

Flood-Driven Spatio-temporal variation of zooplankton and seasonal dynamics of macrobenthos in the Feni river, Bangladesh

Mohammad Shamsil Arafeen, Rahul Deb Brahman, Siamul Alam, Md Arshad Chowdhury, Farzana Yesmin, Mumtahena, Md. Manzoorul Kibria, Md. Mansurul Haque^{1*} and Md. Mahedi Hasan¹

Department of Zoology, University of Chittagong, Chattogram, Bangladesh

Abstract

The ecological importance of zooplankton and benthic communities as freshwater bioindicators is widely recognized, but still commonly undervalued. This study examined the spatio-temporal variations of zooplankton and macrobenthic diversity in the Feni River, Bangladesh between March 2024 and February 2025. Data were collected from three sample locations (stations) of the river, and seasonal patterns were analyzed using abundance (ind./m³), composition, and diversity indices (Shannon-Wiener, H' and Pielou's evenness J'). A total of 30 zooplankton species were recorded, with Copepoda as the dominant group. Following the August 2024 monsoon flood, a marked restructuring of the zooplankton community was observed. Rotifera increased from 11.10% in the pre-monsoon period to 37.85% during the monsoon, whereas Copepoda declined from 52.48% to 41.42% and Cladocera from 36.42% to 20.73%. This shift suggests a rapid response of rotifers to flood-induced hydrological changes, whereas copepods and cladocerans were comparatively more susceptible to flood-related disturbance. Zooplankton abundance peaked in autumn (1,343,061 ind./m³) and was lowest in winter (735,706 ind./m³). Diversity was highest at Station 1 during autumn (H' = 2.42), while evenness remained consistently high (J' > 0.85). These findings align with the flood-pulse concept, demonstrating how seasonal flooding shapes zooplankton dynamics. Macrobenthic diversity, assessed at the family level, was highest in winter (H' = 2.77, J' = 0.9246) and lowest during monsoon (H' = 2.57, J' = 0.9071), indicating a moderately diverse and ecologically balanced community throughout the year. This study implies that the zooplankton and macrobenthic communities are generally altered by periodic flooding, and highlighting their critical value as indicators for tropical river management.

Keywords: Spatio-temporal variation, Zooplankton, Macrobenthos Feni River, Flood

INTRODUCTION

The Feni River rises in Tripura, India, and flows through southeast Bangladesh before emptying into the Bay of Bengal (Islam *et al.*, 2018). This river serves as a lifeline for the local population, playing a vital role in local fisheries, agriculture, and livelihoods (Islam *et al.*, 2018). However, due to increasing human intervention, the river faces severe threats, undermining its plankton and benthic communities (Jannah *et al.*, 2024). As a result, studying the macrobenthic and zooplankton populations has become imperative for assessing the ecological changes and promoting sustainable river management (Jannah *et al.*, 2024).

¹ Laboratory of Fishery and Limnology, Department of Zoology, Jahangirnagar University, Savar, Dhaka-1342, Bangladesh

*Corresponding author. Email: mansurulju@juniv.edu

Zooplankton are heterotrophic and usually minute drifting aquatic organisms that are found in rivers, seas and other water bodies (Bakhtiyar *et al.*, 2020). Because of their short life cycle and rapid responses to various environmental changes, zooplankton serve as potential bioindicators for water quality and climate change assessment (Ferdous and Muktedir, 2009). Spatial variation refers to differences in the environment from place to place such as variations in climates, topography, soil type, water temperature, etc. Temporal variation, on the other hand, refers to changes in environment over time such as day-night, seasons, temperature, precipitation, droughts, fires, etc. (Pinel-Alloul, 1995). Zhou *et al.* (2023) highlighted that flood can influence both the physico-chemical factors of a water body and the zooplankton community. In their study on Huayanghe Lake, they observed that during the flood, the number of rotifer species burgeoned while the abundance of cladoceran and copepod species ebbed. Furthermore, floods reduced the average density and biomass of zooplankton (Zhou *et al.*, 2023). Changes in lake water levels caused by flooding can alter the structure zooplankton communities. For instance, fluctuations in water levels may greatly affect plankton biomass and species composition by disturbing the stability of the plankton community (Zhou *et al.*, 2023). The phenomenon of post-monsoon or autumn peaks in zooplankton growth that is observed in tropical rivers is intricately associated with the “flood pulse concept” proposed by Junk *et al.* (1989). According to the flood pulse concept, the annual flooding in tropical rivers plays an important role in shaping the ecosystem dynamics. During the flood season, the river structure becomes undifferentiated, facilitating an exchange of water, nutrients, and organisms between the surrounding areas and the river—a phenomenon prevalent in large tropical river systems, where the flood pulse is a predictable and vital component of the ecosystem (Junk, 2001; Sleen & Rams, 2023). In a study on the seasonal distribution of zooplankton composition and abundance in a sub-tropical mangrove and salt marsh estuary, Hena *et al.* (2016) observed that, among plankton groups, copepods were the most abundant, and their richness was influenced by rainfall, temperature, and transparency. While zooplankton are mostly associated with surface and mid-level water dynamics, macrobenthos-organism that live in or near the bottom of waterbodies-play an equally important role in giving a comprehensive assessment of an environment (Hena *et al.*, 2016).

According to Tagliapietra & Sigovini (2010), macrobenthos are benthic creatures larger than 0.5-1 mm that inhabit bottom substrates of aquatic environments and are usually retained by standard sieves during sampling. Benthic community are classified as a different group from meiobenthos and microbenthos based on body size, a system of classification commonly used in benthic studies. Macrobenthos play an integral role in an environment by cycling nutrients, decomposing organic matter and mixing sediment layers, commonly known as bioturbation (Covich *et al.*, 1999). Additionally, they also contribute to energy flow and trophic dynamics within aquatic food webs. (Wallace & Webster, 1996). Like zooplankton, macrobenthos also serve as effective bioindicators, as they have limited mobility, relatively long-life cycles and varying tolerance to pollutants, thereby helping to assess an aquatic ecosystem comprehensively (Hellawell, 1986). They observed that community structure and the role of soil microorganisms are intrinsically linked to variations in the environmental conditions.

Despite the zooplankton and macrobenthic communities of lotic ecosystems have been studied extensively, their integrated seasonal responses to the hydrological disturbances induced by floods in tropical river systems of Bangladesh are poorly understood. In particular, the ecological dynamics and post-flood resilience of planktonic and benthic communities in the Feni River has not been well-defined. The aims of this study were to assess the spatio-temporal fluctuation of zooplankton and macrobenthos diversity and to comprehend their ecological responses to flood-induced physiological alterations.

MATERIALS AND METHOD

Study Area: The Feni River is a transboundary river originating in the hill ranges of South Tripura, India, and flowing for approximately 116 km before discharging into the Bay of Bengal in southeastern Bangladesh. The Feni River estuary is located at approximately 22°46'44" N and 91°22'42" E (Islam *et al.*, 2018). Three sampling locations (hereafter station) along the Feni River, S1-Muhuri Sluice Gate, S2-Dhumghat Bazar, and S3-Shuvopur Bridge (Fig. 1), were selected, and an annual survey was carried out to assess the spatial variation. The three stations were of varying extent and nature of environmental influences along the Feni River. S1 (Muhuri Sluice Gate) represented by hydraulically regulated environment associated with the Muhuri Project, while S2 (Dhumghat Bazar) was a relatively human-dominated riverbank influenced by settlement, commerce and agriculture. S3 (Shuvopur Bridge) was an open river-channel type with seasonally varying hydrological fluctuations and localized anthropogenic activities. Each sampling event covered a six-hour period, beginning at 10:00 a.m. and ending at 4:00 p.m. The study period was spaced into four seasons: pre-monsoon (March-May), monsoon (June–September), autumn (October–November), and winter (December–February). This region exhibits seasonal precipitation pattern, with rainfall occurring from June to November and a dry interval from December to May (Islam *et al.*, 2018). The mean annual precipitation is 3302 mm, while yearly temperature fluctuates between a maximum of 34.3 °C and a minimum of 14.4 °C (Miah *et al.*, 2015). The estuary, which flows into the Bay of Bengal, demonstrates salinity levels between 4.20 and 7.50 ppt, with an average of 5.78 ± 1.32 ppt (Miah *et al.*, 2015). The study area endures substantial precipitation and annually inundation, resulting in the formation of fertile alluvial plains adjacent to the Feni River. Consequently, the majority of catchment areas are suitable for the cultivation of both annual and perennial crops, such as rice, red pepper, potato, wheat, beans, bananas, tomato, sunflower, and sugarcane (Ahmed *et al.*, 2024).

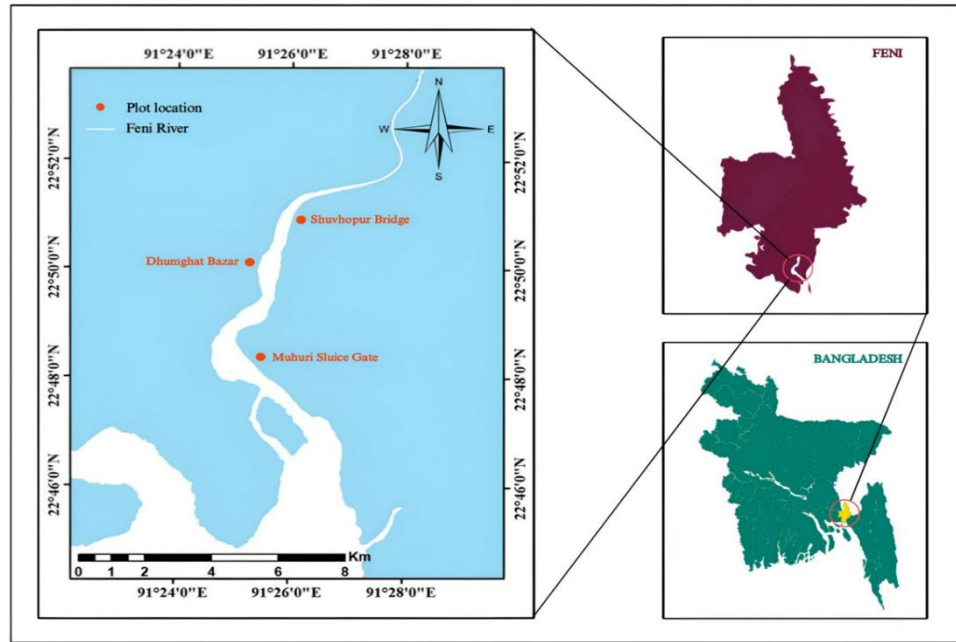


Fig.1. Sampling sites of Feni River

Sample collection, identification, and analysis: Zooplankton samples were collected with the help of a conical nylon plankton net (mesh size: 90 μm ; mouth diameter: 30 cm) by horizontal towing (~ 7 m). Five samples were taken from both littoral and sublittoral zones per station. After collection, samples were preserved in 70% alcohol and labelling with proper information. The samples were subsequently transferred to the laboratory for further analytical processing. Prior to microscope examination, each sample was gently stirred to ensure uniform distribution. Quantitative estimation of zooplankton was conducted using a Sedgwick-Rafter (S-R) counting chamber. From the homogenized sample, 1 ml was transferred into the S-R cell using a wide mouthed graduated pipette. Zooplankton species were then identified under a light microscope (Euromex microscope, OXION; NIS-EU1640407) at magnifications of 40x, and 100x. Identification was performed with the aid of standard taxonomic references (Dang *et al.*, 2015; Bhoyian & Asmat, 1992; Needham & Needham, 1927; Edmondson, 1959). The abundance was calculated using method (Rahman *et al.*, 1992):

$$N = \frac{A \times C \times 1000}{F \times V \times L}$$

Where, V = Volume of the Sedgwick Rafter cell field, F = Number of field count, C = Volume of final concentration of sample, A = Total no. of plankton counted, L = Volume of original water, N = Number of plankton cells per liter.

For the macrobenthic study, benthic organisms were collected using an Ekman grab sampler, and GPS was used to record station coordinates. Additional information was

obtained through informal interviews with local fishermen. Benthic diversity was assessed at the family level using the Shannon-Wiener Diversity Index (H') and Pielou's Evenness Index (J'). Specimen identification was carried out using relevant books and literature, including Needham and Needham (1927); Lenat (1993); Holomuzki *et al.*, (2010).

Diversity indices: Species diversity was calculated using the Shannon-Weiner Index (H') and Pielou's Evenness Index (J'):

$$\text{Shannon-Weiner Index } (H') = - \sum_{i=1}^S p_i \ln(p_i) \quad (\text{Shannon and Wiener, 1948})$$

Where p_i is the proportion of individuals belonging to the i^{th} species and 'S' is the total number of species. A higher H' indicates greater diversity.

Pielou's Evenness Index (J')

$$J' = \frac{H'}{\ln(S)} \quad (\text{Pielou, 1966})$$

Where, H' = Shannon-Weiner Index; S = total number of species (species richness), Which describes how evenly individuals are distributed among the species present.

RESULTS AND DISCUSSION

Zooplankton species composition: Among all zooplankton groups, copepods, rotifers, and cladocerans were observed in the present study. In total, 30 zooplankton species were documented, comprising 10 species of Copepoda belonging to 2 families and 4 genera; 15 species of Rotifera belonging to 4 families and 7 genera; 4 species of Cladocera belonging to 1 family and 3 genera (Table 1). In the pre-monsoon, autumn and winter seasons the most dominant group was Copepoda (55.6%, 52.0% and 52.0% respectively), while the least was Rotifera in pre-monsoon (9.1%) , autumn and winter (both are 16.0%). In contrast, in monsoon, the contribution of Rotifera was highest among all the zooplankton groups, constituting 45.8% of the zooplankton community and that of Cladocera was minimum at 17.6% (Table 2).

Table 1. List of zooplankton species recorded in the Feni River

Group	Family	Genus	Species (Bhouyain and Asmat, 1992)
Copepoda	Cyclopidae	<i>Cyclops</i>	<i>Cyclops vernalis</i>
			<i>Cyclops strennus</i>
			<i>Cyclops sp.</i>
		<i>Diacyclops</i>	<i>Cyclops scutifer</i>
			<i>Cyclops varicans</i>
			<i>Diacyclops thomasi</i>
	Diaptomidae	<i>Mesocyclops</i>	<i>Mesocyclops hyalinus</i>
		<i>Diaptomus</i>	<i>Mesocyclops leuckarti</i>
			<i>Diaptomus gracilis</i>
Rotifera	Brachionidae	<i>Brachionus</i>	<i>Diaptomus thomasi</i>
			<i>Brachionus diversicornis</i>
			<i>Brachionus falcatus</i>
			<i>Brachionus forficula</i>
			<i>Brachionus caudatus</i>
			<i>Brachionus quadridentatus</i>
		<i>Plationus</i>	<i>Brachionus nilsoni</i>
			<i>Brachionus bidentatus</i>
			<i>Brachionus rubens</i>
			<i>Plationus patulus</i>
	Philodinidae	<i>Keratella</i>	<i>Keratella valga</i>
			<i>Keratella cochlearis</i>
	Testudinellidae	<i>Rotaria</i>	<i>Rotaria neptuna</i>
		<i>Testudinella</i>	<i>Testudinella patina</i>
	Notommatidae	<i>Filinia</i>	<i>Filinia camascela</i>
		<i>Monostyla</i>	<i>Monostyla bulla</i>
Cladocera	Daphnidae	<i>Moina</i>	<i>Moina brachiate</i>
		<i>Daphnia</i>	<i>Moina micrura</i>
			<i>Daphnia galeata</i>
			<i>Ceriodaphnia laticaudata</i>

Table 2. Percentage composition of zooplankton groups by seasons and stations

Season	Station	Rotifera (%)	Cladocera (%)	Copepoda (%)
Pre-monsoon	S1	9.1	36.4	54.5
	S2	11.1	33.3	55.6
	S3	13.0	39.1	47.8
Monsoon	S1	45.8	20.8	33.3
	S2	41.2	23.5	35.3
	S3	41.2	17.6	41.2
Autumn	S1	17.2	37.9	44.8
	S2	22.2	25.9	51.9
	S3	16.0	32.0	52.0
Winter	S1	17.2	37.9	44.8
	S2	22.2	25.9	51.9
	S3	16.0	32.0	52.0

Abundance of total zooplankton

Season wise abundance of total zooplankton: A noticeable seasonal variation in the zooplankton abundance in the Feni River was observed, ranging from 735,706 ind./m³ in winter to a peak of 1,343,061 ind./m³ in autumn, contributing 18.19% to 33.21% of annual totals, respectively. Pre-monsoon and monsoon contributed 25.91% and 22.69% (Table 3).

Table 3. Seasonal zooplankton abundance and composition in the Feni River

Season	Total Abundance (ind./m ³)	% composition
Pre-monsoon	1047546.32	25.91
Monsoon	917331.165	22.69
Autumn	1343061.16	33.21
Winter	735706.38	18.19

Station-wise abundance and composition of zooplankton: Spatially, Station 1 (S1) showed the highest average abundance (363,847 ind./m³) and richness ($H' = 1.80\text{--}2.42$), while Station 2 (S2) recorded the lowest (278,489 ind./m³) but maintained stable evenness ($J' = 0.86\text{--}0.90$). Station 3 (S3) had moderate abundance (305,610 ind./m³) but the highest diversity ($H' = 1.72\text{--}2.25$) and evenness ($J' = 0.88\text{--}0.94$), reflecting greater ecological stability (Table 4).

Table 4. Station-wise abundance and composition of zooplankton in the Feni River

Station	Avg. Abundance (ind/m ³)	% Contribution	Diversity (H') Range	Evenness (J') Range
S1	363847.805	38.39	1.80-2.42	0.86-0.89
S2	278489.09	29.38	1.68-2.30	0.86-0.90
S3	305610.2	32.23	1.72-2.25	0.88-0.94

Taxa-Season wise abundance of zooplankton: Copepods dominated across all seasons, with peak abundance (52.48%) during pre-monsoon, while Rotifera displayed a sharp rise in monsoon (37.85%) and winter (33.75%). Cladocera remained comparatively low, especially during monsoon and winter (Table 5).

Table 5. Taxa-season wise abundance of total zooplankton at three stations of the Feni River

Taxa/ Season	Pre-monsoon	Monsoon	Autumn	Winter
Copepoda (%)	52.48	41.42	49.38	46.00
Cladocera (%)	36.42	20.73	33.33	20.24
Rotifera (%)	11.10	37.85	17.29	33.75

Zooplankton species diversity across stations and seasons: Across the three sampling stations, a seasonal variation in zooplankton species diversity was documented. While Station 3 (S3) consistently maintained a high diversity (H' up to 2.25 in pre-monsoon), Station 2 (S2) showed more stable but moderate values ($H' = 1.68\text{--}2.30$). However, diversity at Station 1 (S1) reached its highest point in autumn ($H' = 2.42$), exhibiting a clear

seasonal increase. Evenness remained high ($J' > 0.85$) throughout the study period, in which S2 showed the most uniform distribution ($J' = 0.90$ in three seasons). A slight drop was noticed at S3 during monsoon ($J' = 0.88$) whereas evenness was relatively consistent during the winter across all sites (Table 6).

Table 6. Shannon–Weiner Diversity Index (H') and Pielou’s Evenness Index (J') of zooplanktons across stations and seasons in the Feni River

Station	Pre-monsoon		Monsoon		Autumn		Winter	
	(H')	(J')	(H')	(J')	(H')	(J')	(H')	(J')
S1	1.80	0.86	2.15	0.86	2.42	0.89	1.86	0.89
S2	1.68	0.86	1.75	0.90	2.30	0.90	1.75	0.90
S3	2.25	0.94	1.72	0.88	2.15	0.90	2.05	0.89

Changes in Zooplankton Abundance (Before and After Flood): Comparative data from pre-monsoon and monsoon sampling (Fig. 2) clearly portends that the August 2024 monsoon flood significantly altered zooplankton community structure in the Feni River. During the pre-monsoon period (May 2024), the Feni River showed a higher abundance of copepods (52.48%) and cladocerans (36.42%), indicated by total zooplankton densities reaching approximately 1,047,546 ind./m³ across three sampling sites. However, in the aftermath of the monsoon flood period (September 2024), there was a conspicuous shift, in which rotifers emerged as the dominant taxon (55.60%), and overall zooplankton density decreased to around 892,656 ind./m³ (Fig. 2).

In addition to the zooplankton community, the seasonal variation and bottom-dwelling diversity of macrobenthos were also studied. In pre-monsoon, 57 individuals belonging to 17 families were recorded (Table 7). The Shannon Diversity Index (H') was 2.6445 and the Pielou’s Evenness Index (J') was 0.9334 (Table 8). Channidae emerged as the most abundant family with 7 individuals. The least abundance was recorded equally across multiple families, each represented by a single individual (Table 7). A total of 43 individuals, representing 17 families (Table 7), were observed during the monsoon season. The Shannon Diversity Index (H') stood at 2.5704, and the Evenness Index (J') during this period was 0.9072 (Fig. 3). Among the identified families, Notopteridae was found to be the most abundant, represented by 8 individuals, while the least abundant families were each represented by a single individual (Table 7).

During autumn, 59 individuals were documented across 17 families (Table 7). The Shannon Diversity Index (H') was 2.6106, and the Evenness Index (J') was 0.9214 (Fig 3). Siluridae turned out to be the most diverse family with 9 individuals, whereas several other families showed the lowest abundance, each with a single individual recorded (Table 7). A total of 60 individuals, representing 20 benthic families, were noted in the winter (Table 7). The Shannon Diversity Index (H') was 2.7699, while the Evenness Index (J') was 0.9246 (Fig 3). Notopteridae was the most abundant family, with 8 individuals, whereas several families were least abundant, each represented by only one individual (Table 7). Throughout the study period, a total of 38 benthic organisms could not be identified or associated with any family. These specimens were excluded from the diversity calculation.

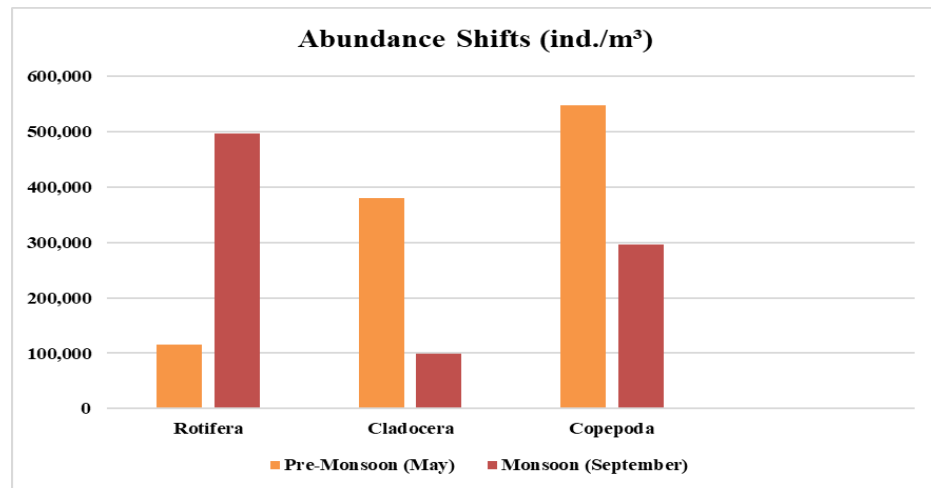


Fig. 2. Abundance shifts (ind./m³) before (Pre-monsoon, May) and after (Monsoon September) flood

Table 7. Abundance of macrobenthos and their subsequent calculation

Season	Pre-monsoon			Monsoon			Autumn			Winter		
Family (Edmondson, 1959)	Abundance (n)	pi	$\ln pi$	Abundance(n)	pi	$\ln pi$	Abundance(n)	pi	$\ln pi$	Abundance(n)	pi	$\ln pi$
Penaeidae	5	0.09	-2.43	2	0.05	-3.07	4	0.07	-2.69	2	0.03	-3.4
Palaemonidae	0	0	0	1	0.02	-3.76	1	0.02	-4.08	1	0.02	-4.09
Portunidae	0	0	0	0	0	0	5	0.08	-2.47	3	0.05	-3
Naididae	2	0.04	-3.35	2	0.05	-3.07	0	0	0	2	0.03	-3.4
Nereididae	1	0.02	-4.04	1	0.02	-3.76	2	0.03	-3.38	1	0.02	-4.09
Syllidae	3	0.05	-2.94	4	0.09	-2.37	1	0.02	-4.08	4	0.07	-2.71
Heteropneustidae	6	0.11	-2.25	0	0	0	1	0.02	-4.08	7	0.12	-2.15
Glyceridae	1	0.02	-4.04	2	0.05	-3.07	0	0	0	2	0.03	-3.4
Mysidae	6	0.11	-2.25	6	0.14	-1.97	0	0	0	6	0.1	-2.3
Siluridae	5	0.09	-2.43	1	0.02	-3.76	9	0.15	-1.88	1	0.02	-4.09
Gobiidae	1	0.02	-4.04	1	0.02	-3.76	0	0	0	1	0.02	-4.09
Lumbrineridae	0	0	0	2	0.05	-3.07	1	0.02	-4.08	2	0.03	-3.4
Mugilidae	4	0.07	-2.66	0	0	0	3	0.05	-2.98	5	0.08	-2.48
Megascolecidae	2	0.04	-3.35	2	0.05	-3.07	4	0.07	-2.69	2	0.03	-3.4
Oxudercidae	0	0	0	1	0.02	-3.76	4	0.07	-2.69	3	0.05	-3
Notopteridae	0	0	0	8	0.19	-1.68	0	0	0	8	0.13	-2.01
Anguillidae	5	0.09	-2.43	5	0.12	-2.15	5	0.08	-2.47	5	0.08	-2.48
Bagridae	4	0.07	-2.66	3	0.07	-2.66	3	0.05	-2.98	3	0.05	-3
Naticidae	1	0.02	-4.04	1	0.02	-3.76	1	0.02	-4.08	1	0.02	-4.09
Capitellidae	1	0.02	-4.04	1	0.02	-3.76	5	0.08	-2.47	1	0.02	-4.09
Dorosomatidae	3	0.05	-2.94	0	0	0	2	0.03	-3.38	0	0	0
Channidae	7	0.12	-2.1	0	0	0	8	0.14	-2	0	0	0
Total	57			43			59			60		



Fig. 3. Shannon-Weiner and Pielou's evenness indices of macrobenthos

From table 5, the results clearly show that during the pre-monsoon season, Copepoda was the most dominant group, representing 52.48% of the total composition, followed by Cladocera (36.42%) and Rotifera (11.10%). This pattern reflects stable hydrological conditions, consistent with the findings of Hena *et al.* (2016), who reported copepods was the most abundant group during dry seasons owing to optimal water quality, temperature, and low turbulence. The lower proportion of rotifers indicates a stable and well-structured community. Additionally, Shannon Diversity Index ($H' = 1.68 - 2.25$), and high evenness ($J' > 0.85$), suggest that the ecosystem was comparatively in equilibrium prior to the onset of flooding (Table 6). Similar observations were reported by Nielsen *et al.* (2002), who found that stable hydrological conditions in floodplain ecosystem supports relatively structure zooplankton communities with balanced taxonomic composition. Likewise, Khalifa *et al.* (2024) documented the dominance of Copepoda during the pre-flood in Lake Nasser, Egypt emphasizing the importance of stable environmental conditions in maintaining copepod abundance and community stability.

A marked change in zooplankton composition was observed during the monsoon. Although the Copepoda remained the dominant group, its contribution decline from 52.48% in the pre-monsoon period to 41.42% during the monsoon, whereas Rotifera increased from 11.10% to 37.85% (Table 5). The post-flood comparison further showed a pronounced increase in Rotifera, which became the dominant group after August 2024 flood (Fig. 2). Following the August flood, the sharp increase in Rotifer abundance suggested an opportunistic response to post-flood conditions, such as an elevated nutrient concentrations and sediment loads. In contrast, Cladocera, which accounted for 20.73% of the population, showed a decline (Table 5), possibly due to physical displacement and sediment clogging. Previous studies have reported similar community shifts triggered by floods. For instance,

Zhou *et al.* (2023) found that flooding can cause changes in the structure of zooplankton communities, which may be detrimental for larger zooplankton like cladocerans and copepods and beneficial for opportunistic species like rotifers. They also observed that there were more occurrences of high levels of total nitrogen, total phosphorus and chlorophyll-a concentrations under extreme water-level fluctuation than under water-level stability (Boon *et al.*, 1994; Zhou *et al.*, 2023). Nielsen *et al.* (2002) similarly demonstrated that flooding alters zooplankton abundance primarily through changes in the relative densities of existing taxa rather than complete species replacement, resulting in temporary restructuring of community composition. Comparable flood-induced shifts were also reported by Khalifa *et al.* (2024), who observed significant modifications in zooplankton assemblages following fluctuations in water level and associated physicochemical parameters. Moreover, the slight decrease in evenness ($J' = 0.88$) observed at station 3 could be attributed to the temporary dominance of certain rotifer species (Table 6).

The drifting zooplankton population rebounded during the post-flood autumn period, reaching its peak abundance at 1,343,061.16 ind./m³ (Table 3). During this season, copepods reemerged as the dominant group, accounting for (49.38%), while the cladoceran population increased sharply to (33.33%) (Table 5), likely as a result of reduced water turbidity and improved nutrient availability. Although the rotifer surged immediately after the flood, their overall population declined to 17.29%, (Table 5) signaling the recolonization phase of the flood pulse concept by the larger-bodied taxa (Junk *et al.*, 1989). Diversity reached its highest level during this period ($H' = 2.42$ at Station 1), and evenness remained uniformly high ($J' = 0.89$ – 0.90) (Table 6). These patterns are consistent with the findings of Sleen & Rams (2023), who emphasized the role of post-flood succession in tropical river ecosystems. The resurgence of cladocerans may also indicate improved microhabitat conditions. A similar post-flood recovery pattern was described by Nielsen *et al.* (2002), who emphasized the importance of recruitment and recolonization processes in restoring zooplankton populations following hydrological disturbances. Likewise, Khalifa *et al.* (2024) observed gradual re-establishment of zooplankton communities during the post-flood period as environmental conditions stabilized.

In the final phase of the study period i.e., winter, zooplankton abundance declined to its lowest level. Nonetheless, Rotifera increased again (33.75%) (Table 5), possibly due to their ability to withstand lower temperature and persist in less productive environment environments. In contrast, cladoceran abundance decreased by 20.24% (Table 5), potentially reflecting seasonal reductions in food availability and changes in water temperature, both of which can influence cladoceran population dynamics in freshwater ecosystems (Adamczuk, 2024). Evenness remained high and consistent across all sites ($J' > 0.89$), despite a slight decline in richness (Table 6). This suggests that the aquatic ecosystem remained comparatively stable during this period.

The seasonal patterns described above strengthen the case for the ecological role of the flood pulse as both a disturbance and a renewal mechanism. Floods can cause partial loss of vegetation by altering the growth and spatial distribution of aquatic plants (Ge *et al.*,

2018). Consequently, the habitat options of zooplanktons restricted, making them more susceptible to fish predation and less able to maintain ecosystem stability (Sun and Arnott, 2022). Following the flood, the sharp increase in rotifer abundance, coupled with a decline in the cladoceran and copepod populations, suggests that different zooplankton taxa respond differently to flood disturbances. Rotifers, with their rapid dominance display rapid life cycles and strong environmental adaptability, can quickly resume reproduction and regain dominance after flooding events (Zhang, 2021). In contrast, cladocerans and copepods, which have comparatively longer growth cycles, are more vulnerable to rapid rises in water level. Their dominance declines because they are often washed away by water before reaching maturity (Paidere, 2009). These findings support the conclusion of Nielsen *et al.* (2002), who identified flooding as a major ecological process regulating zooplankton succession and community organization in floodplain waters. Similarly, Khalifa *et al.* (2024) highlighted the importance of flood regimes in shaping zooplankton abundance, diversity, and spatial distribution in freshwater ecosystems.

The zooplankton community of the Feni River exhibited clear signs of disturbance immediately after the flood, followed by structural recovery in autumn and stabilization during winter-patterns, consistent with flood pulse concept of Junk *et al.* (1989) and the succession model proposed by Zhou *et al.* (2023). Alongside the zooplankton assessment, macrobenthic diversity was also examined to obtain a holistic understanding of the riverbed dynamics. During the pre-monsoon season, the Shannon Diversity Index ($H' = 2.6445$) and Evenness Index ($J' = 0.9334$) were recorded (Fig 3), with a total of 57 individuals belonging to 17 macrobenthic family (Table 7). This relatively low diversity could be attributed to increased water temperatures and reduced dissolved oxygen levels, conditions that hinder growth. Similar seasonal declines in benthic diversity during pre-monsoon have been reported in the Zuari estuary (Sivadas *et al.*, 2011), where warmer conditions influenced community structure. The lowest diversity of benthos was observed during the monsoon, where H' and J' reached 2.7699 and 0.9246 respectively (Fig. 3). The decline in benthic abundance in the present study associated with the monsoon flooding of the Feni River. Comparable responses were documented by Khalifa *et al.* (2024), who reported significant changes in macrobenthic abundance and community composition following flood events, emphasizing the sensitivity of benthic organisms to hydrological disturbances and habitat modification.

Post-monsoon, a slight increase in benthic organisms indicated stabilization of conditions and community recovery. In autumn, Shannon Diversity Index (H') was 2.6106, and Evenness Index (J') was 0.9214 (Fig 3), with 59 individuals from 17 families (Table 7). Similar pos-monsoon increases in benthic diversity were reported in the Cochin estuary (Rehitha *et al.*, 2022) and linked to improved habitat quality, while Sivadas *et al.* (2011), attributed such patterns to enhanced recruitment and reduced stressors. The recovery macrobenthic community observed in the present study is also comparable to the post-flood re-establishment of macrobenthic communities reported by Khalifa *et al.* (2024), suggesting that stabilization of environmental conditions promotes recolonization and community development.

In the final study period during the seasonal shift toward winter, abundance peaked with the highest Shannon Diversity Index ($H' = 2.7699$) and a high Evenness Index ($J' = 0.9246$) (Fig. 3), represented by 60 individuals belonging to 20 families (Table 7). Stabilization of water flow and sediment, optimal salinity, and elevated dissolved likely supported macrobenthic growth. Similar winter peaks were reported by Negi and Mamgain (2013) in the Tons River, attributed to higher dissolved concentrations and reduced temperature. The findings demonstrate clear season-dependent variations in macrobenthic diversity and community composition in the Feni River. Shannon-Wiener Index (H') values ranged from 2.57 to 2.77, while Pielou's Evenness Index (J') values ranged from 0.9071 and 0.9318 (Fig 3), indicating moderate diversity with a relatively even distribution across families. Despite seasonal fluctuations, these values reflect a stable and ecologically balanced benthic community throughout the year. The responses of both zooplankton and macrobenthic organisms show that flooding not only is a disturbance but also serve as an essential component of the ecological process which contributes to succession, community rejuvenation, and biodiversity conservation. The consistency in results obtained in this study and by Nielsen *et al.* (2002); Khalifa *et al.* (2024), and others provides additional evidence of the key role played by hydrological variability in determining the ecology of freshwaters.

Conclusion: Since limited information is available, present study was conducted to gain a comprehensive understanding of how plankton and macrobenthic communities interact and fluctuate within the Feni River ecosystem. Overall, Copepoda was the dominant group across most seasons, while Rotifera showed their highest abundance during the monsoon, suggesting flood-driven disturbance. Zooplankton diversity and abundance peaked in autumn, with the outcomes aligning with the flood-pulse concept. Similarly, macrobenthic diversity was highest in winter, indicating a moderately stable and balanced community. Given their essential ecological roles, it is recommended that zooplankton and macrobenthos be monitored seasonally for effective ecosystem assessment and management. Although the seasonal sampling design provided a useful baseline, it may not have fully captured short-term flood responses and their environmental drivers. Long-term, high-frequency monitoring of hydrological, physicochemical and biological parameters is therefore needed to better understand ecosystem resilience and strengthen adaptive management of the Feni River.

REFERENCES

- Adamczuk, M. 2024. The responses of cladoceran communities to the single and simultaneous effects of environmentally relevant increases in temperature and phosphorus concentration in freshwater ecosystems. *Water*. **16**(2):249. <https://doi.org/10.3390/w16020249>
- Ahmed, M. M., Nur, A. A. U., Sultana, S., Jolly, Y. N., Paray, B. A., Arai, T. and Hossain, M. B. 2024. Risk assessment and sources apportionment of toxic metals in two commonly consumed fishes from a subtropical estuarine wetland system. *Biology*. **13**(4): 260. <https://doi.org/10.3390/biology13040260>
- Bakhtiyar, Y., Arafat, M. Y., Andrabi, S. and Tak, H. I. 2020. Zooplankton: The significant ecosystem service provider in aquatic environment. In *Bioremediation and Biotechnology*. **3**: 227-244. https://doi.org/10.1007/978-3-030-46075-4_10

- Bhouyain, A.M. and Asmat, G.S.M. 1992. Freshwater zooplankton from Bangladesh (1st ed.). Ghazi publishers, Banglabazar, Dhaka. Pp.137.
- Boon, P. I., Bunn, S. E., Green, J. D. and Shiel, R. J. 1994. Consumption of cyanobacteria by freshwater zooplankton: Implications for the success of “top-down” control of cyanobacterial blooms in Australia. *Marine and Freshwater Research*. **45**(5): 875–887. <https://doi.org/10.1071/MF9940875>
- Covich, A. P., Palmer, M. A. and Crowl, T. A. 1999. The role of benthic invertebrate species in freshwater ecosystems. *BioScience*. **54**(2): 119–127. <https://doi.org/10.2307/1313537>
- Dang, P.D, Khoi, N.V., Nga, L. T.N., Thanh, D. N. and Thanh, H.H. 2015. Identification handbook of freshwater zooplankton of the Mekong River and its tributaries. Mekong River Commission, Vientiane. Pp.207
- Edmondson, W.T. 1959. Freshwater Biology. 2nd Edition, John Wiley and Sons Inc., New York. Pp.1248
- Ferdous, Z. and Muktadir, A. K. M. 2009. A review: Potentiality of zooplankton as bioindicator. *American Journal of Applied Sciences*, **6**(10): 1815–1819. <https://doi.org/10.3844/ajassp.2009.1815.1819>
- Ge, Y. W., Zhang, K. and Yang, X. D. 2018. Long-term succession of aquatic plants reconstructed from palynological records in a shallow freshwater lake. *Science of the Total Environment*. **643**: 312–323. <https://doi.org/10.1016/j.scitotenv.2018.06.190>
- Hellawell, J. M. 1986. Biological indicators. In Biological indicators of freshwater pollution and environmental management. Dordrecht: Springer Netherlands. Pp. 45-77. <https://doi.org/10.1007/978-94-009-4315-53>
- Hena, M. K. A., Sidik, J. B., Idris, M. H., Johan, I., Nesarul, N. H., Aysha, A. and Islam, M. S. 2016. Seasonal distribution of zooplankton composition and abundance in a sub-tropical mangrove and salt marsh estuary. *Malaysian Journal of Science*. **35**(2): 257–270. <https://doi.org/10.22452/mjs.vol35no2.13>
- Holomuzki, J. R., Feminella, J. W. and Power, M. E. 2010. Biotic interactions in freshwater benthic habitats. *Journal of the North American Benthological Society*. **29**(1): 220-244. <https://doi.org/10.1899/08-044.1>
- Islam, M. S., Hossain, M. B., Matin, A. and Sarker, M. S. I. 2018. Assessment of heavy metal pollution, distribution and source apportionment in the sediment from Feni River estuary, Bangladesh. *Chemosphere*. **202**: 25-32. <https://doi.org/10.1016/j.chemosphere.2018.03.077>
- Jannah, M. R., Saha, D., Bappy, M. M. M., Nur, A. A. U., Banik, P., Albeshr, M. F. and Hossain, M. B. 2024. Macrobenthos community responses to tidal barrier in a sub-tropical river estuary: Insights for coastal management. *Regional Studies in Marine Science*. **79**: 103842. <https://doi.org/10.1016/j.rsma.2024.103842>
- Junk, W. J. 2001. The flood pulse concept of large rivers: Learning from the tropics. In *Proceedings of the International Association of Theoretical and Applied Limnology*. **27**(7): 3950-3953. <https://doi.org/10.1080/03680770.1998.11901733>
- Junk, W. J., Bayley, P. B. and Sparks, R. E. 1989. The flood pulse concept in river-floodplain systems. *Canadian Special Publication of Fisheries and Aquatic Sciences*. **106**: 110–127. <http://www.dfo-mpo.gc.ca/Library/111846.pdf>
- Khalifa, N., Abdel Gawad, S. S., Gaber, K. M., Abdelhameed, M. S. and Ibrahim, S. M. 2024. Impact of Flood Regime on Zooplankton and Macrobenthos of Lake Nasser. *Egyptian Journal of Aquatic Biology & Fisheries*. **28**(6): 185. <http://doi.org/10.21608/ejabf.2024.391044>
- Lenat, D. R. 1993. Freshwater biomonitoring and benthic macroinvertebrates. *Journal of the North American Benthological Society*. **12**(2): 220–222. <https://doi.org/10.2307/1467358>
- Miah, M. Y., Robel, F. N., Bhowmik, S., Bhattacharjee, S., Paul, S. C., Hossain, M. J. and Hossain, M. Z. 2015. Assessment of the coastal area water quality in Noakhali, Bangladesh. *International Journal of Scientific and Engineering Research*. **6**(2): 1116-1123.

- Needham, J. G. and Needham, P. R. 1927. A guide to the study of fresh-water biology. American viewpoint society, Incorporated. Pp.88.
- Negi, R. K. and Mamgain, S. 2013. Seasonal variation of benthic macroinvertebrates from Tons River of Garhwal Himalaya, Uttarakhand. *Pakistan Journal of Biological Sciences*. **16**(24): 1510–1516. <https://doi.org/10.3923/pjbs.2013.1510.1516>
- Nielsen, D. L., Hillman, T. J., Smith, F. J. and Shiel, R. J. 2002. The influence of seasonality and duration of flooding on zooplankton in experimental billabongs. *River Research and Applications*. **18**(3): 227–237. <https://doi.org/10.1002/rra.641>
- Paidere, J. 2009. Influence of flooding frequency on zooplankton in the floodplains of the Daugava River (Latvia). *Acta Zoologica Lituanica*. **19**: 306–313. <https://doi.org/10.2478/v10043-009-0036-1>
- Pielou, E. C. 1966. Species-diversity and pattern-diversity in the study of ecological succession. *Journal of Theoretical Biology*. **10**(2): 370–383. [https://doi.org/10.1016/00225193\(66\)90133-0](https://doi.org/10.1016/00225193(66)90133-0)
- Pinel-Alloul, B. 1995. Spatial heterogeneity as a multiscale characteristic of a zooplankton community. *Hydrobiologia*. **300**: 17–42. <https://doi.org/10.1007/BF00024445>
- Rahman, M. M., and Hasan, M. R. 1992. A study on fish and fisherman of Kaptai lake. *Bangladesh Agricultural University Research Progress*, Bangladesh Agricultural University, Bangladesh. Pp.495-503.
- Rehitha, T. V., Vineetha, G. and Madhu, N. V. 2022. Ecological habitat quality assessment of a tropical estuary using macrobenthic functional characteristics and biotic indices. *Environmental Science and Pollution Research*. **29**: 47629–47646. <https://doi.org/10.1007/s11356-022-19295-8>
- Shannon, C. E. and Wiener, W. 1948. A mathematic theory of communication. *Bell Syst. Tech. J.* **27**(3): 379–423.
- Sivadas, S., Ingole, B. and Nanajkar, M. 2011. Temporal variability of macrofauna from a disturbed habitat in Zuari estuary, west coast of India. *Environmental Monitoring and Assessment*. **173**(1): 65–78. <https://doi.org/10.1007/s10661-010-1371-1>
- Sleen, P. V. D. and Rams, M. 2023. Flood pulses and fish species coexistence in tropical rivers – A theoretical food web model. *Environmental Biology of Fishes*. **106**(8): 1785–1796. <https://doi.org/10.1007/s10641-023-01458-2>
- Sun, X. Y. and Arnott, S. E. 2022. Interactive effects of increased salinity and heatwaves on freshwater zooplankton communities in simultaneous and sequential treatments. *Freshwater Biology*. **67**(10): 1604–1617. <https://doi.org/10.1111/fwb.13990>
- Tagliapietra, D. and Sigovini, M. 2010. Benthic fauna: Collection and identification of macrobenthic invertebrates. *NEAR Curriculum in Natural Environmental Science*. **88**: 253–261.
- Wallace, J. B. and Webster, J. R. 1996. The role of macroinvertebrates in stream ecosystem function. *Annual Review of Entomology* **41**:115–139. <https://doi.org/10.1146/annurev.en.41.010196.000555>
- Zhang, Y. X. 2021. The effect of removing the fisher purse seine on zooplankton communities structure in the Huayanghe Lakes (Master's thesis, Anhui University, Hefei, China).
- Zhou, M., Zhou, Z. and Chen, W. 2023. Effects of floods on zooplankton community structure in the Huayanghe Lake. *Diversity*. **15**(2): 250. <https://doi.org/10.3390/d15020250>