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Research Article

Drag net catch species diversity in the coastal waters of the northern Bay of Bengal, Bangladesh

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Abstract

The drag net, known as "Moiya jal" is a very popular fishing gear among the fishermen in coastal areas of Bangladesh. To study the catch composition of the drag net and assess the impact of environmental variables on the fish population over time and space, a year-long baseline survey was carried out in the coastal waters of the Karnafuly River, the northern part of the Bay of Bengal, Bangladesh. A total of 36 species were identified throughout the survey and comprised 24 species of finfish (representing 13 families), seven species of shrimp and prawn (two families), and two species of crab (two families), alongside three unidentified specimens. Analysis of the community composition revealed that 16 and 9 species served as the dominant taxa across various seasons and sampling stations, respectively. The family Penaeidae exhibited the highest relative abundance (49.25%), followed by Palaemonidae (24.93%) and Sciaenidae (14.06%). At the species level, *Parapenaeopsis sculptilis* was the most abundant, accounting for 34.97% of the total recorded individuals, followed by *Metapenaeus monoceros* (14.48%) and *Exopalaemon styliferus* (13.02%). The Shannon-Wiener diversity index ranged from 0.81 to 2.22, with a mean of 1.77 ± 0.39. Statistical analysis indicated no significant differences in species diversity across seasons (F=3.101, P=0.089) or sampling stations (F=0.255, P=0.781). The structure and composition of the total communities varied significantly in both temporal and spatial scales, as shown by the similarity percentage analysis: (i) the average species similarity was highest (93.78%) in the post-monsoon and lowest (84.53%) in the winter; (ii) the average species similarity was maximum at (Station 1) Amanat Shah Bridge (49.53%) and minimum at (Station 2) Donar Khaler Mokh (48.30%). Further analysis revealed that different environmental factors such as temperature, salinity, pH, dissolved oxygen, and water transparency significantly influenced the structure of the fish communities. The diverse range of species in the Karnafuly River estuary suggests that this estuary plays a crucial role as a hotspot for the marine resources of Bangladesh.

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Introduction

Bangladesh boasts a rich array of coastal and estuarine resources, including mangroves, salt marshes, seagrasses, and various types of algae, along with a thriving fisheries sector (Pramanik, 1988; Chowdhury *et al*., 2011; Rashed-Un-Nabi *et al*., 2011; Hossain *et al*., 2012; Hoque *et al*., 2021). These resources play a crucial role in the life cycles and sustenance of many coastal organisms and communities. Numerous studies have explored the distribution of fisheries resources along the Bangladesh coast (Kamal, 2000; Islam, 2005; Kamal and Khan, 2009; Chowdhury *et al*., 2011; Rashed-Un-Nabi *et al*., 2011). The populations of estuarine and marine fish in this area exhibit temporal and spatial variations, influenced by monsoonal activities and fluctuations in the hydrological parameters of the Bay of Bengal (Rashed-Un-Nabi *et al*., 2011; Hossain *et al*., 2012). Key hydrological parameters, including water temperature, salinity, transparency, pH, dissolved oxygen, and nutrients, exert a significant impact on both global and regional fisheries diversity (Blaber and Blaber, 1980; Castillo-Rivera *et al*., 2002; Martino and Able, 2003; Jaureguizar *et al*., 2003, 2004; Chowdhury *et al*., 2011; Hossain *et al*., 2012). Reports consistently highlight that intense industrialization puts fisheries resources at greater risk of habitat degradation, resulting in lower species richness and abundance (Miller *et al*., 1988; Deegan *et al*., 1997; Meng *et al*., 2002).

The structural patterns of fish communities in coastal habitats are dynamic, exhibiting variability in species composition and abundance across daily, weekly, monthly, seasonal, and annual timeframes (Nash, 1988; Beck *et al*., 2001; Methven *et al*., 2001; Magill and Sayer, 2002). When environmental variables undergo abrupt changes, fish must adapt by adjusting their physiological functions (Whitfield, 1999; Potter and Hyndes, 1999; Costa *et al*., 2002). Moreover, the complex and ever-changing habitat structure of estuaries is particularly suitable for euryhaline fishes, as many fish and shellfish prefer this ecosystem during their post-larval and juvenile stages of development (Ooi and Chong, 2011). Given that various abiotic and biotic factors influence fish diversity, community structure, and species assemblages in estuaries and coastal waters (Lester *et al*., 1996; Dudgeon *et al*., 2006; Hoque *et al*., 2021), it is essential to examine the environmental factors shaping the structure of species assemblages in these areas (Whitfield, 1999; Meng *et al*., 2002).

The declining water quality of coastal waters, driven by human activities, has clearly harmed the diversity and abundance of fish species, resulting in structural changes within fish communities (Duque *et al*., 2020). It is deeply concerning that aquatic ecosystems are continuously altered by various human activities (Dudgeon, 1992), including urbanization and industrialization, which have adversely affected coastal ecosystems (Stanley, 2004). These changes are believed to have disrupted the physicochemical properties of water, productivity levels, fish community structures, and other aquatic organisms, potentially contributing to the extinction of numerous species (Resh *et al*., 1988; Poff and Ward, 1989). Understanding the

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ecological and environmental processes affecting aquatic resources requires studying or identifying the critical physicochemical factors that influence fish diversity and populations (Chanu *et al*., 2024).

Research has shown that the coastal area of Bangladesh, particularly its estuaries, is richly diverse, hosting small-scale fishing communities that depend solely on fishing for their livelihoods (Chowdhury *et al*., 2011; Hossain *et al*., 2012). The northern part of the Bay of Bengal directly or indirectly supports around 200,000 fishers for their livelihoods and maritime activities. Moreover, roughly 10,000 fishing fleets operate in this coastal area (Azadi and Alam, 2020). The Karnafully River estuary is home to a variety of fisheries resources, providing employment opportunities for coastal residents and contributing to the nation's blue economy (Abdullah *et al*., 2019; Rahman *et al*., 2019). It relies heavily on small-scale and multi-gear fisheries, playing a vital role in both the economic and ecological aspects of the country. This estuary is crucial, serving as spawning, nursing, and feeding grounds for various fish and shellfish species. Unfortunately, the ecosystem faces serious threats from environmental degradation, significantly impacting fisheries resources. Conserving the diversity of fisheries becomes imperative in the face of gradual habitat destruction (Vijaylaxmi *et al*., 2010; Hoque *et al*., 2021). Despite the potential of these resources, the lack of well-documented data on available resources and the identification of biological characteristics pose challenges to fisheries management. A scientific study is urgently needed for the sustainability of these fishery resources. Therefore, the present study aims to: (i) assess fish assemblage structure and fish diversity; (ii) estimate seasonal and spatial variations in fish catches.

Materials and methods

Description of the study area

This study has selected three sampling stations to collect samples from the mouth of the Karnafully River estuary to the Amanat Shah Bridge, covering a total area of approximately 20 km (in length). The approximate geographical coordinates of the sampling stations were: Amanat Shah Bridge (Station 1) (22°19'30.16" N, 91°51'08.53" E), Donar Khaler Mokh (Station 2) (22°18'29.63" N, 91°48'26.51" E), and 15 No Ghat (Station 3) (22°15'00.01" N, 91°49'57.38" E) (Fig. 1). These names are given based on the local administrative name.

Sample collection and identification

The study used a drag net, locally known as Moiya Jal, for sampling (Fig. 2). This net has a rectangular shape with a bamboo pole on the upper side and iron weights on the lower side to sink it under the water. The net is 3 to 4 meters long, 2 to 3 meters wide (sizes can vary), and has mesh sizes of 0.25 to 1 centimeter (Sultana *et al*., 2016). Even though there are estuarine set bag nets (ESBN) available in the Karnafully River estuary region, this study chose Moiya Jal for sampling because ESBNs are considered more harmful to the environment.

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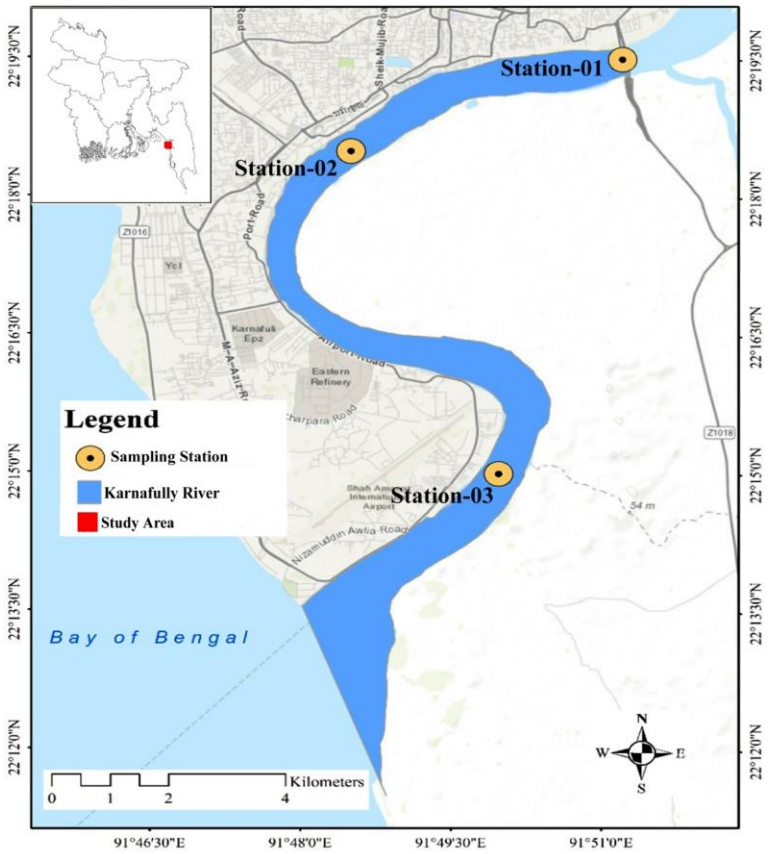


Figure 1: Sampling stations (1–3) in the coastal waters of the northern Bay of Bengal, Bangladesh. Station 1 is located at the Amanat Shah Bridge and takes in freshwater from the upper Halda River. Station 2 is on the opposite side of the Patenga Container Terminal, called Donar Khaler Mokh, and is strongly affected by environmental factors and human activities. Station 3 is at the mouth of the Karnafully River, known as 15 No. Ghat is significantly influenced by environmental factors and the intrusion of saline water from the Bay of Bengal.

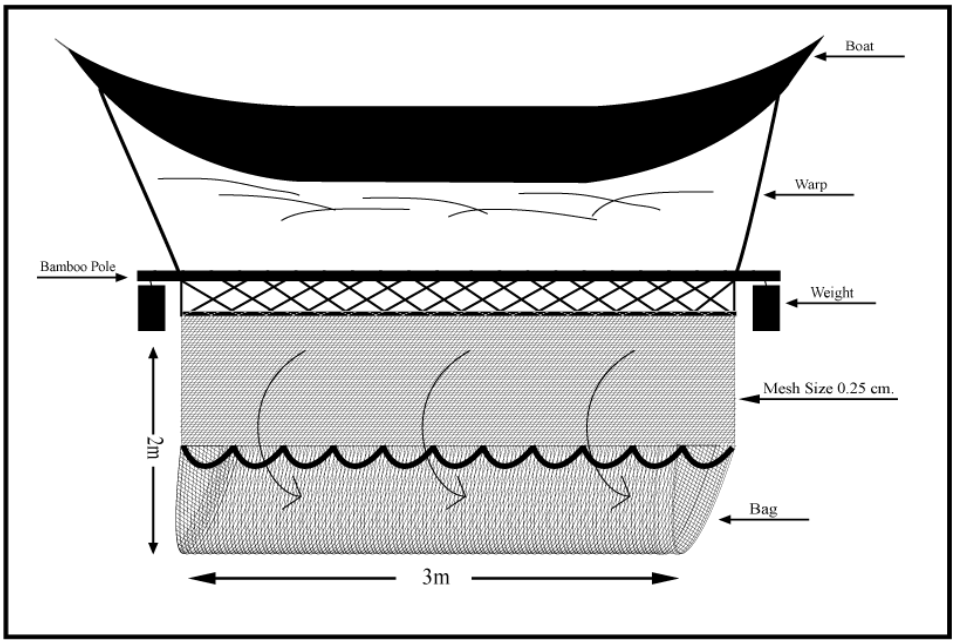


Figure 2: Drag net (Moiya Jal) available in the coastal waters, used for collecting samples from the study area.

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During the sampling period, fish and shellfish samples were collected from December 2019 to November 2020, covering four seasons: winter (December, January, and February), pre-monsoon (March, April, and May), monsoon (June, July, and August), and post-monsoon (September, October, and November) as defined by Mahmood *et al*. (1994). Monthly sampling was done during the full moon and new moon, as fishermen mentioned that fish and shellfish species were more abundant in these periods. About 2 kg of unsorted samples were directly collected from the fishermen during each sampling, but if the catches were less than 2 kg, all samples were collected. The samples were preserved with ice while transporting them to the laboratory for further processing. Specimens were identified up to the species level using methods described by Fischer and Whitehead (1974), Shafi and Quddus (1982a, b), and Talwar and Jhingran (1991).

Environmental parameters at each station were also measured. Salinity, pH, temperature, and dissolved oxygen were determined using a refractometer (NewS-100, TANAKA, Japan), a pen pH meter (s327535, HANNA Instruments), a thermometer (in degree centigrade scale), and a DO meter (HI9142, HANNA Instruments), respectively. Water transparency was measured using a Secchi disc with a 20 cm diameter.

Analysis of data

Species diversity was assessed using the Shannon-Wiener index (H') (Shannon, 1949), richness was determined by the Margalef index (d) (Margalef, 1968), evenness was gauged using Pielou's index (j) (Pielou, 1966), and dominance was measured through the Simpson index (C) (Simpson, 1949). These indices were calculated using the following equations in PAST 4.03 software.

$$H' = \Sigma\ [P_i * \log(P_i)] \quad (1)$$

$$d = (S-1) / \log(N) \quad (2)$$

$$J' = H(s) / H(max) \quad (3)$$

$$C = \Sigma\ (n_i / N)\ 2 \quad (4)$$

Here, P_i represents the proportion of the total count from the i^{th} species; S is the total number of species; N is the total number of individuals; n_i is the number of individuals in the i^{th} species; $H(s)$ is the Shannon-Wiener information function; and $H(max)$ is the theoretical maximum value for $H(s)$ if all species in the sample were equally abundant.

For environmental variables (temperature, salinity, dissolved oxygen, pH, and water transparency) and diversity indices, a one-way analysis of variance (ANOVA) was conducted to assess any statistically significant differences among the three stations. The same procedure was applied for the four seasons. Before ANOVA, all variables were checked for normality and homogeneity. To examine regional and temporal variations in fish and shellfish diversity, a one-way analysis of similarity (ANOSIM) was employed (Clarke and Warwick, 1994). Simper analysis determined the percentage contribution of each species to the average dissimilarity among samples from various seasons and station-pair combinations (Clarke, 1993). Hierarchical agglomerative clustering with average group linkage and

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non-metric multi-dimensional scaling (nMDS) were utilized to explore similarities among stations and seasons (Clarke and Warwick, 1994). The Bray-Curtis similarity metric was also employed in this investigation (Bray and Curtis, 1957). These multivariate analyses were carried out using PRIMER (v7.0.21) software (Plymouth Routines Multivariate Ecological Research). Canonical Correspondence Analysis (CCA) was further conducted to examine associations between species compositions and environmental variables using PAST4.03 software (Hammer and Harper, 2001).

Results

Physicochemical parameters

Figure 3 summarizes the environmental parameters. The water temperature varied from 24.27°C (winter, Station 1) to 31.17°C (monsoon, Station 3), with a mean±SD of 27.73±2.44°C. Water transparency ranged from 28.33 cm (winter, Station 2) to 3.13 cm (post-monsoon, Station 3), with a mean of 15.53±9.21 cm. The highest salinity, 13.50 ppt, was recorded in the winter at Station 3, and the lowest, 2.00 ppt, was in the monsoon at Station 1, with a mean of 6.46±4.32 ppt. Dissolved oxygen (DO) ranged from 6.30 mg/L to 4.09 mg/L, with a mean of 4.96±0.70. The highest pH, 7.93, was in the post-monsoon at Station 3, and the lowest, 5.50, was in the winter at Station 3, with a mean of 6.76 ±0.73. All environmental variables showed significant differences among all seasons except salinity and dissolved oxygen. In contrast, no environmental variables exhibited significant spatial variation except salinity and dissolved oxygen (Table 1).

Species composition

A total of 6154 fish and shellfish specimens belonging to 36 species were identified during the study period. These comprised 24 species of finfishes representing 13 families, seven species of shrimps and prawns under two families, two species of crabs exhibiting two families, and three unidentified species were observed. Penaeidae was the most dominant family (49.25%), followed by Palaemonidae (24.93%), Sciaenidae (14.06%), Cynoglossidae (2.58%), Bagridae (2.18%), Portunidae (1.61%), and Polinemidae (1.25%). The most dominant species were *Parapenaeopsis sculptilis,* which constituted 34.97% of the total individual count, followed by *Metapenaeus monoceros* (14.48%), *Exopalaemon styliferus* (13.02%), *Otolithoides pama* (5.77%), *Macrobrachium dayanum* (4.66%), *Macrobrachium lar* (3.31%), and *Johnius argentatus* (3.10%). The winter, pre-monsoon, monsoon, and post-monsoon seasons made up 27.77%, 19.18%, 31.33%, and 21.72% in the total abundance, respectively, while stations 1, 2, and 3 contributed 34.37%, 36.53%, and 29.10%, respectively. On a temporal scale, the most dominant species for winter, pre-monsoon, monsoon, and post-monsoon seasons were *Parapenaeopsis sculptilis* (71.33%), *Exopalaemon styliferus* (35.68%), *Metapenaeus monoceros* (41.34%), and *Parapenaeopsis sculptilis* (55.12%), respectively. On a spatial scale, the most frequently encountered species at Stations 1, 2, and 3 was *Parapenaeopsis sculptilis,* which contributed 27.57%, 42.93%, and 33.72%, respectively, of the total abundance at each Station (Table 2).

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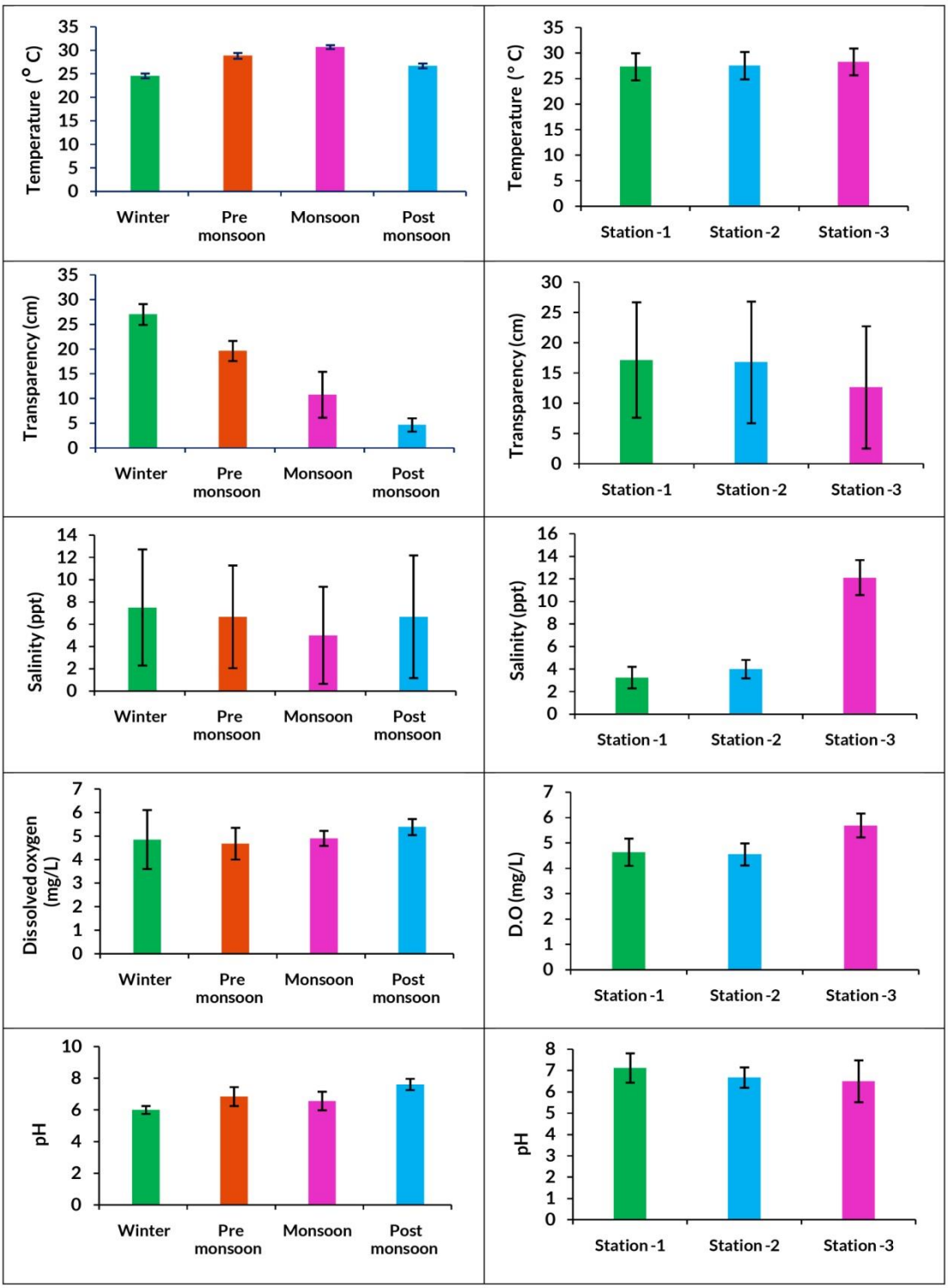


Figure 3: Mean environmental variables for different seasons and stations of the study area.

Species diversity

The Shannon-Wiener diversity index showed a range from 0.81 (winter at station 2) to 2.22 (pre-monsoon at station 3) with a mean of 1.77±0.39. There were no significant differences observed among seasons (F=3.101, P=0.089) or stations (F=0.255, P=0.781).

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Table 1: One-way ANOVA results for environmental variables in different seasons and stations.

Environmental variables		Sum of squares	Degrees of freedom	Mean square	F	Sig.
ANOVA for different seasons						
Temperature	Between groups	63.260	3	21.087	80.900	0.000
	Within groups	2.085	8	0.261		
	Total	65.345	11			
Transparency	Between groups	869.528	3	289.843	36.196	0.000
	Within groups	64.061	8	8.008		
	Total	933.589	11			
Salinity	Between groups	9.896	3	3.299	0.135	0.937
	Within groups	195.833	8	24.479		
	Total	205.729	11			
Dissolved oxygen	Between groups	0.825	3	0.275	0.489	0.699
	Within groups	4.496	8	0.562		
	Total	5.321	11			
pH	Between groups	4.054	3	1.351	6.058	0.019
	Within groups	1.784	8	0.223		
	Total	5.838	11			
ANOVA for different stations						
Temperature	Between groups	2.021	2	1.010	0.144	0.868
	Within groups	63.324	9	7.036		
	Total	65.345	11			
Transparency	Between groups	50.278	2	25.139	0.256	0.779
	Within groups	883.310	9	98.146		
	Total	933.589	11			
Salinity	Between groups	193.792	2	96.896	73.052	0.000
	Within groups	11.938	9	1.326		
	Total	205.729	11			
Dissolved oxygen	Between groups	3.226	2	1.613	6.931	0.015
	Within groups	2.095	9	0.233		
	Total	5.321	11			
pH	Between groups	0.835	2	0.418	0.751	0.499
	Within groups	5.003	9	0.556		
	Total	5.838	11			

The mean Shannon-Wiener diversity indices for winter, pre-monsoon, monsoon, and post-monsoon were 1.38±0.57, 2.05±0.24, 2.01±0.03, and 1.65±0.02, respectively. At stations 1, 2, and 3, the mean Shannon-Wiener diversity indices were 1.85±0.18, 1.65±0.60, and 1.81±0.37, respectively. The Margalef's richness index varied from 2.12 (post-monsoon at station 1) to 3.22 (monsoon at station 1), with a mean of 2.60±0.41. Significant differences were noted among seasons (F=26.695, P=0.000), while no significant differences were observed among stations (F=0.159, P=0.855). The mean Margalef's species richness indices for winter, pre-monsoon, monsoon, and post-monsoon were 2.81±0.23, 2.36±0.11, 3.09±0.14, and 2.13±0.02, respectively. At stations 1, 2, and 3, the mean Margalef's species richness indices were 2.63±0.53, 2.50±0.34, and 2.67±0.46, respectively.

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Table 2: Fish and shellfish species found in the Karnafully River estuary in different seasons and stations, showing relative abundance.

Serial No.	Family	Species name	Total	% contribution	% contribution in different seasons and stations						
					Winter (27.77)	Pre monsoon (19.18)	Monsoon (31.33)	Post monsoon	Station 1 (34.37)	Station 2 (36.53)	Station 3 (29.10)
1	Penaeidae	Parapenaeopsis sculptilis	2152	34.97	71.33	0.00	10.17	55.12	27.57	42.93	33.72
2	Penaeidae	*Exopalaemon styliferus*	1801	13.02	0.00	35.68	12.09	10.99	20.33	8.94	9.49
3	Palaemonidae	*Metapenaeus monoceros*	891	14.48	5.50	0.00	41.34	0.00	11.82	15.08	16.86
4	Sciaenidae	*Otolithoides pama*	355	5.77	1.76	12.20	5.55	5.53	6.62	5.52	5.08
5	Palaemonidae	*Macrobrachium dayanum*	287	4.66	0.00	13.90	0.00	9.20	3.83	4.67	5.64
6	Palaemonidae	*Macrobrachium lar*	204	3.31	0.00	0.00	10.58	0.00	4.82	1.60	3.69
7	Sciaenidae	*Johnius argentatus*	191	3.10	2.57	0.00	3.99	5.24	2.65	2.31	4.63
8	Palaemonidae	*Johnius elongatus*	148	2.04	0.00	6.78	3.53	0.00	1.70	2.62	2.96
9	Sciaenidae	*Macrobrachium rosenbergii*	151	2.45	0.82	4.66	3.48	1.12	2.17	2.54	2.68
10	Bagridae	*Mystus gulio*	134	2.18	2.69	0.00	1.71	4.11	2.41	1.78	2.40
11	Sciaenidae	*Johnius coitor*	120	1.95	3.86	4.58	0.00	0.00	3.40	1.25	1.12
12	Portunidae	*Scylla olivacea*	99	1.61	1.81	3.39	0.36	1.57	2.27	1.29	1.23
13	Cynoglossidae	*Cynoglossus puncticeps*	93	1.51	1.35	1.44	1.35	2.02	1.70	1.47	1.34
14	Palaemonidae	*Macrobrachium mirabile*	92	1.49	0.00	7.80	0.00	0.00	0.05	2.67	1.73
15	Cynoglossidae	*Cynoglossus cynoglossus*	84	1.36	1.99	2.29	0.00	1.72	1.61	1.11	1.40
16	Polynemidae	*Polynemus paradiseus*	77	1.25	1.23	3.47	0.78	0.00	2.08	0.62	1.06
17	Sciaenidae	*Johnius dussumieri*	50	0.81	1.17	0.00	1.56	0.00	0.85	0.67	0.95
18	Gobiidae	*Glossogobius giuris*	44	0.71	0.88	1.44	0.00	0.90	0.61	0.62	0.95
19	Engraulidae	*Setipinna taty*	22	0.36	0.99	0.00	0.26	0.00	0.57	0.31	0.17
20	Cynoglossidae	*Cynoglossus arel*	20	0.32	0.00	1.69	0.00	0.00	0.71	0.18	0.06
21	Cynoglossidae	*Cynoglossus bilineatus*	18	0.29	0.00	0.00	0.93	0.00	0.19	0.31	0.39
22	Butidae	*Butis melanostigma*	16	0.26	0.00	0.00	0.83	0.00	0.38	0.18	0.22
23	Engraulidae	*Stolephorus tri*	15	0.24	0.88	0.00	0.00	0.00	0.38	0.13	0.22
24	Pangasiidae	*Pangasius pangasius*	15	0.24	0.00	0.00	0.78	0.00	0.14	0.36	0.22
25		Unidentified (Poa)	13	0.21	0.00	0.00	0.00	0.97	0.09	0.13	0.45
26	Varunidae	*Varuna litterata*	12	0.19	0.41	0.42	0.00	0.00	0.14	0.09	0.39
27		Unidentified (goby-1)	11	0.18	0.00	0.00	0.00	0.82	0.19	0.13	0.22
28		Unidentified (goby-2)	9	0.15	0.00	0.00	0.00	0.67	0.14	0.18	0.11
29	Engraulidae	*Coilia dussumieri*	7	0.11	0.41	0.00	0.00	0.00	0.19	0.04	0.11
30	Chacidae	*Chaca chaca*	6	0.10	0.18	0.00	0.16	0.00	0.09	0.09	0.11
31	Sillaginidae	*Sillago domina*	4	0.06	0.00	0.00	0.21	0.00	0.05	0.00	0.17
32	Gobiidae	*Odontamblyopus rubicundus*	3	0.05	0.18	0.00	0.00	0.00	0.05	0.04	0.06
33	Bregmacerotidae	*Bregmacero ssp*	3	0.05	0.00	0.00	0.16	0.00	0.05	0.04	0.06
34	Eleotridae	*Eleotris fusca*	3	0.05	0.00	0.25	0.00	0.00	0.05	0.04	0.06
35	Sciaenidae	*Pennahia anea*	2	0.03	0.00	0.00	0.10	0.00	0.05	0.00	0.06
36	Clupeidae	*Anodontostoma chacunda*	2	0.03	0.00	0.00	0.10	0.00	0.05	0.04	0.00

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Pielou's evenness index varied from 0.12 (winter at station 2) to 0.61 (pre-monsoon at station 3), with a mean of 0.37±0.13. There were significant differences among seasons (F=5.841, P=0.021), while no significant differences were observed among stations (F=0.039, P=0.961). The mean Pielou's evenness indices for winter, pre-monsoon, monsoon, and post-monsoon were 0.23±0.13, 0.53±0.12, 0.36±0.01, and 0.37±0.01, respectively (Fig. 4).

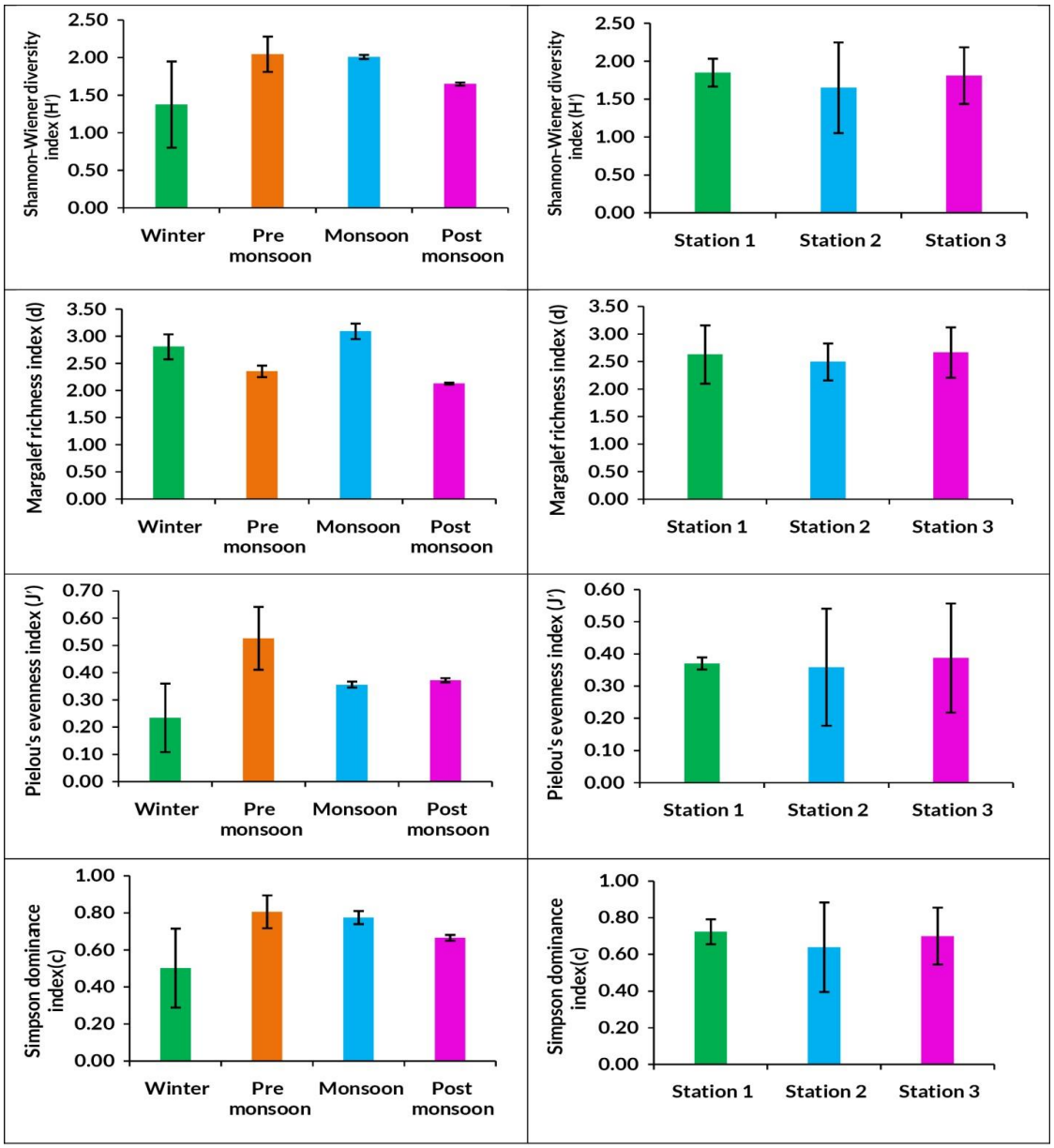


Figure 4: Temporal and spatial variation of different diversity indices in the Karnafully River estuary during the study period.

At stations 1, 2, and 3, the mean Pielou's evenness indices were 0.37±0.02, 0.36±0.18, and 0.39±0.17, respectively. The Simpson's dominance index varied from 0.29 (winter at station 2) to 0.86 (pre-monsoon at station 3), with a mean of 0.69±0.16. Significant differences were observed among seasons (F=4.123,

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P=0.048), while no significant differences were noted among stations (F=0.255, P=0.781) (Table 3). The mean Simpson's dominance indices for winter, pre-monsoon, monsoon, and post-monsoon were 0.50±0.21, 0.81±0.09, 0.78±0.04, and 0.67±0.02, respectively. At stations 1, 2, and 3, the mean Simpson's dominance indices were 0.72±0.07, 0.64±0.24, and 0.70±0.16, respectively (Fig. 4).

Table 3: One-way ANOVA outputs for different diversity indices in the Karnafully River estuary among different seasons and stations.

Indices		Sum of squares	Degrees of freedom	Mean square	F	Sig.
		ANOVA for different seasons				
Shannon–Wiener diversity index	Between groups Within the groups Total	0.899 0.774 1.673	3 8 11	0.300 0.097	3.101	0.089
Margalef richness index	Between groups Within groups Total	1.699 0.170 1.868	3 8 11	0.566 0.021	26.695	0.000
Pielou's evenness index	Between groups Within groups Total	0.129 0.059 0.188	3 8 11	0.043 0.007	5.841	0.021
Simpson dominance index	Between groups Within groups Total	0.170 0.110 0.279	3 8 11	0.057 0.014	4.123	0.048
		ANOVA for different stations				
Shannon–Wiener diversity index	Between groups Within the groups Total	0.090 1.595 1.685	2 9 11	0.045 0.177	0.255	0.781
Margalef richness index	Between groups Within groups Total	0.064 1.805 1.868	2 9 11	0.032 0.201	0.159	0.855
Pielou's evenness index	Between groups Within groups Total	0.002 0.186 0.188	2 9 11	0.001 0.021	0.039	0.961
Simpson dominance index	Between groups Within groups Total	0.015 0.264 0.279	2 9 11	0.007 0.029	0.255	0.781

Species assemblage

The average species similarity during the winter, pre-monsoon, monsoon, and post-monsoon seasons were 84.53%, 87.38%, 90.89%, and 93.78%, respectively. The contributing species for each season, along with their percentage contributions, are detailed in Table 4. Likewise, the average species similarities for stations 1, 2, and 3 were 49.53%, 48.30%, and 48.91%, respectively. A list of contributing species at each station, along with their percentages, is presented in Table 4.

There were significant differences in species similarity among the seasons (Global R=0.926; P=0.001).

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Table 4: SIMPER analysis shows the average similarity and contributing species in each season and station.

Contributory species (%)	Average similarity for seasons and stations						
	Winter (84.53%)	Pre monsoon (87.38%)	Monsoon (90.89%)	Post monsoon (93.78%)	Station 1 (49.53%)	Station 2 (48.30%)	Station 3 (48.91%)
Parapenaeopsis sculptilis	16.29	-	8.72	15.92	10.93	11.67	11.09
Metapenaeus monoceros	9.71	-	11.94	-	-	-	-
Cynoglossus cynoglossus	7.1	5.87	-	5.79	5.89	5.79	-
Mystus gulio	6.59	-	4.69	8.27	-	-	6.57
Scylla olivacea	6.53	-	-	5.49	8.55	8.12	7.56
Otolithoides pama	6.47	11.1	6.75	9.06	14.12	14.57	12.89
Johnius argentatus	6.32	-	6.35	8.5	6.28	5.76	7.19
Johnius coitor	6.29	7.62	-	-	-	-	-
Cynoglossus puncticeps	5.03	-	-	-	8.15	10.39	8.26
Polynemus paradiseus	-	6.35	-	-	-	-	-
Macrobrachium rosenbergii	-	8.32	6.66	-	9.02	9.01	8.96
Johnius elongatus	-	8.93	6.63	-	-	-	-
Macrobrachium dayanum	-	11.46		10.67	-	-	-
Exopalaemon styliferus	-	12.78	8.77	11.14	10.13	9.59	9.83
Macrobrachium lar	-	-	8.3	-	-	-	-
Johnius dussumieri	-	-	4.61	-	-	-	-

However, in pairwise comparisons, no significant differences were evident between winter vs. pre-monsoon (R=1; *P*=0.1), winter vs. monsoon (R=1; P=0.1), winter vs. post-monsoon (R=0.556; P=0.1), pre-monsoon vs. monsoon (R= ; P=0.1), pre-monsoon vs. post-monsoon (R=1; P=0.1), or monsoon vs. post-monsoon (R=1; P=0.1). Furthermore, no significant differences in species similarity among the stations were observed (Global R = -0.225; P = 0.973). In pairwise comparisons among stations, no significant differences in species similarity were noted for station 1 vs. station 2 (R= -0.229; P=0.857), station 1 vs. station 3 (R= -0.219; P=0.886), or station 2 vs. station 3 (R= -0.26; P= 1) (Table 5).

Table 5: One-way ANOSIM (R value and significance level) analysis for fish and shellfish abundance for different seasons and stations at Karnafully River estuary.

Seasons and stations	Pairwise tests				
	ANOSIM		SIMPER		
	R statistic	P	Average dissimilarity (%)	Most discriminating species	% contribution
Winter vs. pre-monsoon	1	0.1	58.64	*Parapenaeopsis sculptilis*	12.79
Winter vs. Monsoon	1	0.1	47.60	*Exopalaemon styliferus*	9.95
Winter vs. Post monsoon	0.556	0.1	58.97	*Metapenaeus monoceros*	10.59
Pre monsoon vs. Monsoon	1	0.1	43.22	*Exopalaemon styliferus*	11.74
Pre monsoon vs. Post monsoon	1	0.1	47.07	*Parapenaeopsis sculptilis*	15.5
Monsoon vs. Post monsoon	1	0.1	50.97	*Metapenaeus monoceros*	12.55
Station 1 vs. Station 2	-0.229	0.857	41.10	*Parapenaeopsis sculptilis*	7.79
Station 1 vs. Station 3	-0.219	0.886	41.10	*Metapenaeus monoceros*	7.09
Station 2 vs. Station 3	-0.26	1	40.87	*Parapenaeopsis sculptilis*	7.8

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Table 5 also provides a summary of the group-wise comparative results obtained through SIMPER and ANOSIM analysis, highlighting the most discriminating species for each group.

Six individual groups were identified through cluster analysis at 75% similarity. Group I comprised solely one station sampled during the winter season. Group II included all stations from the post-monsoon season. Group III comprised stations 1 and 3 of the winter season. Group IV contained all stations sampled during the monsoon season, whereas the fifth group contained only station 1 in the pre-monsoon season. Finally, group VI consisted of stations 2 and 3 of the pre-monsoon season (Fig. 5). A similar result was obtained when (nMDS) was performed using the collected data (Fig. 6).

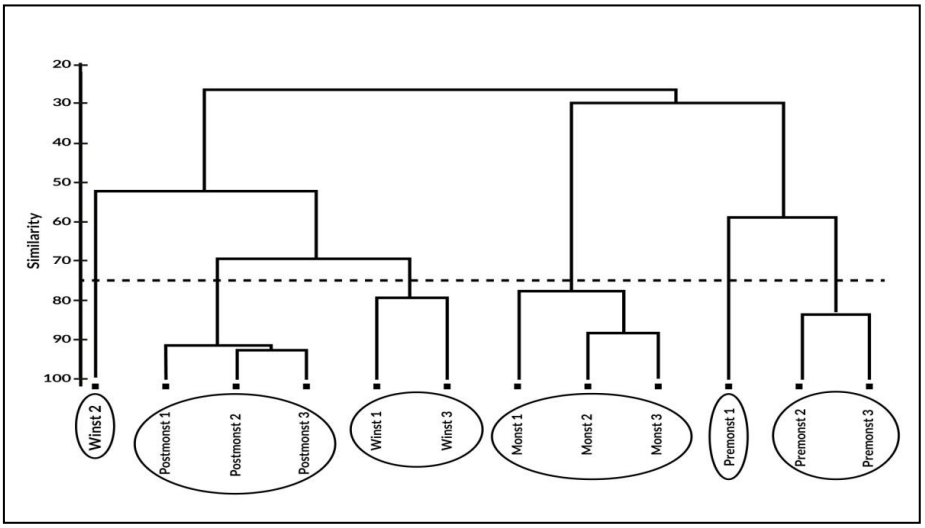


Figure 5: Dendrogram representing the cluster based on the Bray-Curtis similarity matrix of catch composition.

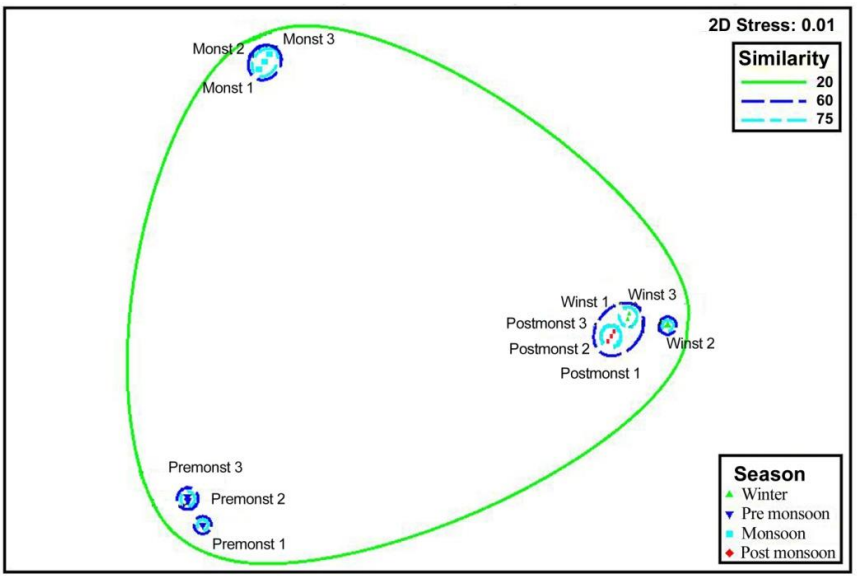


Figure 6: Non-metric multidimensional scaling of catch composition in the study area across various levels of similarity.

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In the Canonical Correspondence Analysis, only the 16 species contributing more than 1% of the total abundance were considered. The eigenvalues for axes 1, 2, 3, 4, and 5 were 0.44, 0.12, 0.05, 0.01, and 0.00, respectively. Axis 1 accounts for 71.50%, axis 2 for 19.22%, axis 3 for 7.43%, axis 4 for 1.85%, and axis 5 for 0.00% of the total variability in species-environmental relationships. The vector length of a variable indicates its significance in CCA analysis. Water temperature, with the longest vector along the first axis, exhibits the strongest correlation with stations 1, 2, and 3 during the pre-monsoon season. pH, with the highest eigenvalue (0.75) at axis 3, demonstrates its importance. Water transparency, associated with the post-monsoon, has a positive eigenvalue along the first axis. Dissolved oxygen (DO) and salinity, with the highest eigenvalues in the third and fourth axes, respectively, show the strongest correlation with the winter and post-monsoon seasons. Environmental parameters with an eigenvalue close or over 0.5 strongly affect species distribution and species composition. The species included in the analysis are *Johnius elongates*, *Macrobrachium rosenbergii*, *Otolothoides pama*, *Macrobrachium mirabile*, and *Metapenaeus monoceros,* each of which showed affinity to water temperature as it was plotted near the vector of water temperature at axis 1. Winter and post-monsoon were weakly correlated with salinity and DO, and *Mystus gulio* and *Parapenaeopsis sculptilis* partially depend on these environmental parameters. *Cynoglossus cynoglossus*, *Scylla olivacea*, *Johnius coitor*, and *Macrobrachium dayanum* were influenced by transparency and pH. In contrast, *Macrobrachium lar*, *Cynoglossus puncticeps*, *Exopalaemon styliferus*, and *Johnius argentatus* in the monsoon season were not influenced by any environmental variables. *Cynoglossus puncticeps* responded equally to average values of all environmental parameters and hence plotted near the central axis (Fig. 7).

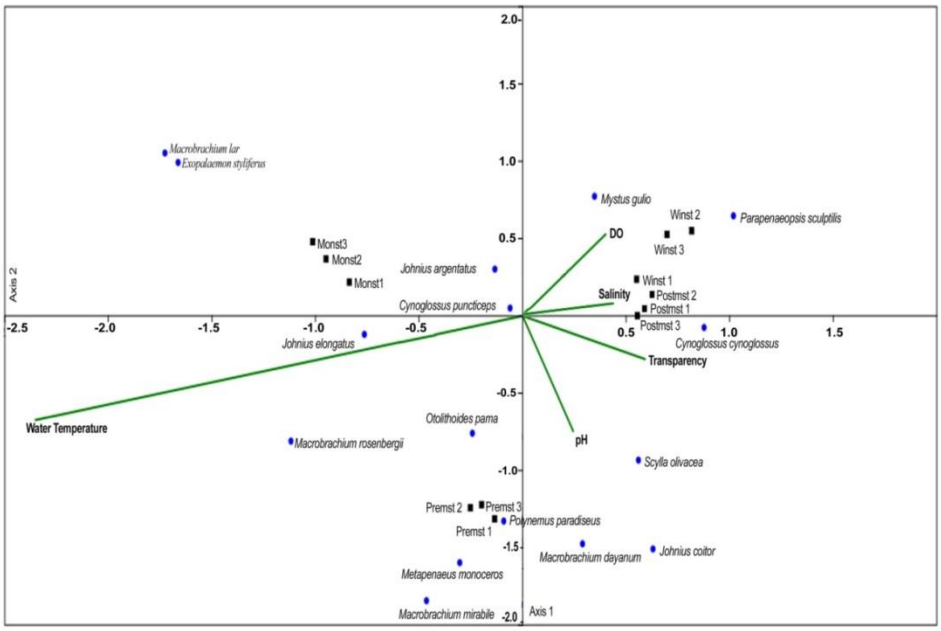


Figure 7: The ordination of species abundance and environmental parameters at various seasons and stations in the study area using Canonical Correspondence Analysis (CCA).

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Discussion

Various interacting physical and biological factors and processes impact the occurrence, distribution, abundance, and diversity of fish and shellfish in estuaries at different scales and in diverse ways (Whitfield, 1999; Blaber, 2000; Franca *et al*., 2011). The parameters examined in this study are recognized as crucial determinants in estuarine fish ecology (Whitfield, 1999; Blaber, 2000). Throughout this study, no significant spatial variation was observed for temperature, transparency, and pH, while notable differences were marked for salinity and dissolved oxygen. This is likely due to the short distances between the sampling stations and the tidal fluctuations of the sea. While it was anticipated that station 1 (Amanat Shah Bridge) might be influenced by freshwater discharge from the Halda River, this influence was mitigated by the significant tidal fluctuations (Akin *et al*., 2005). Though a significant seasonal variation was observed for temperature, transparency, and pH but salinity and dissolved oxygen did not exhibit any significant differences which is a common phenomenon in the coastal areas of Bangladesh (Rozengurt and Hedgepeth, 1989; Arthington and Welcome, 1995; Cyrus and McLean, 1996; Whitfield, 1999; Hossain, 2001; Kamal and Khan, 2009; Rashed-Un-Nabi *et al*., 2011; Maes *et al*., 2004; Abdullah Al *et al*., 2019).

Fish are highly sensitive to environmental changes, such as low dissolved oxygen levels (<5 mg/L), which place them under stress and make prolonged survival in poorly oxygenated water impossible (Bozorg-Haddad *et al*., 2021). Water temperature plays a crucial role in influencing fish growth, metabolism, and reproduction and is regarded as a key factor in shaping fish assemblage structure and overall abundance in coastal waters (Miranda *et al*., 2022). Environmental disruptions, including periodic inundation and extreme weather events, along with salinity fluctuations, directly or indirectly affect fish assemblage patterns and migration (Nsor and Obodai, 2016). Salinity plays a pivotal role in determining fish distribution and assemblage in coastal wetlands. Freshwater inflow is widely acknowledged as a significant factor in shaping estuarine fish diversity (Strydom *et al*., 2002). Additionally, seasonal variations in estuarine fish community structures are closely linked to salinity, which is regulated by seasonal rainfall and freshwater input (Mukherjee *et al*., 2013).

This study found 36 different species of fish and shellfish. However, Bhuiyan and Gafur (1977) reported 74 species, Kamal (2000) found 46 finfish species, and Rashed-Un-Nabi *et al*. (2016) recorded 41 finfish species in the Karnafully River estuary. Azadi and Alam (2020) documented a total of 112 finfish species and 18 shellfish species from the rivers Karnafully, Sikalbaha, and Chandkhali over ten years (2010 to 2020) survey. The number of species reported in the present study is significantly lower than in the previous studies. This decline in diversity may be attributed to industrial pollution from the Chittagong Metropolitan city, combined with overfishing and high fishing pressure within the Karnafully River estuary. Other factors, such as the types of fishing gear, sampling time, and location,

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might also contribute to the differences. However, Islam *et al*. (1992) recorded a total of 185 species along the coastal waters of Bangladesh by using an estuarine set bag net (ESBN).

The size of estuaries and their geographic distance also have a significant influence on species composition (Loneragan *et al*., 1987; Martino and Able, 2003). Hillebrand (2004) and Nicoloas *et al*. (2010) highlight the impact of estuarine hydrodynamics, geomorphology, climate, and catchment properties on fish species abundance. The nature and depth of nearby marine waters, along with estuary location and aquatic features such as ocean currents, canyons, and reefs, can also shape the fish fauna in estuaries (Blaber, 2000). As Whitfield (1999) noted, each estuary is unique, so the variation in species composition in this study is normal.

Seasonal variations in species diversity are a common occurrence in tropical and subtropical estuaries, and the Karnafully River estuary under investigation is no exception (Blaber, 2000; Hoque *et al*., 2021). Despite this, among the diversity indices applied in the Karnafully River estuary, the Shannon-Wiener index did not show significant differences on either temporal or spatial scales. On the other hand, Margalef's species richness, Pielou's evenness index, and Simpson dominance index exhibited significant differences among the seasons but not among the stations. The study indicates considerable variation in species diversity among the stations, suggesting that each station has a distinct ecosystem where environmental factors influence species diversity. In contrast, Rashed-Un-Nabi *et al*. (2016) reported significant seasonal variations in species diversity in the Karnafully River estuary, with Shannon-Wiener diversity values ranging from 2.41 to 2.67, much higher than the present study's findings (0.81 to 2.22). Similarly, Shamsuzzaman *et al*. (2017) found no significant difference in the Shannon-Wiener diversity index among seasons at the Karnafully River estuary, aligning with the present study. However, Shamsuzzaman *et al*. (2017) reported a higher Shannon-Wiener diversity value ranging between 2.15 and 1.95, surpassing the current findings. Chowdhury *et al*. (2011) also demonstrated a higher Shannon-Wiener diversity index than the present study, primarily attributed to the use of different sampling gear and effort (Ramos *et al*., 2006).

The analysis of similarity indicates that seasonal variations in the species assemblage at the Karnafully River estuary are more distinct than spatial variations. This seasonal fluctuation in assemblage structure may be attributed to changes in water parameters throughout the seasons, consistent with studies in other estuaries such as the Caete River estuary (Barletta *et al*., 2002), Lima estuary (Ramos *et al*., 2006), and Bakkhali River estuary (Rashed-Un-Nabi *et al*., 2011). Maes *et al*. (2004) suggested that strong seasonal variations in estuarine assemblages are influenced by the recruitment pattern of marine and estuarine species rather than the estuary's environmental parameters. Cardoso *et al*. (2011) found seasonal variations in fish assemblages in Portuguese estuaries, emphasizing positive responses to various environmental changes.

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In Canonical Correspondence Analysis (CCA), species plotted closer to a given vector exhibit strong relationships with the associated environmental parameter(s). In our study, all variables influenced species distribution, with most species, seasons, and stations showing correlations (positive or negative) with these variables. For instance, *Johnius elongates*, *Macrobrachium rosenbergii*, *Otolothoides pama*, *Macrobrachium mirabile*, and *Metapenaeus monoceros* were strongly correlated with high temperature, while *Cynoglossus cynoglossus*, *Scylla olivacea*, *Johnius coitor*, and *Macrobrachium dayanum* were correlated with transparency and pH. The Canonical Correspondence Analysis suggests that nearly all parameters play a role in influencing the assemblage of fish and shellfish in the Karnafully River estuary. Rashed-Un-Nabi *et al*. (2016) and Shamsuzzaman *et al*. (2017) identified different key environmental parameters (temperature, salinity, pH, dissolved oxygen, and transparency) shaping the fish assemblage structure and species diversity in the same estuary.

Conclusion

In summary, seasonal changes in environmental conditions coincide with significant shifts in the fish assemblage of the Karnafully River estuary. Variations in total abundance, species diversity, and the community structure of fish and shellfish are observed across seasons and stations. *Parapenaeopsis sculptilis* was consistently the most dominant species, comprising 34.97% of the total species composition throughout the study period. However, other species exhibit comparatively lower distributions across seasons and stations. The Karnafully River estuary serves as a nursery ground for some truly marine species in their juvenile stages, indicating its importance for their early development. The overall fisheries diversity in this estuary is low, likely due to heavy pollution from industrial sources, viz., oil tankers, fertilizer factories, and the Chittagong City Corporation, as well as over-harvesting of juvenile fish by estuarine set bag nets, compromising the ecological condition of the estuary. Further comprehensive research is recommended to better understand the ecosystem's functionality, interactions with environmental parameters, and habitat characteristics over time. Despite the challenges, the findings of this study underscore the significance of the Karnafully River estuary as a crucial nursery, breeding, and spawning ground for various fish and shellfish species.

Conflicts of interest

The authors declare that they have no conflicts of interest that could have influenced the results of this study.

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