and Khan, M.A.A., Coastal and estuarine recourses of Bangladesh: management and conservation issues. *Maejo Intern. J. Sci. Technol.*, 3(2) (2009): 313–342.
- 2 Rashed-Un-Nabi, Md., Al-Mamun, M.A., and Ullah, M.H., Temporal and spatial distribution of fish and shrimp assemblages in the Bakkhali river estuary of Bangladesh in relation to some water quality parameters. *Mar. Biol. Res.*, 7 (5) (2011): 436–452.
- 3 Chowdhury, M.S.N., Hossain, M.S. and Das, N.G., Environmental variables and fisheries diversity of the Naaf River Estuary, Bangladesh. *J. of Coastal Conservation*, 15 (2011): 163–180.
- 4 Shafi M&Quddus MM A,Bangladesher Matsya Sampad (in Bangla), Bangla Academy, Dhaka, 1982.
- 5 Hossain M M, Das NG & Chowdhury MSN, Fisheries Management of the Naaf River. Chittagong, Coastal and Ocean Research group of Bangladesh, 2007, 257 p.
- 6 Hossain, M.M., Das, N.G., and Sarkar, S., Fish diversity and habitat relationship with environmental variables at Meghna river estuary, Bangladesh. *Egyptian J. of Aquat. Res.*, 38 (2012): 213–226.
- 7 Islam, Catch composition of set bag net fishery with emphasis on population dynamics of two commercially important fish species from Chittagong coastal water in the Bay of Bengal. M.Sc. Thesis, Institute of Marine Sciences and Fisheries, University of Chittagong, 2005.
- 8 Kamal M M, Temporal and Spatial variation in species diversity of fishes in the Karnafully River Estuary, Chittagong. M.Sc. Thesis. Institute of Marine Sciences and Fisheries, University of Chittagong. Bangladesh, 2000.
- 9 Thiel, R., Sepúlveda, A. and Kafemann, R., Environmental factors as forces structuring the fish community of the Elbe Estuary. *J. of Fish Biol.*, 46 (1995): 47–69.
- 10 Griffiths, S.P., Factors influencing fish composition in an Australian intermittently open estuary. Is stability salinity dependent? *Estuarine, Coastal Shelf Sci.*, 52 (2001): 739–751.
- 11 Castillo-Rivera, M., Zavala-Hurtado, J.A., and Zarate, R., Exploration of spatial and temporal patterns of fish diversity and composition in a tropical estuarine system of Mexico. *Rev. in Fish Biol. Fisheries*, 12 (2002): 167–177.
- 12 Moyle P B & Cech J J, *Fishes: an introduction to ichthyology*, 5th ed. Upper Saddle River: Prentice-Hall, 2004.
- 13 Harrison, T.D., and Whitfield, A.K., Temperature and salinity as primary determinants influencing the biogeography of fishes in South African estuaries. *Estuar., Coast. Shelf Sci.*, 66 (2006): 335–345.
- 14 Jaureguizar, A.J., Menni, R., and Bremec, C., Fish assemblages and Environmental patterns in the Rio de la Plata estuary. *Estuar., Coast. Shelf Science*, 56 (2003): 921–933.
- 15 Jaureguizar, A.J., Menni, R., and Guerrero, R., Environmental factors structuring fish communities of the Rio de la Plata estuary. *Fisheries Res.*, 66 (2004): 195–211.
- 16 Martino, E.J., and Able, K.W., Fish assemblages across the marine to low salinity transition zone of a temperate estuary. *Estuar., Coast. Shelf Sci.*, 56 (2003): 969–987.
- 17 Whitfield, A.K., Ichthyofaunal assemblages in estuaries: a South African case study. *Rev. Fish Biol. Fisheries*, 9 (1999): 151–186.
- 18 Hyndes, G.A., Platell, M.E., and Potter, I.C., Does the composition of the demersal fish assemblages in temperate coastal waters change with depth and undergo consistent seasonal changes? *Marine Biol.*, 134 (1999): 335–352.
- 19 Marshall, S., and Elliot, M., Environmental influence on the fish assemblage of the Humber estuary, UK. *Estua. Coast Shelf Sci.*, 46 (1998): 175–184.
- 20 Cyrus, D.P., and McLean, S., Water temperature and the 1987 fish kill at Lake St Lucia on the south eastern coast of Africa. *Southern African J. of Aquatic Science*, 22 (1996): 105–110.
- 21 Peterson, M.S., and Ross, S.T., Dynamics of littoral fishes and decapods along a coastal river-estuarine gradient. *Estuar., Coastal Shelf Sci.*, 33 (1991): 467–483.
- 22 Blaber, S.J.M., and Blaber, T.G., Factors affecting the distribution of juvenile estuarine and inshore fish. *J. of Fish Biol.*, 17 (1980): 143–162.
- 23 Abdullah Al, M., Akhtar, A., Abu Hena, M. K., Islam, M.S., Uddin, M.M., Alam, M.D. and Xu, H., Seasonal pattern of zooplankton communities and their environmental response in subtropical maritime channels systems in the Bay of Bengal, Bangladesh. *Acta Ecol. Sinica*, 38 (2018): 316–324.
- 24 Tietze, U., Lee, R., and Siar, S., (eds.) *Fishing with beach seines*. FAO Fisheries and Aquaculture Technical Paper. No. 562. Rome, 2011, 149 pp.
- 25 Howlader, “A Taxonomic Account of Penaeid shrimps of Bangladesh waters. *Bangladesh J. of Sci. Indust. Res.*, XI (1976): 122–138.
- 26 Ahmed, A.T.A., Ahmed, Z.U. and Kabir, S.M.H. (eds). *Encyclopedia of Flora and Fauna of Bangladesh*. Volume 18(2): Arthropoda (Crustacea). Asiatic society of Bangladesh, Dhaka, 2008. 226 pp.
- 27 Ahmed, A. T. A., Z. U. Ahmed, and S. M. H. Kabir (eds). *Encyclopedia of Flora and Fauna of Bangladesh*. Volume 24: Marine Fishes. Asiatic society of Bangladesh, Dhaka, 2009, 491pp.
- 28 Anderson M J, Gorley RN, and Clark KR, *PREMANOVA + for PRIMER Guide to Software and Statistical Methods*. PRIMER-E Ltd, Plymouth, 2008.
- 29 Clark RK, & Gorley RN, *PRIMER 7; User Manual/Tutorial*. PRIMER-E Ltd, Plymouth, 2015.
- 30 Alongi DM, *The Energetics of Mangrove Forests*. London: Springer, 2009, 212 pp.

- 31 Arthington AH, & Welcome RL, The conditions of large river systems of the world. In. Armantrout NB, editor. Condition of the World's Aquatic Habitats. Proceedings of the World Fisheries congress, Theme 1. Lebanon, New Hampshire, USA: Science Publishers Inc. 1995, p 45–75.
- 32 Keskin, C., and Unsal, N., The Fish Fauna of Gokceada Island, NE Aegean Sea, Turkey. *Italian J. of Zool.*, 65 (1998): 299–302.
- 33 Maes, J.S., Damme, V.P., and Meire, F., Statistical modeling of seasonal and environmental influences on the population dynamics of an estuarine fish community. *Marine Biology*, 145 (2004): 1033–1042.
- 34 Cyrus, D.P., and Blaber, S.J.M., The influence of turbidity on juvenile marine fishes in estuaries. Part1. Field studies at Lake St Lucia on the south eastern coast of Africa. *J. of Expe. Mari. Biol. Ecol.*, 109 (1987): 53–70.
- 35 Blaber, S. J. M., Albaret, J. J., Chong, V. C., Effects of fishing on the structure and functioning of estuarine and near shore ecosystem. *ICES J. of Mari. Sci.* 57 (2000): 590–602.
- 36 Hotos, G.N., and Vlahos, N., Salinity tolerance of *Mugilcephalus* and *Chelonlabrosus* (Pisces: Mugilidae) fry in experimental condition. *Aquaculture*, 167 (1998) 329–338.
- 37 Thomson, L.M., The grey mullets. *Oceanography and Marine Biology. An Annual Review*, 4 (1966) 301–335.
- 38 Khan MG, Bangladesh coast and marine fisheries and environment. pp 1–35. In: Hussain, M.G. and hoq, M.F (eds.), Sustainable management of fisheries resources of the Bay of Bengal. Support to BOBLME Project, Bangladesh *Fish. Res. Ins.*, Bangladesh, 2010, 122 p.
- 39 Rozengurt, M.A., and Hedgepeth, J.W., The impact of altered river flow on the ecosystem of the Caspian Sea. *Review of Aquatic Science*, 1 (1989) 337–362.