

PLANKTON DIVERSITY OF TWO HILL RIVERS OF BANGLADESH

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Abstract: This study was made for one year and dealt with the phytoplankton and zooplankton of the rivers Halda and Karnaphuli with respect to their monthly variations, abundance, and diversity as determined by Shannon-Wiener diversity index and Evenness index for major taxa. A total of 23 and 18 genera belonging to five groups of phytoplankton (Blue green Algae, Green Algae, Non-motile green Algae, Desmids, and Diatoms) and a total of 16 and 13 genera belonging to four groups of zooplankton (Cladocera, Copepoda, Rotifera and Protozoa) were recorded in Halda and Karnaphuli rivers respectively. Monthly mean total numbers of phytoplankton varied from 13927/m³ to 197304/m³ and zooplankton from 21278/m³ to 86616/m³ in the Halda River, and from 11993/m³ to 99297/m³ phytoplankton and 15797/m³ to 92204/m³ zooplankton in the Karnaphuli River. Halda River was found to be richer in phytoplankton than the Karnaphuli River. The Shannon-Wiener diversity index (*H'*) for phytoplankton ranged from 0.00 to 1.85, that of zooplankton from 0.00 to 2.00, and the evenness (*J'*) of phytoplankton from 0.00 to 0.99 and of zooplankton from 0.00 to 1.00 in the Halda and Karnaphuli rivers, respectively. Diversity indices (*H'*) of these two rivers indicated poor to very poor water quality. Evenness values for both rivers indicated that community members were not distributed equally and that the water bodies were polluted.

Key words: Halda River, Karnaphuli River, Plankton, Diversity

INTRODUCTION

The study of the abundance and diversity of riverine phytoplankton and zooplankton is essential for understanding the ecological health and productivity of river ecosystems. The abundance and diversity of these plankton communities reflect the water quality, nutrient status, and environmental conditions of rivers. Changes in their composition can indicate pollution, eutrophication, habitat degradation, and the impacts of climate change. Moreover, the assessment of plankton diversity helps in evaluating the biological productivity of rivers, supporting fisheries management, and conserving aquatic biodiversity. Among

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the rivers in Chittagong, the Halda and Karnaphuli rivers are particularly important to Bangladesh's economy and fisheries sector. The Halda River is recognized as a unique natural spawning ground of major carps. It serves as the primary source of naturally collected carp eggs and fry for the country's aquaculture industry. In contrast, the Karnaphuli River supports the Kaptai Reservoir, the largest man-made freshwater reservoir in South Asia, which is utilized for hydroelectric power generation and fish production. Both rivers are tidal, and the Halda River is a major tributary of the Karnaphuli River (Azadi and Arshad-ul-Alam, 2013).

Despite their immense ecological and economic significance, limnological studies encompassing physico-chemical and biological aspects of the Halda and Karnaphuli rivers remain limited. Among the pioneering studies are the first academic investigations on the limnology of the Halda River and the spawning of major carps conducted by Azadi (1979), followed by studies on the limnology of the Halda River (Patra and Azadi, 1985a), factors influencing the spawning of major carps (Patra and Azadi, 1985b), and the ecology of planktonic organisms in the Halda River (Patra and Azadi, 1987). Subsequent notable studies include fisheries and environmental surveys of the Karnaphuli River estuary (Hossain *et al.*, 2007), investigations on the ichthyofauna of the Halda River (Azadi and Arshad-ul-Alam, 2013), assessment of heavy metal pollution in the Karnaphuli River (Ahmed *et al.*, 2016), evaluation of water quality in the Halda River (Islam *et al.*, 2020), studies on the ichthyodiversity of five interconnected rivers of Chattogram (Azadi and Arshad-ul-Alam, 2020), assessment of the role of the Karnaphuli River in the national economy of Bangladesh (Hossain *et al.*, 2021), and a checklist of zooplankton of the Halda River (Islam *et al.*, 2022).

Although different studies have addressed various ecological and fisheries-related aspects of these rivers, research on plankton abundance, diversity, and associated diversity indices remains scarce. Therefore, the present study was undertaken to generate additional information on the abundance, diversity, and indices of phytoplankton and zooplankton communities in the Halda and Karnaphuli rivers. The findings will be useful to the scientific understanding and sustainable fisheries management of these ecologically and economically important river systems.

MATERIAL AND METHODS

Study Area: Five sampling stations (St. 1–St. 5) were selected along the Halda and Karnaphuli rivers, covering approximately 38 km (Fig. 1). Monthly sampling was conducted from May 2010 to April 2011 to assess phytoplankton and zooplankton abundance and diversity.

The Halda River (22°30'-23°15' N, 88°15'-89°10' E), the largest tributary of the Karnaphuli River, was represented by three stations. Station 1 (Sattar Ghat), located in Hathazari Upazila, was characterized by a narrow channel (68 m wide), semidiurnal tidal influence, and high turbidity from sediment input. Approximately 12 km downstream, Station 2 (Ramdas Hat) had a wider channel (110 m), rooted aquatic vegetation along the western bank, seasonal floodplain inundation, and localized bank erosion. Further 8 km downstream, Station 3 (Moduna Ghat) was the widest Halda station (148 m) and was characterized by strong currents and persistently high turbidity.

The Karnaphuli River (21°45'-22°30' N, 88°45'-90°0' E) was represented by two stations in its lower reach. Station 4 (Kalurghat), located about 1 km downstream of the Halda–Karnaphuli confluence, was characterized by strong currents, intensive boat traffic, muddy intertidal banks, and active fisheries. Approximately 10 km downstream, Station 5 (Firingi Bazar Ferry Ghat) was situated near major municipal and industrial discharge points and represented the most polluted site, with heavy vessel traffic, high turbidity, and strong water currents throughout the year.

Sample Collection, Preservation, and Analysis: Plankton samples were collected monthly from each station throughout the study period using a plankton net (Hydro-Bios, Germany) with a mesh size of 55 μm . Sampling was conducted from a traditional wooden country boat (sampan). At each station, the net was towed at approximately 30 cm below the water surface over a distance of 7 m, then rapidly retrieved. This procedure was repeated three times at different locations within each station, yielding a total tow length of 21 m per station.

The volume of water filtered was calculated using the formula:

$V = \pi r^2 L$, where V is the volume of filtered water (m^3), r is the radius of the net mouth, and L is the total tow length. Plankton abundance was subsequently expressed as the number of individuals per cubic meter (m^3) of water filtered.

Immediately after collection, samples were preserved in 5 mL of commercial formalin and adjusted to a final volume of 100 mL, following APHA (2012). In the laboratory, each sample was thoroughly homogenized, and a 1 mL subsample was transferred using a wide-mouthed pipette into a Sedgewick–Rafter counting chamber (Model S50, England) for quantitative analysis.

Phytoplankton and zooplankton were enumerated under a binocular compound microscope. Each sample was examined in triplicate, and nine fields were counted during each examination from the 1,000-grid Sedgewick–Rafter cell. The mean counts obtained from the 1 mL subsample were used to estimate total plankton abundance, which was subsequently converted to individuals per cubic meter of river water.

Identification of plankton taxa was carried out following the keys and descriptions provided by Needham and Needham (1962), Edmondson (1992), Bhuiyan and Asmat (1992), Shiel (1995), APHA (2012), and Phan *et al.* (2015). The collected data were compiled, processed, and analyzed using Microsoft Excel 2013.

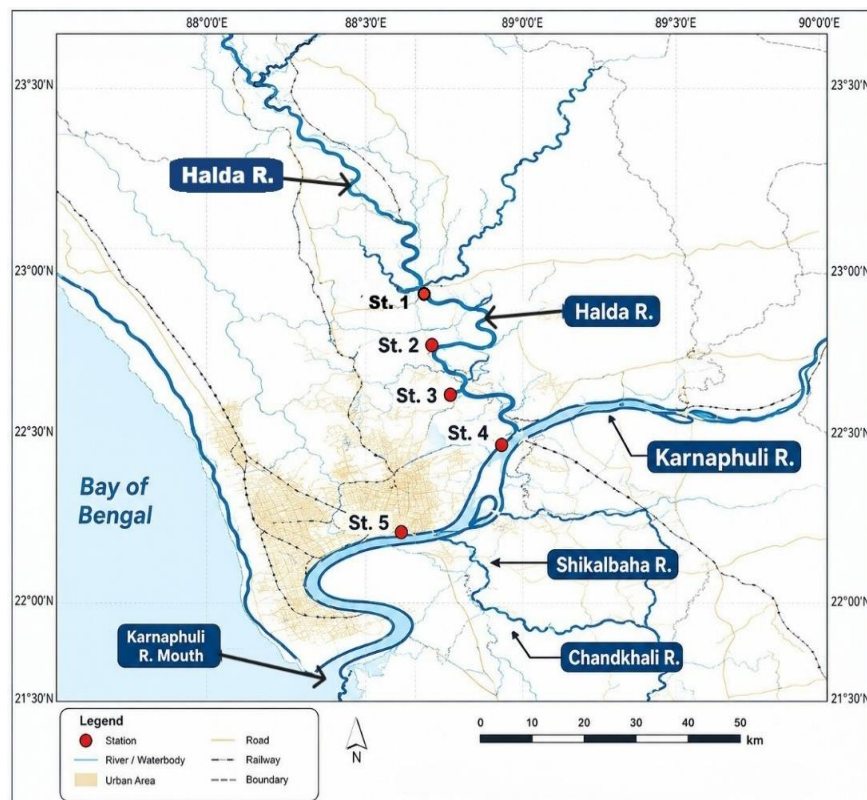


Fig. 1. Map showing the sampling stations at Halda (St. 1; St. 2, and St. 3) and Karnaphuli Rivers (St. 4 and St. 5).

Diversity Indices:

Genus Richness (S): The total number of unique genera identified in each sample was defined as the genus richness (S).

Maximum Shannon Diversity (H'_{max}): The maximum possible Shannon diversity for a given number of genera was calculated using the following formula, which is subsequently used to determine evenness:

$$H'_{max} = \ln S$$

Genus Diversity (H'): The Shannon-Wiener index was used to determine the genus diversity of plankton using the following formula: $H' = -\sum_{i=1}^S p_i \ln p_i$

Genus Evenness (J'): Pielou's evenness index (Pielou, 1966) was calculated using the following formula to express the distribution of individuals among the identified genera:

$$J' = \frac{H'}{H'_{\max}}$$

[Where, J' is the Evenness of individual allotment, H' is genus diversity and $H'_{\max}$ is the maximum Shannon diversity ($\ln S$)]. For specific sampling instances where only a single genus was present ($S=1$), the mathematical calculation of the formula yields an undefined ratio (0/0). These cases were operationally handled by assigning an evenness value of 0.00, as a single-genus community inherently lacks distribution equity among multiple taxa.

RESULTS AND DISCUSSION

Phytoplankton Abundance, Diversity and Evenness: Plankton communities are largely influenced by hydrodynamic conditions, with their distribution and abundance closely associated with water currents (Khan *et al.*, 2025). Phytoplankton constitute the primary producers of aquatic ecosystems and are widely recognized as reliable indicators of water quality (Nahid *et al.*, 2020; Islam, 2021). They form the foundation of aquatic food webs, linking nutrient dynamics to higher trophic levels, including zooplankton, fish, and other aquatic organisms (Lomartire *et al.*, 2021). In the Halda River, a unique spawning, nursery, and feeding ground for Indian major carps, plankton play a critical ecological role (Patra and Azadi, 1987).

During the study period (May 2010–April 2011), phytoplankton abundance exhibited marked temporal variation in both rivers. In the Halda River, the highest monthly mean abundance ($197,304 \pm 279,370$ individuals m^{-3}) was recorded in November 2010, whereas the lowest abundance ($13,927 \pm 10,059$ individuals m^{-3}) occurred in April 2011 (Fig. 2). In the Karnaphuli River, the highest mean abundance ($99,297 \pm 20,061$ individuals m^{-3}) was observed in July 2010 and the lowest ($11,993 \pm 2,736$ individuals m^{-3}) in April 2011 (Fig. 2). Similar seasonal patterns have been reported from Kaptai Lake and the Halda River (Islam, 2021; Khan *et al.*, 2025). The elevated phytoplankton abundance during the monsoon and post-monsoon periods likely resulted from increased nutrient inputs associated with surface runoff (Courboulès *et al.*, 2023). Spatially, Station 3 (Moduna Ghat) recorded both the highest ($519,180$ individuals m^{-3} in November 2010) and lowest ($3,869$ individuals m^{-3} in April 2011) phytoplankton abundances among the Halda River stations (Fig. 3). In the Karnaphuli River, the highest abundance ($136,952$ individuals m^{-3}) was recorded at Station 4 (Kalurghat) in February 2011, while the lowest abundance

(10,059 individuals m^{-3}) occurred at Station 5 (Firingi Bazar) in April 2011 (Fig. 4).

A total of 23 phytoplankton genera belonging to five major groups were identified in the Halda River, whereas 18 genera were recorded in the Karnaphuli River (Tables 1 and 2). In the Halda River, diatoms constituted the dominant group (34.78%), followed by blue-green algae, green algae, and non-motile green algae (17.39% each), and desmids (13.04%). Similarly, diatoms dominated the Karnaphuli River assemblage (33.33%), followed by blue-green algae and green algae (22.22% each), non-motile green algae (16.67%), and desmids (5.56%). The Halda River exhibited a comparatively higher phytoplankton abundance and supported a greater number of genera than the Karnaphuli River. This pattern may reflect the influence of pollution, as disturbed aquatic environments are often characterized by reduced species richness and the proliferation of a limited number of tolerant taxa (Anyinkeng *et al.*, 2016).

The Shannon–Wiener diversity index (H') indicated substantial temporal variability in phytoplankton diversity. In the Halda River, monthly mean H' values ranged from 0.70 ± 0.65 in August 2010 to 1.25 ± 0.37 in June 2010 (Fig. 5). In the Karnaphuli River, the lowest diversity was recorded in June and December 2010 ($H' = 0.49$), while the highest value (1.36 ± 0.24) occurred in January 2011 (Fig. 5). Overall, phytoplankton diversity varied between 0.00 and 1.85 in both rivers (Fig. 7). According to established Shannon–Wiener-based water quality classifications, H' values below 2 indicate poor to very poor ecological conditions (Ajayan and Ajitkumar, 2015; Anyanwu *et al.*, 2023). The consistently low diversity values observed in this study therefore suggest degraded water quality, likely associated with industrial discharges, municipal wastewater, and urban runoff entering both river systems (Islam, 2021).

The evenness (J') also exhibited considerable temporal variation. In the Halda River, monthly mean evenness ranged from 0.46 ± 0.23 in August 2010 to 0.90 ± 0.06 in May 2010 (Fig. 6). In the Karnaphuli River, values ranged from 0.49 in June and December 2010 to 0.96 ± 0.03 in March 2011 (Fig. 6). Overall, J' values varied between 0.30 and 0.99 in the Halda River and between 0.00 and 0.99 in the Karnaphuli River (Fig. 8). The observed fluctuations indicate uneven distribution of individuals among taxa and suggest varying degrees of environmental stress. According to Ren *et al.* (2011), low evenness values are commonly associated with increased pollution pressure and community dominance by a few tolerant species. The patterns recorded in both rivers therefore support the influence of organic pollution in the Halda River and industrial, municipal, and urban runoff in the Karnaphuli River (Islam, 2021).

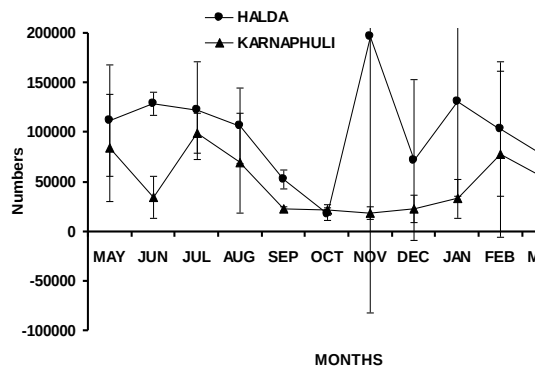


Fig. 2. Monthly variation in mean phytoplankton numbers ($\pm$ SD) in the Halda and Karnaphuli rivers from May 2010 to April 2011.

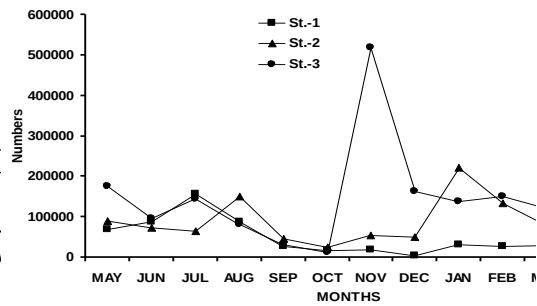


Fig. 3. Monthly variation in total phytoplankton abundance (m^{-3}) at stations 1, 2, and 3 of the Halda River during May 2010 to April 2011.

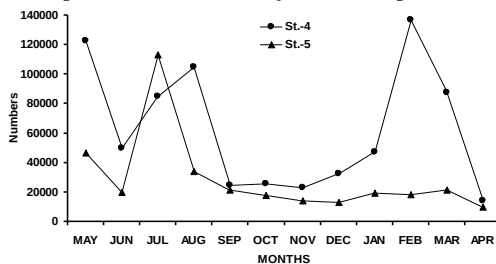


Fig. 4. Monthly variation in total phytoplankton abundance (m^{-3}) at stations 4 and 5 of the Karnaphuli River during May 2010 to April 2011.

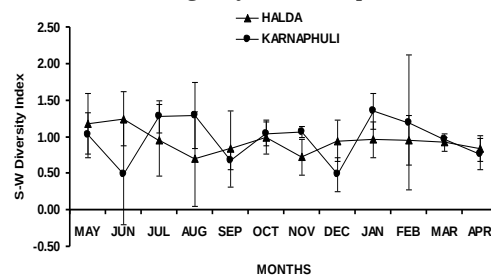


Fig. 5. Monthly variation in the mean Shannon-Wiener diversity index of phytoplankton ($\pm$ SD) at the Halda and Karnaphuli rivers from May 2010 to April 2011.

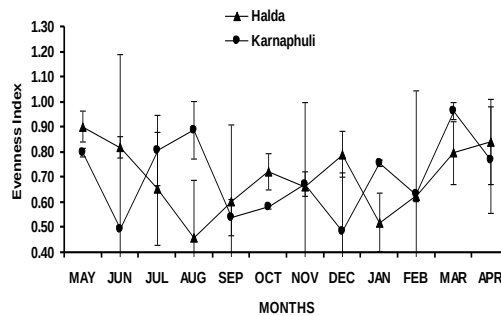


Fig. 6. Monthly variation in the mean Evenness index of phytoplankton ($\pm$ SD) in the Halda and Karnaphuli rivers from May 2010 to April 2011

Zooplankton Abundance, Diversity, and Evenness: Zooplankton abundance exhibited marked temporal and spatial variation in both rivers during the study period. In the Halda River, the highest monthly mean abundance ($86,616 \pm 33,876$ individuals m^{-3}) was recorded in April 2011, whereas the lowest ($21,278 \pm 13,084$ individuals m^{-3}) occurred in November 2010 (Fig. 9).

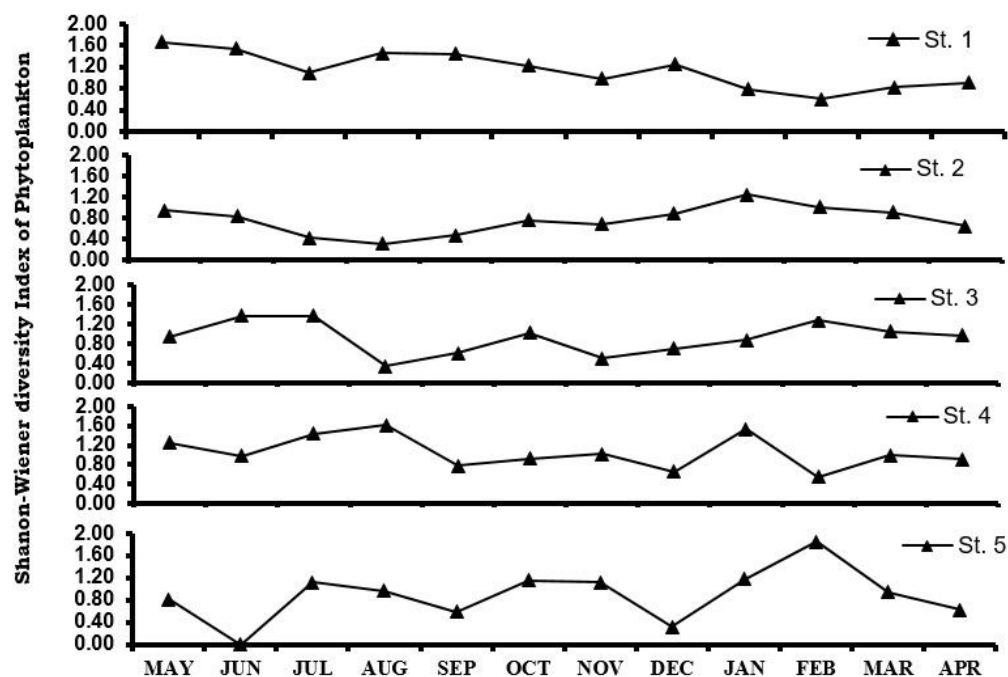


Fig. 7. Monthly variation in the Shannon-Wiener diversity index of phytoplankton at Halda (St. 1; St. 2, and St. 3) and Karnaphuli rivers (St. 4 and St. 5) during May 2010 to April 2011.

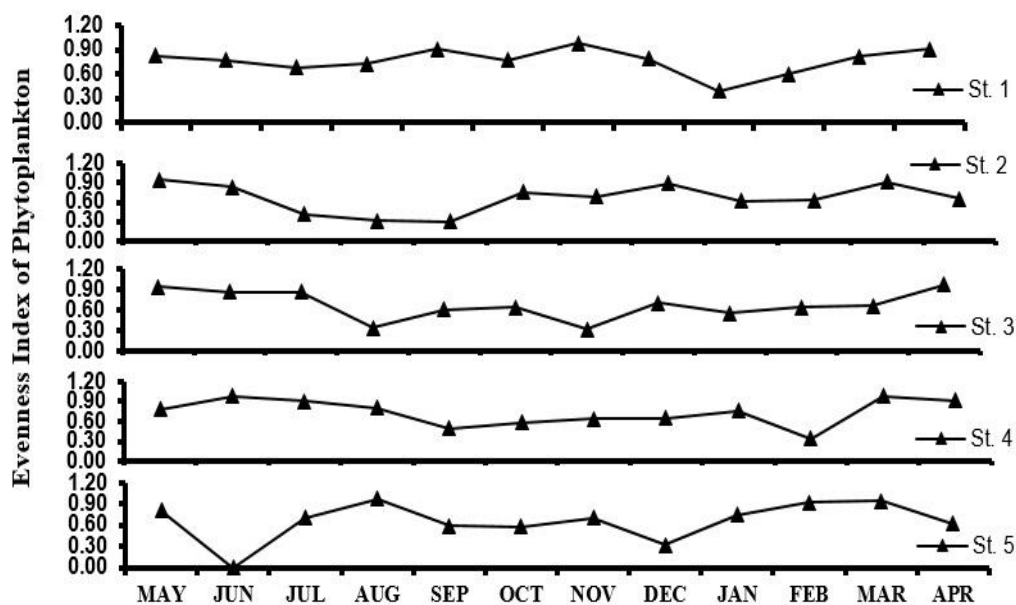


Fig. 8. Monthly variation of the Evenness index of phytoplankton at Halda (St. 1; St. 2, and St. 3) and Karnaphuli rivers (St. 4 and St. 5) during May 2010 to April 2011.

Table 1: Total number and percentage of different phytoplankton groups and genera in the Halda River from May 2010 to April 2011

Groups	Genus	Total No.	Percentage (%)
Blue-green Algae	<i>Anacystis</i>	4	17.39
	<i>Lyngbya</i>		
	<i>Spirulina</i>		
	<i>Phormidium</i>		
Green Algae	<i>Ulothrix</i>	4	17.39
	<i>Spirogyra</i>		
	<i>Tribonema</i>		
	<i>Zygnema</i>		
Nonmotile green Algae	<i>Scenedesmus</i>	4	17.39
	<i>Ankistrodesmus</i>		
	<i>Schizomeris</i>		
	<i>Pediastrum</i>		
Desmids	<i>Genicularia</i>	3	13.04
	<i>Micrasterias</i>		
	<i>Closterium</i>		
	<i>Diatoma</i>		
Diatoms	<i>Surirella</i>	8	34.78
	<i>Cyclotella</i>		
	<i>Nitzschia</i>		
	<i>Stephanodiscus</i>		
	<i>Navicula</i>		
	<i>Synedra</i>		
	<i>Melosira</i>		

Table 2: Total number and percentage of different phytoplankton groups and genera in the Karnaphuli River during May 2010 to April 2011

Groups	Genus	Total No.	Percentage (%)
Blue-green Algae	<i>Anacystis</i>	4	22.22
	<i>Phormidium</i>		
	<i>Spirulina</i>		
	<i>Lyngbya</i>		
Green Algae	<i>Ulothrix</i>	4	22.22
	<i>Tribonema</i>		
	<i>Microspora</i>		
	<i>Zygnema</i>		
Nonmotile green Algae	<i>Pediastrum</i>	3	16.67
	<i>Tetrastrum</i>		
	<i>Schizomeris</i>		
Desmids	<i>Genicularia</i>	1	5.56
Diatoms	<i>Diatoma</i>	6	33.33
	<i>Surirella</i>		
	<i>Cyclotella</i>		
	<i>Stephanodiscus</i>		
	<i>Synedra</i>		
	<i>Melosira</i>		

The spring peak in zooplankton abundance observed in April (Halda River) and March (Karnaphuli River) likely reflects a classic predator-prey time lag following earlier nutrient influxes and phytoplankton productivity. Although the lowest phytoplankton abundance (minima) was recorded in April due to intense grazing

pressure by the high density of zooplankton, the primary production from the preceding months provided a sufficient food base to support the subsequent zooplankton population explosion. In the Karnaphuli River, the highest mean abundance ($92,204 \pm 30,091$ individuals m^{-3}) was observed in March 2011, while the lowest ($15,797 \pm 14,134$ individuals m^{-3}) was recorded in May 2010 (Fig. 9). These findings generally agree with previous observations from the Halda River (Patra and Azadi, 1987), although differences may reflect variation in sampling locations, hydrological conditions, rainfall patterns, and long-term environmental changes.

Among the Halda River stations, the maximum zooplankton abundance ($125,733$ individuals m^{-3}) was recorded at Station 1 (Sattar Ghat) in April 2011, whereas the minimum ($8,705$ individuals m^{-3}) occurred at Station 3 (Moduna Ghat) in November 2010 (Fig. 10). In the Karnaphuli River, Station 4 (Kalurghat) recorded the highest abundance ($113,482$ individuals m^{-3}) in March 2011, while the lowest abundance ($5,803$ individuals m^{-3}) was observed at Station 5 (Firingi Bazar) in May 2010 (Fig. 11).

A total of 16 zooplankton genera belonging to four major groups (Cladocera, Copepoda, Rotifera, and Protozoa) were identified in the Halda River, compared with 13 genera in the Karnaphuli River (Tables 3 and 4). In the Halda River, Rotifera constituted the dominant group (37.50%), followed by Cladocera (25.00%), Copepoda (18.75%), and Protozoa (18.75%). In the Karnaphuli River, Cladocera and Rotifera each contributed 30.77%, followed by Copepoda (23.08%) and Protozoa (15.38%). Similar community compositions have been reported from the Halda River (Patra and Azadi, 1987; Nahid *et al.*, 2020), the Meghna River (Masud *et al.*, 2022), and the Mouri River (Rahi and Sabbir, 2010). Although the Karnaphuli River supported higher zooplankton abundance, it contained fewer genera than the Halda River, suggesting dominance by a limited number of pollution-tolerant taxa, a pattern commonly associated with environmentally stressed ecosystems (Anyinkeng *et al.*, 2016).

The Shannon–Wiener diversity index (H') revealed low zooplankton diversity in both rivers. In the Halda River, monthly mean H' values ranged from 0.47 ± 0.49 in December 2010 to 1.09 ± 0.06 in March 2011 (Fig. 12). In the Karnaphuli River, H' ranged from 0.79 ± 0.10 in November 2010 to 1.57 ± 0.47 in October 2010 (Fig. 12). Overall, zooplankton diversity varied between 0 and 2.0 (Fig. 14), indicating poor to very poor ecological conditions according to established diversity-based water quality classifications (Ajayan and Ajitkumar, 2015; Anyanwu *et al.*, 2023). The low diversity observed may reflect the influence of industrial discharges, municipal wastewater, and urban runoff entering both river systems (Islam, 2021).

The evenness (J') also varied considerably throughout the study period. In the Halda River, monthly mean J' values ranged from 0.37 ± 0.39 in June 2010 to 0.79 ± 0.20 in November 2010 (Fig. 13). In the Karnaphuli River, the lowest mean evenness (0.50 ± 0.71) was recorded in May 2010, while the highest (0.97 ± 0.04) occurred in April 2011 (Fig. 13). Overall, J' values ranged from 0.00 to 1.00 in both rivers (Fig. 15). The generally low to moderate evenness values indicate uneven distribution of individuals among taxa and suggest varying degrees of environmental stress and pollution. These patterns likely reflect the influence of organic, industrial, and municipal pollutants entering the Halda and Karnaphuli rivers from multiple sources (Islam, 2021).

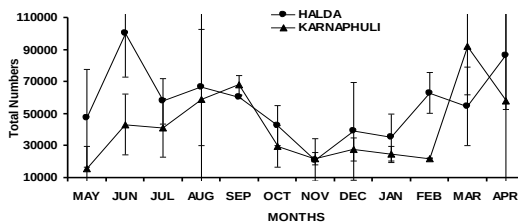


Fig. 9. Monthly variation in mean zooplankton numbers ($\pm$ SD) in the Halda and Karnaphuli rivers from May 2010 to April 2011.

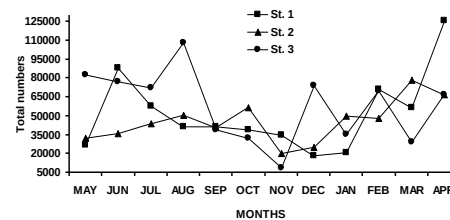


Fig. 10. Monthly variation in the total number of zooplankton (m^{-3}) at Stations 1, 2, and 3 of the Halda River during May 2010 to April 2011.

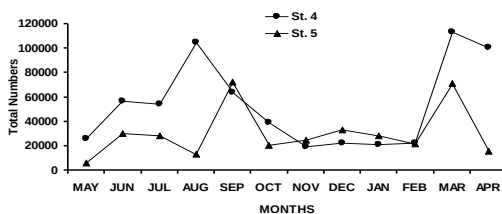


Fig. 11. Monthly variation in total zooplankton abundance (m^{-3}) at Stations 4 and 5 of the Karnaphuli River during May 2010 to April 2011.

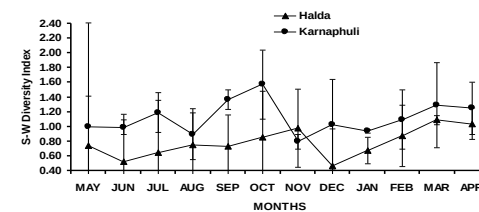


Fig. 12. Monthly variation in the mean Shannon-Wiener diversity index of zooplankton ($\pm$ SD) in the Halda and Karnaphuli rivers from May 2010 to April 2011.

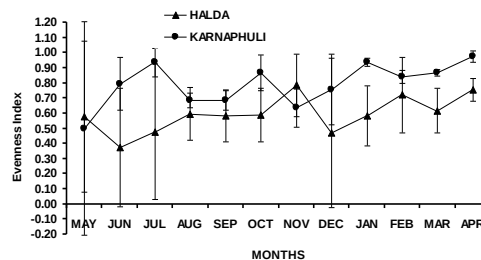


Fig. 13. Monthly variation in the mean Evenness index of zooplankton ($\pm$ SD) in the Halda and Karnaphuli rivers from May 2010 to April 2011.

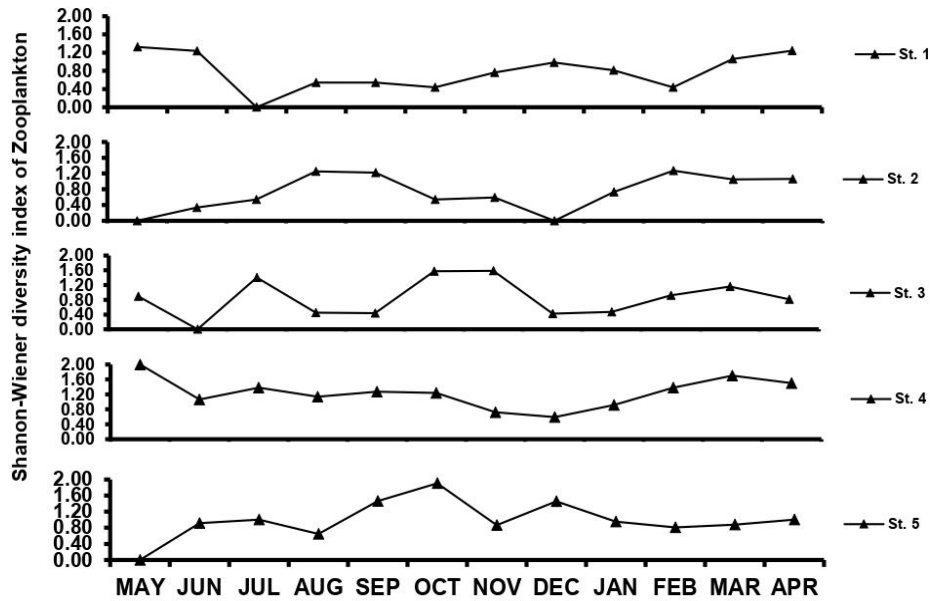


Fig. 14. Monthly variation in the Shannon-Wiener diversity index of zooplankton (H') at Halda (St. 1; St. 2, and St. 3) and Karnaphuli Rivers (St. 4 and St. 5) during May 2010 to April 2011.

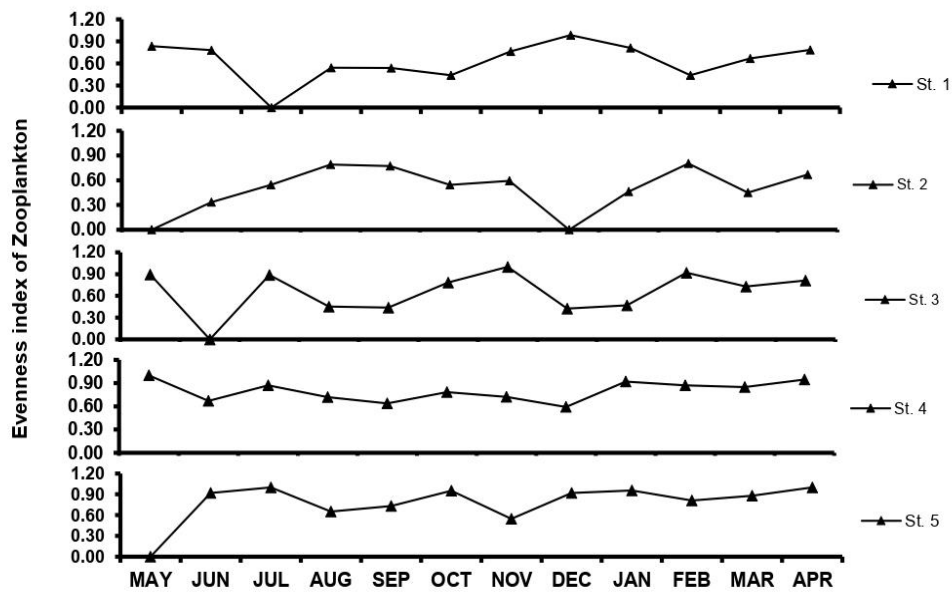


Fig. 15. Monthly variation in Evenness index of zooplankton at Halda (St. 1; St. 2, and St. 3) and Karnaphuli Rivers (St. 4 and St. 5) during May 2010 to April 2011

Table 3: Total numbers and percentages of zooplankton groups and genera in the Halda River from May 2010 to April 2011

Groups	Genus	Total No.	Percentage (%)
Cladocera	<i>Daphnia</i>	4	25.00
	<i>Diaphanosoma</i>		
	<i>Alona</i>		
	<i>Moina</i>		
Copepoda	<i>Cyclops</i>	3	18.75
	<i>Microcyclops</i>		
	<i>Mesocyclops</i>		
	<i>Brachionus</i>		
Rotifera	<i>Monostyla</i>	6	37.50
	<i>Keratella</i>		
	<i>Conochilus</i>		
	<i>Filinia</i>		
Protozoan	<i>Trichocerca</i>	3	18.75
	<i>Paramecium</i>		
	<i>Centropyxis</i>		
	<i>Arcella</i>		

Table 4: Total numbers and percentages of groups and genera of zooplankton in the Karnaphuli River from May 2010 to April 2011

Groups	Genus	Total No.	Percentage (%)
Cladocera	<i>Daphnia</i>	4	30.77
	<i>Moina</i>		
	<i>Diaphanosoma</i>		
	<i>Alona</i>		
Copepoda	<i>Cyclops</i>	3	23.08
	<i>Microcyclops</i>		
	<i>Mesocyclops</i>		
	<i>Brachionus</i>		
Rotifera	<i>Trichocerca</i>	4	30.77
	<i>Keratella</i>		
	<i>Filinia</i>		
	<i>Arcella</i>		
Protozoa	<i>Paramecium</i>	2	15.38

CONCLUSION

Among the major rivers of Bangladesh, Halda and Karnaphuli are the two most highly valued rivers. An ecological investigation was conducted to assess the abundance and diversity of phytoplankton and zooplankton in these two rivers over a year, from May 2010 to April 2011. Plankton are of great importance because they are linked to fish production and distribution. The present study indicated that Halda River water was less polluted. In contrast, poor plankton diversity indices had been found at the lower reaches of the Karnaphuli River, especially at Firingi Bazar Ferry Ghat (Station 5) indicative of high anthropogenic stress. This is also supported by existing evidence of heavy

metal pollution (Ahmed *et al.*, 2016; Hossain *et al.*, 2007) and industrial pollution in this river stretch, which is a serious threat for the long-term sustainability of local fisheries and aquatic organisms. From a planktonic point of view, higher abundance and more genus were observed in the clear water body of the Halda River than in the polluted water body at Station 5 in the Karnaphuli River. Further investigation is suggested up to the mouth of the Karnaphuli River (estuary) to obtain a clearer picture of the river's overall ecology.

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