Journal of Fisheries
Volume 13 Issue 2 August 2025
Peer Reviewed | Open Access

eISSN 2311-3111
pISSN 2311-729X

DOI: https://doi.org/10.17017/j.fish.706

Original Article

Impact of environmental factors on the dietary preferences of *Salmophasia bacaila* in the Dhepa River, Bangladesh

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Manuscript history
Received 26 May 2024 | Accepted 13 April 2025 | Published online 7 May 2025

Citation
Hossain MA, Yesmin MS, Aktar S, Mamun M, Roy KC, Alam MA, Haque MR (2025) Impact of environmental factors on the dietary preferences of *Salmophasia bacaila* in the Dhepa River, Bangladesh. Journal of Fisheries 13(2): 132201. DOI: 10.17017/j.fish.706

Abstract

This study investigates the environmental variability and gut contents of an indigenous fish chela (*Salmophasia bacaila*) in the Dhepa River, Bangladesh. We conducted fish sampling and measured water quality across three sites from September 2017 to February 2018. The results revealed significant fluctuations in water temperature, dissolved oxygen, and pH (PERMANOVA: $p = 0.001$). There was spatio-temporal variation in water transparency (PERMANOVA: $p = 0.001$). The prey analysis identified 13 prey groups in the diet of fish, predominantly consisting of phytoplankton (92.9%), while zooplankton contributed only 7.1%. Twenty phytoplankton and seven zooplankton genera were recorded in the guts, with significant temporal variations in prey diversity (PERMANOVA: $p = 0.010$). These findings highlight that *S. bacaila* are primarily plankton feeders, with shifts in prey diversity driven by environmental factors in the Dhepa River. This research enhances our understanding of ecological dynamics and the relationship between *S. bacaila* and their prey in riverine ecosystems.

Keywords: Dhepa River; environmental variable; freshwater fish; plankton; prey

1 | INTRODUCTION

Food selection and preference are crucial to understanding fish species' feeding biology in the community (Costello *et al.* 1990). Fish growth can be significantly impacted by the variation in prey composition as the early life stages of most fish species are greatly influenced by prey selection (Gupta and Banerjee 2014; Nunn *et al.* 2012). In contrast, prey selection by fishes can be regulated by relative abundance, distribution, and presence of prey types in aquatic environments (Cantanhêde *et al.* 2009). Thus, food selection and preferences of a species can be significantly influenced by the variability in food resources regulated by the environmental changes in inland and other aquatic habitats (Platell *et al.* 2006).

Among the inland resources, the river is typically a dynamic and productive ecosystem. Rivers often function as habitats for migration, breeding, and feeding grounds for fish and other fauna (Anzum *et al.* 2023). Thus, a productive riverine system supports the abundance and diversity of fish species (Kabir *et al.* 2015). However, habitat and food availability in the riverine system largely influence fish's ontogeny, survival, and growth (Winemiller and Jepsen 1998). Typically, riverine productivity is spatiotemporally variable due to physical and biological factors that extensively regulate environmental changes (Thorp *et al.* 2006) and primary production within the dynamic system (Hossain *et al.* 2022).

Dhepa River is a tributary of and originated from the River Atrai at Mohanpur and falls into the Punarbhaba River in Bangladesh. This river is located in the northern part of Bangladesh. It runs about 40 km with an average depth of about 6 meters. The river supports the enormous biodiversity of aquatic organisms like fish, mollusks, phytoplankton, zooplankton, aquatic birds, amphibians, and reptiles. The Dhepa River is a vital fishery habitat. It is well-known in the Dinajpur district in Bangladesh for fish production and source of income for many fishermen living beside it. Along with other freshwater fish, a few small Indigenous fish species (SIS) such as mola (*Amblypharyngodon mola*), chela (*Salmophasia bacaila*), chapila (*Gudusia chapra*), bata (*Labeo bata*), and darkina (*Esomus danricus*) are commonly found in the Dhepa River (Hossain and Afroze 1991).

Research has shown that SIS fish are crucial for food security in Bangladesh, as they provide numerous micro and macronutrients to the general population (Thilsted *et al.* 1997). These small fish are rich in various micronutrients that are essential for numerous biochemical and metabolic processes in the human body, acting as enzymes (Mohanty *et al.* 2013; Islam *et al.* 2023). Consequently, these species play a vital role in combating malnutrition among the population. Unfortunately, despite their nutritional importance, many SIS are critically endangered or have become extinct due to environmental degradation in Bangladesh.

Although SIS has significant nutritional importance, aquaculture practices of these species are not well-developed. Only about 16 SIS have been identified for aquaculture (Felts *et al.* 1996), of which *A. mola*, *Puntius* sp., *G. chapra*, and *S. bacaila* are taken into consideration for aquaculture by the fish farmers. Among these SIS, *S. bacaila*, belonging to the Cyprinidae family, is widely distributed over Bangladesh, northern India (the Ganga-Brahmaputra and Mahanadi drainages in Orissa), and Pakistan (the Indus drainage). *Salmophasia bacaila* is also reported to be shared in the Himalayan waters of Nepal.

Previous studies on SIS fishes mostly emphasized the development of aquaculture production systems in Bangladesh and Indian subcontinents (e.g. Thilsted *et al.* 1997; Kohinoor *et al.* 2001; Kadir *et al.* 2007; Nandi *et al.* 2013; Saha and Barman 2020). Few studies also focused on the reproductive biology (Divipala *et al.* 2013), length-weight relationship, and growth pattern (Masud and Singh 2015; Yeasmin *et al.* 2015) of *S. bacaila*. However, very little is known about the feeding ecology of *S. bacaila* from open water habitats in Bangladesh, where environmental variability is ubiquitous. The current study has focused on environmental changes and the variability in food selection of this threatened species in the Dhepa River. The results of this study will also be helpful in developing appropriate aquaculture technology for this SIS.

2 | METHODOLOGY

2.1 Study area

The Dhepa River is located in the Dinajpur district in northern Bangladesh (25°53′N 88°43′E); the river joins the Punarbhaba River. The total length of this river is about 40 km (Banglapedia 2014). The river originated from the right bank of the Atrai near Mohonpur and flowed southeast. Dhepa River is rich in aquatic flora and fauna including many indigenous fish species (Parvez *et al.* 2017). In addition, this river serves as a feeding, breeding, and nursing ground for various native fish species, including *S. bacaila*.

2.2 Field sampling

Field sampling was conducted at three sites (Site 1: Birganj, Site 2: Vadga, and Site 3: Kornai) in the Dhepa River (Figure 1) from September 2017 to February 2018. These three sites were selected according to the water availability and ecological significance in the Dhepa River. At each site, fish were sampled using a seine net or cast net in the Dhepa River. If the fish catch was unsuccessful, fish were collected from commercial fishermen at the study sites to ensure sufficient fish for this study. Among the collected fish, 10 individuals of *S. bacaila* were preserved in 10% formalin for gut content analysis. In addition, physicochemical variables including dissolved oxygen (DO), water temperature, and pH were measured 30 cm below the water surface using a water quality meter (model: HANNA, USA) around mid-day. Water transparency was also measured using a Secchi disk. Three replicates were used at each sampling site.

2.3 Gut content analysis

The entire gut of each fish was removed by a small incision through the abdomen and transferred to a petri dish. Then, the gut contents were removed using fine forceps. The collected gut from each fish was separately taken in a 25 ml plastic bottle containing 10% formalin for preservation. Gut contents were identified visually at the Petri dish and counted at the first stage. Next, the rest of the contents were identified and counted using a compound microscope (WF10×) for each fish up to the lowest taxon.

We followed Doan Dang *et al.* (2015) and Moore (1980) for plankton species identification. The abundance of gut content was calculated using the following formula.

$N = (A \times 1000 \times C) / (V \times F \times L)$ (Rahman 1992)

Where, N = Number of plankton cells per liter; A = Total number of planktons counted; C = Volume of final concentration of samples in ml; V = Volume of field in cubic millimeter; F = Number of fields counted; L = Volume of original water in liter. The average number of planktons was recorded and expressed cells per liter of water (cells L^{-1}) numerically.

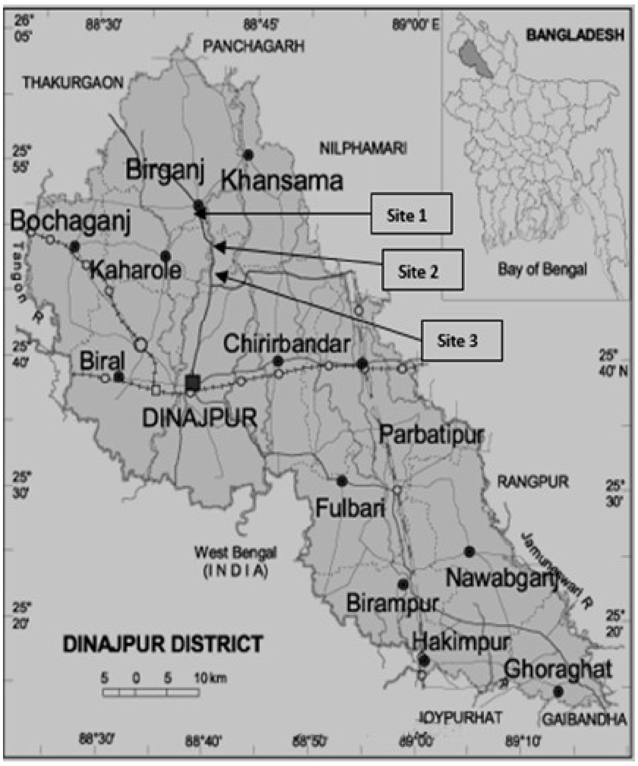

FIGURE 1 Map of Dhepa River showing three sampling sites (Site 1: Birganj, Site 2: Vadga and Site 3: Kornai) [source: Banglapedia].

2.4 Dietary analysis

The Shannon-Weaver index (H′) was used to assess the prey diversity of the dietary contents in each forage fish species. The H′ was calculated as

$H' = -\Sigma p_i \ln p_i$.

Where p is the relationship between the total number of prey of species i and the total number of prey in the sample (Clarke and Warwick 2001; Clarke and Gorley 2006).

Diet data were expressed as composition in the stomach of each forage fish by frequency of occurrence (% F) in the diets to determine diet composition (Hyslop 1980):

$\% F_i = (N_i / N) \times 100$

where Fi = percent frequency of prey type i, Ni = number of prey i in the gut, and N is the total number of preys in the gut contents.

2.5 Data analysis

Environmental variables were normalized and employed to construct Euclidean distance resemblance matrices. The Shannon-Weaver index (H′) data of the diet of each fish individual (univariate) were used to construct a Euclidean distance resemblance matrix (Anderson *et al.* 2008). Permutational analysis of variance (PERMANOVA; pseudo-*p* > 0.05) was run using Euclidean distance resemblance matrices of the Shannon-Weaver index from the diet of each chela individual to test the diet difference among the months and sites in the Dhepa River (Clarke and Warwick 2001). The analysis comprised two factors: sampling months (six levels) and sampling sites (three levels). If the main effects were significant, pairwise post-hoc comparisons using the multivariate analog of the *t*-test (pseudo-*t*) were performed at each level to identify the significant difference. Unrestricted permutation was accomplished for each factor and interaction with 999 permutations to detect differences at $\alpha = 0.05$ (Anderson 2001). All tests were performed using PRIMER v6 (Clarke and Gorley 2006) with the PERMANOVA+ add–on (Anderson *et al.* 2008).

3 | RESULTS

3.1 Water quality

PERMANOVA results showed significant differences in water temperature among the months (*p* = 0.001; Table 1), while the site-wise temperature variation was not evident. The highest water temperature (27°C) was recorded at site 1 (Birganj) in September 2017, whereas site 2 (Vadga) had the lowest temperature (16°C) in January 2018 (Figure 2a). A significant difference in DO among the months was also evident (*p* = 0.001; Table 1). However, DO did not show any significant changes across sites in the Dhepa River. The highest DO (8.73 ± 0.15 mg L^{-1}) was found at site 3 (Kornai) in September 2017 and December 2018, and the lowest DO (6.30 ± 0.23 mg L^{-1}) was recorded in January 2018 at the same site (Figure 2b). There were spatial and temporal changes in water transparency among the sites (PERMANOVA: *p* = 0.001; Table 1), and months (PERMANOVA: *p* = 0.001; Table 1). Water transparency was variable and ranged from 13.67 ± 1.86 cm to 55.67±2.33 cm during the study period (Figure 2c). pH also differed across months (PERMANOVA: *p* = 0.001; Table 1) that ranged from 6.30 ± 0.06 to 7.97 ± 0.07 (Figure 2d).

3.2 Dietary composition

Gut content analysis of 180 individuals of *S. bacaila* [16 – 85 mm total length] revealed 13 prey groups in the gut contents. Phytoplankton was highly dominant in the diets, contributed 92.9% of the total diet amount whereas remaining 7.1% was zooplankton (Figure 3).

In the current study, eight groups of phytoplankton, including Bacillariophyceae, Dinophyceae, Chrysophyceae, Chlorophyceae, Cyanophyceae Euglenophyceae, Ulvophyceae, and Fragillariophyceae were found in the gut of *S. bacaila* (Table 2). Bacillariophyceae (76.47%) were most dominantly occurred phytoplankton community followed by Cyanophyceae (7.54%), Chlorophyceae (7.45%), Euglenophyceae (0.42%), Fragillariophyceae (0.38%), Ulvophyceae (0.37%), Chrysophyceae (0.14%) and Dinophyceae (0.12%).

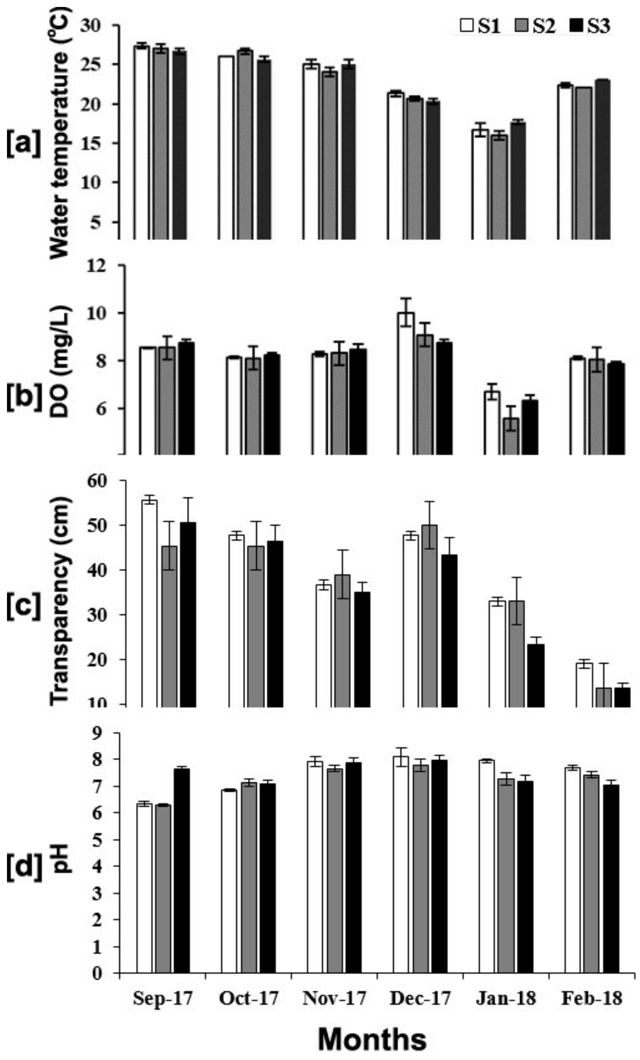

FIGURE 2 Temporal variation in water quality parameters at each sampling site in the Dhepa River. Values are represented as mean ± SE.

Similarly, Crustacean (3.61%), Actinobacteria (2.64%), Cladocera (0.71%), Rotifera (0.08%), and Copepoda (0.06%) were the dominant zooplankton groups found in the diet. About 20 genera of phytoplankton and seven genera of zooplankton were recorded in the gut of *S. bacaila* from the Dhepa River. Among the phytoplankton, five genera of Bacillariophyceae, seven genera of Cyanophyceae, three genera of Chlorophyceae, one fragillariophyceae, one genus of Ulvophyceae, one genus of Chrysophyceae, one Dinophyceae and one genus of Euglenophyceae were recorded. Among the zooplankton, one genus of Rotifera, three genera of Cladocera, one genus of Actinobacteria, and one genus of crustacean were found in the diet composition of *S. bacaila*.

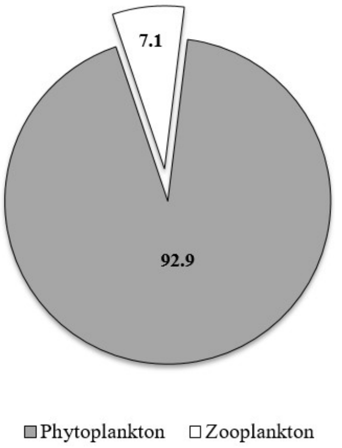

FIGURE 3 Total prey composition preyed by *Salmophasia bacaila* in the Dhepa River during September 2017 to February 2018.

3.3 Variation of prey diversity

PERMANOVA results showed a significant temporal variation in the prey diversity of *S. bacaila* (PERMANOVA: p = 0.010; Table 3). There was a significant interaction between the site and months (PERMANOVA: p = 0.010; Table 3). Pairwise tests detected significant differences in the diversity of dietary prey in *S. bacaila* between September 2017 and November 2017 (pseudo-t: 2.189, p = 0.033), between October 2017 and November 2017 (pseudo-t: 2.75, p = 0.008), between October 2017 and January 2018 (pseudo-t: 2.13, p = 0.04) and between November 2017 and February 2018 (pseudo-t: 3.06, p = 0.002; Table 4).

4 | DISCUSSION

Knowledge of the food and feeding habits of Chela fish is essential for effective management and exploitation within riverine systems. The diet of *S. bacaila* is primarily influenced by the availability, mobility, and distribution of its prey in the water column (Mondal *et al.* 2015; Winkler *et al.* 2017; Sittenthaler *et al.* 2019). The current study reveals that *S. bacaila* consumes a diverse range of prey, including Chlorophyceae, Bacillariophyceae, Cyanophyceae, Euglenophyceae, Fragillariophyceae, Ulvophyceae, Chrysophyceae, Dinophyceae, Cladocera, Rotifera, crustaceans, and Actinobacteria.

Among these, Bacillariophyceae, such as *Cyclotella* spp., *Nitzschia* spp., *Navicula* spp., *Surirella* spp., and *Microphora* spp., are the most prevalent in the gut content analysis. The second, third, and fourth most common food sources for *S. bacaila* are Cyanophyceae, Chlorophyceae, and Actinobacteria, respectively. This indicates that *S. bacaila* is primarily a planktivorous species. Previous research on *Puntius ticto* and *A. mola* has shown that small indigenous species are primarily planktivores (Hoque *et al.* 2016). However, the presence of various crustaceans, rotifers, and cladocerans suggests that *S. bacaila* is capable of foraging in the water column for food.

TABLE 1 Water quality parameters at three sites in the Dhepa River, recorded between September 2017 and February 2018. This table includes fixed factors contributing to the changes in water quality parameters during this study, obtained through permutational analysis of variance (PERMANOVA).

Water quality	Source	*df*	SS	MS	Pseudo-*F*	*p* (perm)
Temperature	Site	2.00	0.12	0.06	1.39	0.261
	Month	5.00	50.50	10.10	227.05	0.001
	Site × Month	10.00	0.77	0.08	1.74	0.110
	Residuals	36.00	1.60	0.04		
Transparency	Site	2.00	0.90	0.45	2.99	0.051
	Month	6.00	44.80	7.47	49.40	0.001
	Site × Month	10.00	1.76	0.18	1.16	0.335
	Residuals	35.00	5.29	0.15		
Dissolved oxygen	Site	2.00	0.96	0.48	3.18	0.061
	Month	6.00	41.80	6.97	46.03	0.001
	Site × Month	10.00	3.10	0.31	2.05	0.053
	Residuals	35.00	5.30	0.15		
pH	Site	2.00	1.57	0.78	3.03	0.064
	Month	6.00	27.71	4.62	17.85	0.001
	Site × Month	10.00	14.78	1.48	5.71	0.001
	Residuals	35.00	9.06	0.26		

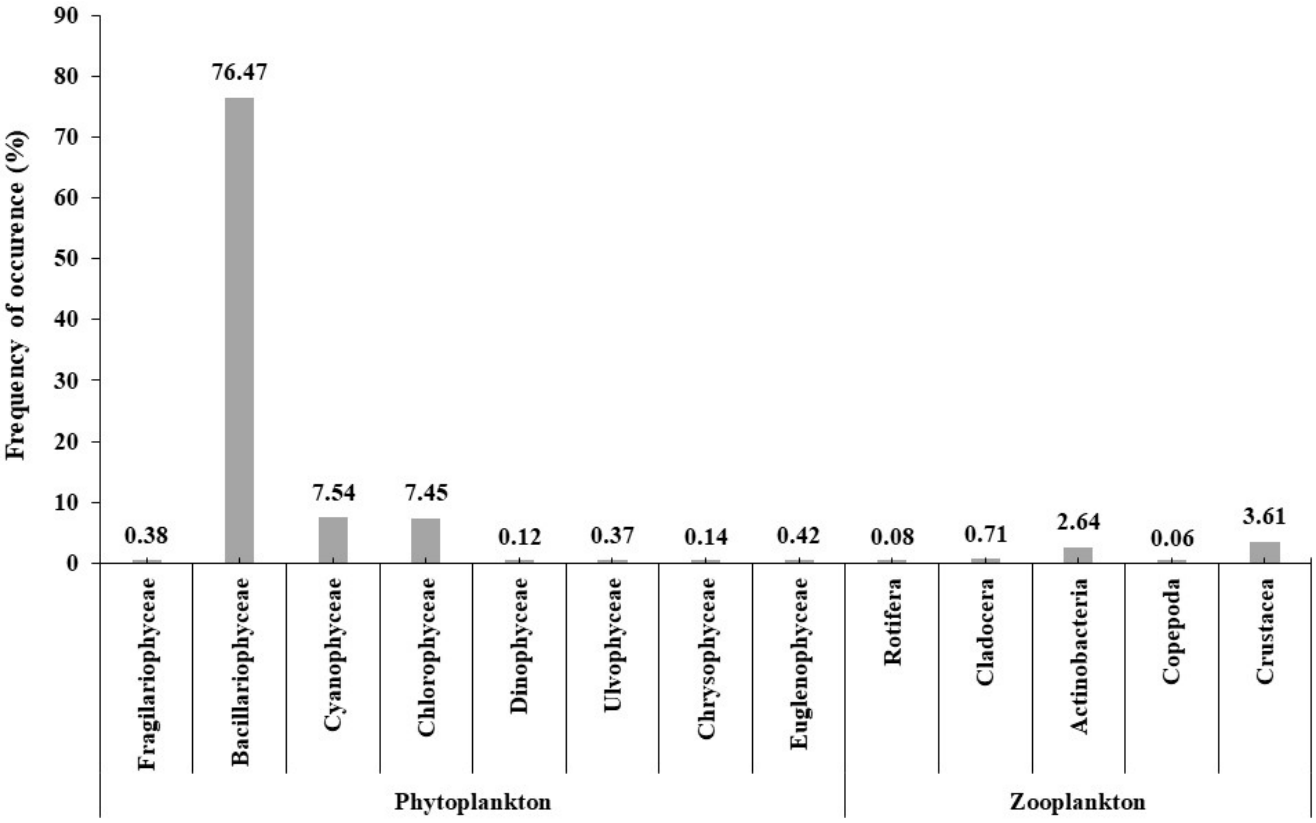

FIGURE 4 The frequency of occurrence of each prey type was determined from *Salmophasia bacaila* diets in the Dhepa River.

TABLE 2 List of plankton recorded from the diets of *Salmophasia bacaila* in the Dhepa River.

Group and family	Genus or type
Phytoplankton	
Chlorophyceae	*Chaetophora*, *Chlorella*, *Botryococcus*
Dinophyceae	*Dinophysis*
Ulvophyceae	*Enteromorpha*
Chrysophyceae	*Dinobryon*
Bacillariophyceae	*Cyclotella*, *Nitzchia*, *Navicula*, *Surirella*, *Microphora*
Fragilariophyceae	*Fragilaria*
Cyanophyceae	*Nostoc*, *Microcystis*, *Anabaena*, *Oscillatoria*, *Aphanizomenon*, *Phormidium*, *Lyngbya*
Euglenophyceae	*Euglena*
Zooplankton	
Cladocera	*Daphnia*, *Bosmina*, *Moina*
Rotifera	*Keratella*
Actinobacteria	*Micrococcus*
Crustacean	Nauplius
Copepoda	*Cyclops*

TABLE 3 PERMANOVA results of the Shannon-Weaver index of dietary prey of *Salmophasia bacaila* at three sites in the Dhepa River during the study period. This PERMANOVA table includes fixed factors contributing to the changes in prey diversity.

Source	*df*	SS	MS	Pseudo-*F*	*p* (perm)
Site	2	0.04	0.02	0.30	0.740
Month	5	1.04	0.21	2.96	0.010
Site × Month	10	1.96	0.20	2.78	0.010
Residuals	162	11.41	0.07		

TABLE 4 PERMANOVA results of pairwise comparisons of prey diversity in *Salmophasia bacaila* over the study period.

Groups	pseudo-*t*	*p* (perm)
Sep 17 vs. Oct 17	1.203	0.230
Sep 17 vs. Nov 17	2.189	0.033
Sep 17 vs. Dec 17	0.953	0.355
Sep 17 vs. Jan 18	1.422	0.163
Sep 17 vs. Feb 18	0.994	0.339
Oct 17 vs. Nov 17	2.756	0.008
Oct 17 vs. Dec 17	1.852	0.061
Oct 17 vs. Jan 18	2.133	0.043
Oct 17 vs. Feb 18	0.863	0.396
Nov 17 vs. Dec 18	1.338	0.185
Nov 17 vs. Jan 18	0.605	0.538
Nov 17 vs. Feb 18	3.065	0.002
Dec 17 vs. Jan18	0.700	0.459
Dec 17 vs. Feb 18	1.660	0.101
Jan 18 vs. Feb 18	1.894	0.065

Prey diversity of *S. bacaila* exhibited significant spatial and temporal variation. A PERMANOVA analysis revealed a notable difference in prey diversity across different months. Pairwise comparisons showed substantial differences in the dietary prey diversity of *S. bacaila* between the following months: September 2017 and November 2017 (p = 0.033), October 2017 and November 2017 (p = 0.008), October 2017 and January 2018 (p = 0.04), and November 2017 and February 2018 (p = 0.002). These results suggest that the variation in prey diversity for *S. bacaila* is likely linked to fluctuations in the abundance and distribution of prey within their environment. Environmental variability can influence prey abundance, as noted in previous studies (Kohinoor *et al.* 2001; Mondal *et al.* 2015). Additionally, the presence of phytoplankton and zooplankton in the fish's gut indicates that their abundance and distribution likely impact the plankton community in the Dhepa River (Mondal *et al.* 2015). Consequently, variability in plankton can affect the abundance and distribution of small indigenous fish in riverine ecosystems.

In running waterbody, the growth and production of fish and prey organisms are highly regulated by water quality parameters (Mondal *et al.* 2015; Winkler *et al.* 2017; Mamun and An 2018). Optimum water quality parameters are prerequisites for a healthy aquatic environment and better production. The primary productivity of marine systems is primarily determined by physical and chemical parameters (Rahman 1992; Kim *et al.* 2001; Jones and Knowlton 2005; Hossain *et al.* 2017). The significant spatiotemporal variation in water quality parameters can be considered as the essential factors for variation of primary and secondary production in the riverine aquatic system (Kim *et al.* 2001; Mondal *et al.* 2015). Consequently, this can impact on the photosynthesis, distribution, and abundance of plankton communities in the ecosystem (Jones and Knowlton 2005; El-Serehy *et al.* 2018).

The current study revealed that water temperature varied significantly across different months and locations, aligning with findings from previous research in lotic systems (Rakiba and Ferdoushi 2013; Chaklader *et al.* 2014). Water transparency is strongly linked to total suspended materials, light availability, and algal chlorophyll (Kadir *et al.* 2007; Hossain *et al.* 2017; Mamun and An 2017). Rahman (1992) noted that transparency should be 40 cm or less for optimal fish growth. In this study, transparency ranged from 13.67 ± 1.86 cm to 55.67 ± 2.33 cm, consistent with findings in other running water bodies (Rakiba and Ferdoushi 2013; Chaklader *et al.* 2014).

Dissolved oxygen is crucial for the survival and growth of aquatic and terrestrial ecosystems (Rahman 1992). Optimal DO levels between 5.0 mg L^{-1} and 10.0 mg L^{-1} support vital production processes (Rahman 1992; Kim *et al.* 2001). In the Dhepa River, DO fluctuates significantly, ranging from 6.30 ± 0.23 mg L^{-1} to 8.73 ± 0.15 mg L^{-1}, underscoring the need for ongoing monitoring. These findings, supported by previous research, highlight the importance of maintaining healthy DO levels to preserve biodiversity in our water bodies (Rakiba and Ferdoushi 2013).

The pH level of aquatic systems is crucial for enhancing both primary and secondary productivity. It is generally accepted that a pH range of 6.5 to 8.5 is optimal for the growth of phytoplankton and for marine organisms (Mondal *et al.* 2015). In the present study, the observed pH levels ranged from 6.30 ± 0.06 to 7.97 ± 0.07. Additionally, Rakiba and Ferdoushi (2013) reported pH values between 6.50 and 7.90 in the Dhepa River, noting that this range is suitable for fish and other aquatic life. Overall, the findings of the present study suggest that the physicochemical parameters are within an appropriate range, which is beneficial for the growth and survival of marine organisms, particularly *S. bacaila*, in the Dhepa River.

5 | CONCLUSIONS

The present study revealed significant spatial and temporal variations in water quality in the Dhepa River throughout the study period. Regarding diet, there was a notable temporal variation in the prey diversity found in the gut contents of *S. bacaila*. Phytoplankton made up a substantial portion of their diet, accounting for 92.9%, while zooplankton constituted 7.1%. Among the identified phytoplankton groups found in the gut contents were Bacillariophyceae, Cyanophyceae, Chlorophyceae, Fragillariophyceae, Ulvophyceae, Chrysophyceae, Dinophyceae, and Euglenophyceae. In contrast, the predominant zooplankton in the diet of *S. bacaila* during the study period included Rotifera, Cladocera, Actinobacteria, and copepods. Overall, the diversity and occurrence of prey indicate that *S. bacaila* in the Dhepa River primarily exhibit surface feeding habits. This study enhances our understanding of prey selection and the diversity of *S. bacaila* diets within this rich riverine ecosystem in Bangladesh.

ACKNOWLEDGEMENTS

We want to thank the local council and fisherman community for supporting sampling fish and water from the Dhepa River. The Institute of Research and Training (IRT) supported and funded this project at the Hajee Mohammad Danesh Science and Technology University (HSTU), Dinajpur, Bangladesh (Grant Ref. IRT, Code 5921). The authors would like to thank IRT for providing the research grant.

CONFLICT OF INTEREST

The author declares no conflict of interest.

AUTHORS' CONTRIBUTION

MAH: research design, supervision, analysis, manuscript writing; MSY: data collection, data analysis; SA: critical review and editing the MS; MM: data analysis and reviewing the MS; MAA: MS writing; KCR: data analysis; MRH: review, and editing.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on a reasonable request from the corresponding author.

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