



Research article

Impacts of freshwater mussels on planktonic communities and water quality

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ABSTRACT

Live Freshwater Mussels (FMs) have remarkable characteristics to support other species and the ecosystem. The objective of the study was to identify the planktonic composition; dye absorbance by living FMs; analyze the water quality indicators; and determine the heavy metals from FMs of different rivers in Bangladesh. In order to assess the planktonic composition, planktons were collected from the experimental ponds and then identified under the microscope. Methyl blue (MB) and methyl red (MR) dye absorbance were assessed using live FMs. After co-cultivating Silver barb (*Barborymus gonionotus*) with FMs, water quality indicators (including pH, DO, hardness, total dissolved solids, ammonia, nitrite, and nitrate) were recorded. For determining heavy metals (Cu, Cr, Cd, Pb, Zn), mussels (*Lamellidens marginalis*) samples were collected from different rivers of Bangladesh. The findings of the study showed that the planktons were significantly ($p < 0.01$) greater in the 'Fish' group, compared to the 'Mussels' and 'Mussels + Fish' groups. Also, the MB and MR dye absorption were significantly higher ($p < 0.01$) in mussels, indicating that live FMs can accumulate hazardous dyes. Furthermore, the hardness value in the 'Mussels' and 'Mussels + Fish' groups were significantly ($p < 0.01$) greater than in the 'Fish' group. In addition, the values of nitrite and nitrate in the 'Fish' group were also significantly ($p < 0.05$) greater than those in the 'Mussels + Fish' group. The heavy metals content in the mussels of the Buriganga river was significantly ($p < 0.05$) higher compared to the mussels of the Rupsha and Brahmaputra rivers. This study revealed that the live FMs have the profound potential to consume plankton, absorb hazardous wastewater dyes, and maintain good water quality which may serve as the ecological indicators in freshwater environment.

1. Introduction

Bivalves (class: Bivalvia) are a class of both freshwater and marine mollusks with two different hinged shells, the same as mussels, oysters, clams, and scallops, and which exhibit a diverse array of life-history aspects as well as play essential ecological roles Dameand Kenneth, 2011 [1,2]. Because of the effects that they have on suspended particles and the formation of shells, they are able to sustain,

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alter, and even establish entire habitats [2]. Bivalves are primarily filter feeders, while certain species consume detritus (i.e., deposit or pedal feeding) [3]. In freshwater environments, mussels belonging to the Unionoida order, generate extensive assemblages, often containing numerous species that are crucial for ancillary production as well as the recycling of elements [1]. Ultimately, assemblages of bivalves are able to reach extremely high concentrations, resulting in ecological consequences at wide spatial dimensions [4].

Although bivalves have long been recognized for their importance in aquatic ecosystems, most research has concentrated on marine bivalves [5]. Bivalves play four essential ecosystem-level tasks, according to Ref. [6]: trophic (substrate and food web modification), nutrient cycling, structural habitat (i.e., mussel beds, oyster reefs), and monitors and indicators (invertebrate species composition and abundance). Suspension feeding by bivalves will significantly impact both planktons and suspended sediments. Bivalves regulate benthic-pelagic interaction and modify several features of the planktonic ecology [7]. They alter the water column by filtration, grazing, and nutrient cycle modification through organic deposits in sediments that are remineralized directly and by microbiological means [8,9]. They also perform such indicators of environmental stress (Vaughn, 2008). The populations and blooms of phytoplankton can be influenced by large bivalve assemblages. They have the ability to reduce the intensity of phytoplankton blooms as well as regulate the amount of phytoplankton that thrive in shallow conditions. Decreased turbidity resulting from bivalve feeding might result in more light, which is a factor inhibiting the development of other organisms, such as algae [10,11]. However, seasonal successional cycles in phytoplankton composition are reinforced by grazing [12]. Rising water temperatures as well as variations in the proportions of organic nitrogen to inorganic nitrogen, promote picoplankton, which is likewise inadequately maintained by bivalve gills. However, grazing systematically removes nanoplankton [13]. Bivalves influence the nutrient cycle by ingesting particulate, dissolving organic matter, and excreting inorganic nutrients [12]. They use their shells to form structures and can move or stabilize sediments. Biologically, they have an impact on community structure and can have an impact on community stability, diversity, and interspecies relationships [14]. Considering freshwater mussels (FMs) are filter-feeding benthic species, they are subjected to elements that are dissolved into water, bound to suspended materials, and accumulated in the sedimentary bottom. In this way, FMs are capable of bioaccumulating metals to amounts much beyond those dissolved in water [15].

Hence, the goal of the research was to determine the impacts of FMs on planktonic communities and water quality through assessing the planktonic diversity, dye absorbance, water quality parameters, and heavy metals content in FMs of different rivers in Bangladesh.

2. Materials and methods

2.1. Collection of mussels sample

Prior to the execution of the experiment, freshwater mussels (*Lamellidens marginalis*) were collected from different rivers in Bangladesh, such as the Rupsha river located in Khulna, Brahmaputra river located in Mymensingh and Buriganga river in Dhaka. Most of the individuals were in the adult stage, having a mean diameter of 9.12 ± 0.95 cm.

2.2. Culture of fish and mussels and analysis of plankton

A total of twelve cisterns were used as control, treatment-1 (T-1), treatment-2 (T-2), and treatment-3 (T-3). In control or plankton groups, there were only phytoplankton and zooplankton in the water. For the T-1 group, 20 FMs were stocked in each of the three cisterns. In T-2, *Barbonymus gonionotus* and live FMs (*Lamellidens marginalis*) were co-cultured in three separate cisterns, where each cistern had 80 fish and 20 mussels. Furthermore, for T-3, only 80 *Barbonymus gonionotus* were stocked in each cistern. The initial mean weight of *Barbonymus gonionotus* was 1.42 ± 0.016 g for the T-1 group and 1.43 ± 0.063 g for the T-2 group. The experiment was carried out for five months. Supplemental local feed was provided twice a day for each group up to satiation level. Phytoplankton and zooplankton were also equally provided for mussels and fish with the supplemental feed. The phytoplankton and zooplankton were collected by plankton net (20 μ) from pond and provided at one-day intervals. Water was exchanged daily up to 50% and adjusted with pond water. Water temperature in the cisterns were maintained between 24-25 °C.

For analyzing the planktonic community, collected plankton samples were separated by using tiny brushes, needles, forceps, and an inverting microscope (Model: OPTIA B-350, Italy). A sample of plankton was obtained using a plastic dropper and placed on the glass slides for later microscopic observation. According to Ref. [16]; phytoplanktons were identified, and zooplanktons were identified using [17] method. Furthermore, to assess the degree of plankton diversity, the Shannon-Weaver diversity index (1949) was constructed.

2.3. Dye absorption by mussels

To conduct this experiment, a total of 12 plastic bowls were used, afterwards the bowls were classified into two categories depending on the dye and concentration. The first six plastic bowls (maximum capacity 3 l/bowl) were filled with 5 ppm concentrated 250 ml methyl blue (MB) dye solutions, and the remaining six were filled with 5 ppm concentrated 250 ml methyl red (MR) dye solutions. In each group, three bowls were used as a treatment (three live mussels were present in the per bowl as an absorbent in dye solution), and three bowls were used as a control (without mussels). The Animal Welfare and Experimental Ethics Committee of Bangladesh Agricultural University in Mymensingh-2202, Bangladesh (AWEEC/BAU/2021) gave its stamp of approval for the use of test mussels in the study.

For the preparation of methyl blue and methyl red dye solution, 5 mg of methyl blue sample (absorbate) was weighed using an

electronic analytical balance (0.0001 g Analytical Balance, BA-P Series). Then, the prepared 5 mg of methyl blue absorbate was placed into a 1000 ml water solution to keep the MB dye concentration at 5 ppm. Finally, 250 ml of prepared 5 ppm methyl blue dye solution was poured into six plastic bowls. Then, the exact procedure was followed for getting a 5 ppm methyl red dye solution and poured into six other plastic bowls.

This experiment was carried out for 7 consecutive days, and the absorbance value of the dye solutions was measured in every 24 h. Absorption was determined from both bowls of control and treatment solutions using Eppendorf Biospectrometer (SPECTRONIC GENESYS™5) at 664 nm wavelength for the MB dye solutions and 430 nm wavelengths for MR dye solutions. Absorbance difference was measured by excluding final absorbance from initial absorbance.

2.4. Determination of water quality parameters during co-culture of fish and mussels

Fish (*B. gonionotus*) and bivalves (*L. marginalis*) were cultured together in cisterns. Three replications were maintained in determining water quality parameters during the co-culture of fish and mussels. Water quality parameters in ponds and cistern water were measured during the co-culture of fish and mussels. At two intervals, water pH was measured using a pocket-sized HANNA digital pH meter (HI 98107, Romania). A dissolved oxygen device (DO-5509, China) was used in order to acquire readings for the level of dissolved oxygen (DO) at two weeks intervals. Total dissolve solid (TDS) was measured by a pocket-sized HANNA portable TDS tester (HI 98302, Romania). Hardness was measured by using a Hardness test kit (HI 3812, Romania). Nitrite was measured by using HANNA (HI 3873-0) nitrite reagent kit. Nitrate was measured by using HANNA (HI 3874-0) nitrate reagent kit. Ammonia was measured by using a HANNA ammonia reagent kit.

Table 1
List of plankton genera found from experimental cisterns during the study period.^a

Plankton	Group	Mussels	Diversity	Mussels + Fish	Diversity	
		Genera/species	Index (H')	Genera/species	Index (H')	
Phytoplankton	Bacillariophyceae	<i>Navicula</i> sp.	3.3	<i>Navicula</i> sp.	2.6	
		<i>Gyrosigma</i> sp.		<i>Gyrosigma</i> sp.		
		<i>Nitzschia</i> sp.		<i>Nitzschia</i> sp.		
		<i>Synedra</i> sp.		<i>Synedra</i> sp.		
		<i>Cyclotella</i> sp.		<i>Bacillaria</i> sp.		
		<i>Bacillaria</i> sp.				
	Chlorophyceae	<i>Rhizosolenia</i> sp.	3.1	<i>Spirogyra</i> sp.	2.2	
		<i>Chaetoceros</i> sp.		<i>Ulothrix</i> sp.		
		<i>Spirogyra</i> sp.		<i>Volvox</i> sp.		
		<i>Ulothrix</i> sp.		<i>Spirulina</i> sp.		
		<i>Volvox</i> sp.		<i>Chlorella</i> sp.		
		<i>Spirulina</i> sp.				
Cyanophyceae	<i>Coleochaete</i> sp.	3.0	<i>Oscillatoria</i> sp.	1.8		
	<i>Microspora</i> sp.					
	<i>Melosira</i> sp.					
	<i>Cosmarium</i> sp.					
Euglenophyceae	<i>Oscillatoria</i> sp.	2.9	<i>Euglena</i> sp.	1.7		
	<i>Anabaena</i> sp.		<i>Phacus</i> sp.			
	<i>Microcystis</i> sp.		<i>Trachelomonas</i> sp.			
Average Zooplankton	Rotifera	<i>Brachionus</i> sp.	3.10 ± 0.17 ^a	<i>Brachionus</i> sp.	2.10 ± 0.41 ^b	
		<i>Keratella</i> sp.				<i>Keratella</i> sp.
		<i>Filinia</i> sp.				
		<i>Asplanchna</i> sp.				
	Cladocera	<i>Polyarthra</i> sp.	3.1	<i>Moina</i> sp.	1.6	
		<i>Moina</i> sp.		<i>Daphnia</i> sp.		
		<i>Daphnia</i> sp.				
	Copepoda	<i>Bosmina</i> sp.	3.1	<i>Cyclops</i> sp.	1.7	
		<i>Diaphanosoma</i> sp.		<i>Diaptomus</i> sp.		
		<i>Cyclops</i> sp.		<i>Macrocyclus</i> sp.		
		<i>Diaptomus</i> sp.		<i>Mesocyclops</i> sp.		
	Average			3.13 ± 0.58 ^a		1.63 ± 0.12 ^b

^a Values are presented as mean ± S.E in triplicates (n = 3), where values with different supercripts (a,b,c) indicate significantly different ($p < 0.05$).

2.5. Determination of heavy metals

The heavy metal content of mussel samples was determined by collecting them from the Brahmaputra, Rupsa, and Buriganga rivers. A Teflon reactor was loaded with each of the 0.2 g of dried mussel flesh, fish flesh, and water for metal analysis. Following the addition of 3 ml Milli-Q water, 5 ml of nitric acid concentration (Merk Suprapur), and 2 ml of H₂O₂ at 30% concentration, the reactor was heated to a maximum of 210 °C in a microwave digester for 20 min. Following chilling, the volume was brought up to 25 ml by adding Milli-Q water, and then it was transferred to a container made of low-density polyethylene. Then it was maintained at 4 °C before spectrophotometer analysis. An inductively coupled plasma-mass spectrometer (ICP-MS, PerkinElmer 3300, Waltham, MA, USA) was used to analyze the samples for Cu, Cr, Cd, Pb, and Zn.

2.6. Statistical analysis

The statistically significant difference between the plankton groups was determined using [Microsoft Excel 2016] software with *t*-test analysis. Analysis of variance (ANOVA) was performed using the SPSS software (version 26.0) to determine statistical differences among treatment and control groups for water quality parameters and heavy metals content. At an level of 0.05 or 0.01 ($p < 0.05$ or $p < 0.01$), differences were regarded either significant or highly significant, respectively.

3. Results

3.1. Plankton composition of experimental ponds

A number of 23 phytoplankton species from four classes were found in the experimental ponds of mussels. Eight species of Bacillariophyceae, nine Chlorophyceae species, three Cyanophyceae species, and three Euglenophyceae species were found in different classes of the phytoplankton group. For the mussel with fish cultured in experimental ponds, The numerous groups of phytoplanktons that were identified in the water bodies included five species of Bacillariophyceae, three Chlorophyceae species, one Cyanophyceae species, and two Euglenophyceae species (Table 1). There were found to be a total of three distinct types of zooplankton during the study period in the ponds of mussels, i.e., Rotifera, Cladocera, and Copepoda. Among them, five Rotifera species, four Copepoda species, and four Cladocera species were found. A total of six zooplankton species were identified (Table 1) from the mussel with the fish group. Indicators of phytoplankton diversity ranged between 2.9 and 3.3 in the mussel group and 1.7 to 2.6 in the mussel with the fish group, with a mean value of 3.10 ± 0.17 and 2.10 ± 0.41 , respectively. In contrast, The diversity of zooplankton in the mussel group ranged from 3.1 to 3.2 and 1.6 to 1.7 in the 'mussel with the fish' group with a mean value of 3.13 ± 0.58 and 1.63 ± 0.12 , respectively (Table 1). The 'Mussels' group had significantly higher ($p < 0.05$) plankton diversity than the 'Mussels + Fish' group. Different varieties/species of planktons were found in three different treatment groups. The number of plankton/L (including both phytoplankton and zooplankton) were shown in Table 2 for the one control and three treatment groups. The number of plankton was significantly higher in the control group where fish or mussels were absent compared to the treatment other groups ($p < 0.05$). However, the plankton count among treatment groups was significantly ($p < 0.01$) higher in the 'Fish' group, followed by the 'Mussels' group and the 'Mussels + Fish' group. In this experiment, there was no evidence of mussel or fish mortality.

3.2. Dye absorption by mussel

Absorption rates of both methyl blue and methyl red by mussels were found to be statistically ($p < 0.01$) greater than in the control group (Figs. 1 and 2). After five days of absorption, the methyl blue concentration was 3.6 ppm for the control group and 2.5 ppm for the mussel-contained bowls. After five days of absorption of methyl red dyes, the concentration of control and mussel groups were 3.8 ppm and 2.3 ppm, respectively. There was no mortality of mussel observed during the dye absorption experiment.

3.3. Water quality parameters from different cisterns

During the research period, Table 3 presented the various water quality parameters for the three different treatments and one control group during the study period. For the control (planktons) group, the pH value was 8.00 ± 0.50 and the other parameters such

Table 2
Total plankton count (plankton/L) in experimental cisterns.^a

Treatment	Plankton (Cells/L)	
	Phytoplankton	Zooplankton
Control (only planktons)	$15.5 \times 10^4 \pm 2500^a$	$5.42 \times 10^2 \pm 95^a$
Mussels (T1)	$11.04 \times 10^4 \pm 2620^c$	$3.13 \times 10^2 \pm 60^c$
Mussels + Fish (T2)	$8.12 \times 10^4 \pm 1563^d$	$2.08 \times 10^2 \pm 43^d$
Fish (T3)	$14.97 \times 10^4 \pm 2947^b$	$4.21 \times 10^2 \pm 71^b$

^a Values are presented as mean \pm S.E in triplicates ($n = 3$), where values with different superscripts (a,b,c) indicate significantly different ($p < 0.05$).

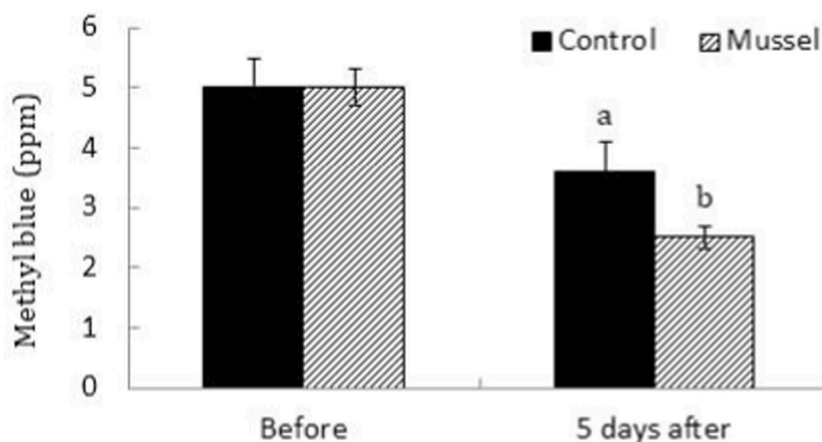


Fig. 1. Absorption of methyl blue by freshwater mussels. Values (n = 3) with different superscripts (a,b) indicate statistical significance ($p < 0.01$).

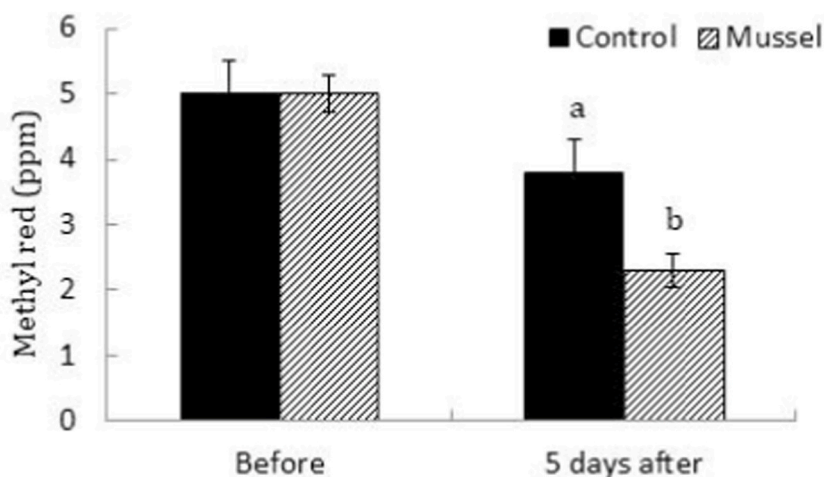


Fig. 2. Absorption of methyl red by freshwater mussels. Values (n = 3) with different superscripts (a,b) indicates statistical significance ($p < 0.01$).

Table 3

Water quality parameters from different cisterns of 3 treatment groups during the study period.^a

Treatment	Water quality				Fish wastes		
	pH	Dissolved Oxygen (ppm)	Hardness (ppm)	Total Dissolved Solid (ppm)	Nitrites (ppm)	Nitrate (ppm)	Ammonia (ppm)
Control (only planktons)	8.00 ± 0.50	7.45 ± 0.64	156 ± 7.53 ^c	230 ± 4.85	0	0	0
Mussels (T1)	8.10 ± 0.60	6.95 ± 0.10	165 ± 7.53 ^b	230 ± 3.75	0	0	0
Mussels + Fish (T2)	8.10 ± 0.15	6.70 ± 0.15	177 ± 11.74 ^a	240 ± 4.37	0.2 ± 0.01 ^b	0.2 ± 0.01 ^b	0
Fish (T3)	7.80 ± 0.16	6.70 ± 0.08	144 ± 7.07 ^d	230 ± 3.33	0.3 ± 0.01 ^a	0.3 ± 0.01 ^a	0.001

^a Values are presented as mean ± S.E in triplicates (n = 3), where values with different superscripts (a,b,c) indicate significantly different ($p < 0.05$).

as dissolved oxygen, hardness, and total dissolved solid was 7.45 ± 0.64 ppm, 156 ± 7.53 ppm and 266 ± 4.85 ppm, respectively. The pH value of the three treatment groups was similar in the ‘Mussels’ and ‘Mussels + Fish’ (8.1) groups; for the ‘Fish’ group, the value was 7.8. The dissolved oxygen (DO) was similar (6.7 ppm) for the ‘Mussels + Fish’ and ‘Fish’ groups, whereas the DO value was 6.95 ± 0.10 ppm for the ‘Mussels’ group. There was a significant ($p < 0.05$) increase in the total hardness in the ‘Mussels + Fish’ group (177 ± 11.74 ppm) than that in the ‘Control’ (156 ± 7.53), ‘Mussels’ (165 ± 7.53 ppm) and ‘Fish’ (144 ± 7.07) groups. Total dissolved solids (TDS) concentration was observed to be greater in the ‘Mussels + Fish’ group (240 ± 4.37 ppm), however, for the ‘Control’, ‘Mussels’

and 'Fish' groups showed almost similar results. The nitrites, nitrate, and ammonia in the cistern water of the 'Control' and 'Mussels' groups were zero. A significantly ($p < 0.05$) higher amount of nitrites (0.3 ± 0.01 ppm) and nitrate (0.3 ± 0.01 ppm) were found in the water of the 'Fish' group compared with the nitrite (0.2 ± 0.01 ppm) and nitrate (0.2 ± 0.01 ppm) of the 'Mussels + Fish' group (Table 3). An insignificant amount of ammonia found in the cistern water of the 'Fish' group.

3.4. The heavy metal concentration of mussels

The mussels from the Buriganga river (Cd: $0.59 \mu\text{g/g}$, Cr: $3.5 \mu\text{g/g}$, Cu: $4.37 \mu\text{g/g}$ and Pb: $5.67 \mu\text{g/g}$) had significantly ($p < 0.01$) higher heavy metal contents than those from the Brahmaputra river (Cr: $8.2 \mu\text{g/g}$, Cu: $1.11 \mu\text{g/g}$, Pb: $2.01 \mu\text{g/g}$, and Zn: $35.02 \mu\text{g/g}$), and Rupsha river (Cd: $0.24 \mu\text{g/g}$, Cu: $2.37 \mu\text{g/g}$, Pb: $0.67 \mu\text{g/g}$ and Zn: $33.30 \mu\text{g/g}$) (Table 4). On the other hand, Zn ($13.20 \mu\text{g/g}$) content in mussels was significantly higher in the Brahmaputra river than in the Buriganga and Rupsha rivers. The Cd and Cr were not detected in the mussels of Brahmaputra and Rupsha rivers, respectively.

4. Discussion

4.1. Planktonic diversity

In this study, a number of 23 various species of phytoplankton were classified into four different groups from the study area. The majority of these phytoplanktons were consistently highlighted by Uddin et al. (2022) [18]; and [19]. Uddin et al. [20] found 29 species of phytoplankton belonging to 8 major classes from the rivers of Sundarbans. In our findings, varieties of different genera/species of planktons were identified in three treatment groups where the mussels' diversity index (H') showed a significant ($p < 0.05$) variation than the co-culture group of fish and mussels. 'Fish' group had the largest concentration of planktons, followed by 'Mussels' group, and finally 'Mussels + Fish' group. It indicated that mussels consumed more plankton than fish. Wilson [21] also found a greater consumption of plankton by mussels. In his study, within seven days, 53% less phytoplankton were seen when zebra mussels were introduced. The Diversity Index (H') also indicated that the 'Mussels' group had significantly greater ($p < 0.05$) phytoplankton species as well as zooplankton than the 'Mussels + Fish' group.

4.2. Dye absorption by mussels

FMs absorbed the dye and reduced the concentration level of dye solutions from its methyl blue as well as methyl red. When there were no FMs in the dye solutions of methyl blue and methyl red, the absorbance levels were significantly greater and remained nearly constant for seven consecutive days. However, the absorbance values gradually decreased over seven days when FMs were present in the methyl blue and methyl red dye solutions. This result revealed that the trend of dye absorbance value of methyl blue and methyl red dye solution in treatment was significantly different ($p < 0.01$) from its control groups. Anand and Vardhanan [22] such *Perna viridis* byssus thread have the ability to remove metals and dyes from water. They hypothesized that the byssus thread of the mussel comprises a mix of DOPA-rich protein and His-rich protein, as well as collagen. They anticipated that by combining these proteins with their specific structure, would facilitate the elimination of the dye and heavy metals. Dandil et al. [23] also examined that calcined waste mussels shells act as adsorbents to remove the dye. This result has confirmed that the presence of FMs in water bodies has significant importance for removing dyes from waste or polluted water. Wang et al. [24] provided novel findings in the use of mussel-inspired materials for wastewater remediation. These data have indicated that live FMs act as a super absorbent. Mussels show this unique characteristic because of their shell characteristics, the presence of their byssus thread, or may have other reasons [15].

4.3. Water quality parameters

This study measured the water quality parameter, i.e., pH, dissolved oxygen, hardness, total dissolved solids, nitrite, nitrate, and ammonia in different treatment groups, as shown in Table 3. The average values of water quality parameters including pH, DO, TDS, ammonia, nitrite, and nitrate in the 'Mussels' group and 'Mussels + Fish' group remained the same during the study period, and when compared to the 'Fish' group, no statistically ($p > 0.05$) significant difference was observed. These might happen due to the small fish size and less total number. However, the hardness values in the 'Mussels' group and 'Mussels + Fish' group shown statistically ($p < 0.05$) higher significant than in the 'Fish' group. The nitrite and nitrate values in 'Fish' were also significantly ($p < 0.05$) higher than

Table 4

The heavy metal concentration of mussels collected from the Brahmaputra, Rupsha, and Buriganga river.¹

Stations of Mussels	Heavy metal concentrations ($\mu\text{g/g}$)				
	Cd	Cr	Cu	Pb	Zn
Brahmaputra	ND	0.82 ± 0.05^b	1.11 ± 0.12^c	2.01 ± 0.15^b	35.02 ± 2.15^a
Rupsha	0.24 ± 0.01^b	ND	2.37 ± 0.45^b	0.67 ± 0.08^c	33.30 ± 2.08^b
Buriganga	0.59 ± 0.10^a	3.5 ± 0.24^a	4.37 ± 0.56^a	5.67 ± 0.89^a	13.20 ± 1.10^c

ND: Not Detected; ¹Values are presented as mean \pm S.E in triplicates ($n = 3$), where values with different supercripts (a,b,c) indicate significantly different ($p < 0.01$).

the 'Mussels' group. Our current finding was similar to those the [25]; who investigated the water quality parameter during the culture of freshwater mussel *Lamellidens marginalis* in the pond. They recorded at 7.3, 6.2 mg/l, and 280 mg/l as pH, dissolved oxygen, and total dissolved solids, respectively. They also recorded the total hardness value as 310 mg/l, which was greater than the results of the present study.

Glaser et al. [26] investigated that Zebra mussels can reduce the dissolved oxygen concentration in river water, and within the study area, their population can maintain the water quality. According to model sensitivity assessments, lowering the Zebra mussel population in half led to an increase in DO of around one mg/l at Bladwinville on the river of Seneca, New York. Bhatnagar and Singh [27] stated that up to 5 ppm DO value is essential for good fish production. In this study, wherein the presence of FMs, the mean DO values were more or less similar, and the ranges were 6.7–6.95 mg/l.

The "Fish" group had a mean value of nitrite (0.3 ± 0.01 ppm) that was significantly ($p < 0.05$) higher than the "Mussels + Fish" group (0.2 ± 0.01) and the 'Mussels' group (0 ppm). This higher value of nitrite may be caused due to the uneaten feed and fish wastes remaining in the water. Clement and Comeau [28] reported that different types of mussel shells and tissue have a unique ability to deposit nitrogen. The study reflected that the nitrite content was comparatively lower and optimum for aquaculture in the presence of FMs.

Michaud et al. [29] reported that the bivalves found in estuaries have linked fluctuations in O_2 , NH_4^+ , and NO_3^- fluxes caused by mussels to shifts in microbial community composition. The nitrate content was found to be significantly ($p < 0.05$) greater in 'Fish' group (0.3 ± 0.01 ppm) compared to the 'Mussels + Fish' group (0.2 ± 0.01 ppm). A relatively higher amount of nitrate might also occur due to the water's uneaten feed and fish waste. The study reflected that in the presence of FMs, the nitrate content was optimum and desired level for aquaculture.

Ammonia is the most critical water quality parameter for fish culture and other aquatic organisms [30]. This study observed a trace amount (0.001) of ammonia in the treatment group where only fish was cultured. In the presence of FMs, however, no ammonia was detected in Mussels or Mussels + Fish groups which indicates the efficiency of FMs in reducing ammonia level in water. The primary source of ammonia in fish ponds is fish excretion and uneaten feed particles [31]. High ammonia can arise from overfeeding with protein-rich feed that ultimately can decay to liberate toxic ammonia gas [32]. In conjunction with the fish and mussels, this ammonia may accumulate to a lower level in the present study. In water, ammonia is present in molecular and ionic forms. Its concentration is deficient in the unpolluted water body (<1 mg/l). It may increase up to 12 mg/l or more, becoming lethal to fish (Augsburger et al., 2003). Ammonia concentrations of 1.75 mg/l to 2.5 mg/l at pH 8 have acute effects, and chronic levels of 0.3 mg/l to 1.0 mg/l can be fatal [33].

4.4. Heavy metal levels in mussels

In the present study, mussels from the Buriganga river had significantly ($p < 0.01$) higher levels of heavy metals than those from the Brahmaputra and the Rupsha rivers. In the mussels of the Buriganga river, the Cd, Cr, Cu, and Pb levels were greater than in the Brahmaputra and Rupsha rivers. However, in the mussels of the Buriganga river, only the Zn level was substantially ($p < 0.01$) lower than in the Brahmaputra and Rupsha rivers. The Cd level in the mussels of the Brahmaputra river and the Cr level in the mussels of the Rupsha river were not detected. It could happen because of the greater quantity of contaminants in the Buriganga river. The concentrations of the metals were too low and below the detection limit. One consequence of a comparatively lower amount of Zn in the Buriganga rivers is the deposition of zinc-treated sludge on the river banks. During the dry season [34], reported that the Buriganga river was heavily polluted with heavy metals, which is detrimental to the river environment. Mussels in both saltwater and freshwater could really accumulate high amounts of some metals without any adverse effects [35,36]. According to [Hossain et al 2021], heavy metals in river water can cause biochemical and enzymatic changes in freshwater fish [37]. Any changes to the fish body cause physiological abnormalities, substantially compromising normal function, growth rate, and survival in nature [38]. These findings reported the negative impacts of heavy metals in river water on river ecosystems, particularly freshwater living species.

5. Conclusion

This study revealed that FMs could absorb excessive phytoplankton and maintain good water quality conditions. In addition, FMs absorbed different concentrations of hazardous dyes and organic wastes from wastewater. Therefore, the water quality parameters were almost in optimum ranges during the co-culture of FMs with fish, including pH, DO, TDS, hardness, nitrite, nitrate, and ammonia. The present study also revealed that the heavy metals content of Buriganga river mussels was higher than the mussels of the Rupsha and Brahmaputra rivers, indicating that they have the capability to accumulate heavy metals within an optimum range. Overall, the results indicate that freshwater mussels can reduce the possible algal bloom in water by rapid absorption of phytoplankton, improve the water quality for good aquaculture practices, deplete the industrial dyes and heavy metals through the bioaccumulation process. However, further study warranted the growth, toxicity and concentration of heavy metals as well as health status of fish and mussels under environmentally relevant water pollution condition.

Author contribution statement

Tutul Kumar Saha: Performed the experiments; Analyzed and interpreted the data; Wrote the paper. Md. Zehad Rafsan Jany: Performed the experiments; Wrote the paper. Selina Yeasmine; Yahia Mahmud: Contributed reagents, materials, analysis tools or data. Mohammad Moniruzzaman: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data. Zakir Hossain:

Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

Declaration of interest's statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

- [1] D.L. Strayer, Freshwater mussel ecology, in: *Freshwater Mussel Ecology*, University of California Press, 2008.
- [2] C.C. Vaughn, T.J. Hoellein, Bivalve impacts in freshwater and marine ecosystems, *Annual Review of Ecology, Evolution, and Systematics* 49 (1) (2018).
- [3] R.F. Dame, M.J. Kennen, *Ecology of Marine Bivalves: an Ecosystem Approach*, Taylor & Francis. CRC press, Boca Raton, FL, 2011, p. 284.
- [4] C.L. Atkinson, C.C. Vaughn, Biogeochemical hotspots: temporal and spatial scaling of the impact of freshwater mussels on ecosystem function, *Freshw. Biol.* 60 (3) (2015) 563–574.
- [5] C.C. Vaughn, S.J. Nichols, D.E. Spooner, Community and foodweb ecology of freshwater mussels, *J. North Am. Benthol. Soc.* 27 (2) (2008) 409–423.
- [6] R.F. Dame, *Ecology of Marine Bivalves: an Ecosystem Approach*, CRC Marine Science Series, USA, 1996.
- [7] D.E. Spooner, C.C. Vaughn, Context-dependent effects of freshwater mussels on stream benthic communities, *Freshw. Biol.* 51 (6) (2006) 1016–1024.
- [8] O.S. Board, National Research Council, *Ocean Acidification: a National Strategy to Meet the Challenges of a Changing Ocean*, National Academies Press, 2010.
- [9] C.W. McKinsey, P. Archambault, M.D. Callier, F. Olivier, Influence of suspended and off-bottom mussel culture on the sea bottom and benthic habitats: a review, *Can. J. Zool.* 89 (7) (2011) 622–646.
- [10] P.J. Cranford, P.M. Strain, M. Dowd, B.T. Hargrave, J. Grant, M.C. Archambault, Influence of mussel aquaculture on nitrogen dynamics in a nutrient enriched coastal embayment, *Mar. Ecol. Prog. Ser.* 347 (2007) 61–78.
- [11] R.I. Newell, Ecosystem influences of natural and cultivated populations of suspension-feeding bivalve molluscs: a review, *J. Shellfish Res.* 23 (1) (2004) 51–62.
- [12] G.W. Hopper, T.P. DuBose, K.B. Gido, C.C. Vaughn, Freshwater mussels alter fish distributions through habitat modifications at fine spatial scales, *Freshw. Sci.* 38 (4) (2019) 702–712.
- [13] A.Y. Karatayev, L.E. Burlakova, D.K. Padilla, Impacts of zebra mussels on aquatic communities and their role as ecosystem engineers, in: *Invasive Aquatic Species of Europe. Distribution, Impacts and Management*, Springer, Dordrecht, 2002, pp. 433–446.
- [14] M. Österling, *Ecology of Freshwater Mussels in Disturbed Environments* (Doctoral Dissertation, Fakulteten För Samhälls-Och Livsvetenskaper), 2006.
- [15] T.J. Naimo, A review of the effects of heavy metals on freshwater mussels, *Ecotoxicology* 4 (6) (1995) 341–362.
- [16] D.C. Bellinger, K.M. Stiles, H.L. Needleman, Low-level lead exposure, intelligence and academic achievement: a long-term follow-up study, *Pediatrics* 90 (6) (1992) 855–861.
- [17] A.M. Bhouyain, G.S. Asmat, *Freshwater Zooplankton from Bangladesh*, Labiba Laila, Nilufer Begum, 1992.
- [18] T.K. Saha, J. Hosen, Z. Hossain, Fish culture in net cages improves the livelihood of Charland population: a case study from Padma (Ganga) River, Munshiganj, Bangladesh, *Asian Journal of Medical and Biological Research* 7 (2) (2021) 174–181.
- [19] Z. Hossain, M.S. Hossain, M.R. Uddin, Z. Rahman, Present status of fish and plankton Biodiversity at the Padma river in Munshiganj District, Bangladesh, *World Appl. Sci. J.* 38 (2020) 386–394.
- [20] M.N. Uddin, I.J. Tumpa, Z. Hossain, Diversity of Biological communities along the major rivers of Sundarbans in Bangladesh, *Asian Fish Sci.* 34 (2021) 127–137.
- [21] A.E. Wilson, Effects of zebra mussels on phytoplankton and ciliates: a field mesocosm experiment, *J. Plankton Res.* 25 (8) (2003) 905–915.
- [22] P.P. Anand, Y. Shibu Vardhanan, Dye and Metal Ion Adsorption Ability of Asian Green Mussel Byssus Thread Complex; Their Microscopic and Thermal Property Characterisation, *Environmental Technology*, 2021, pp. 1–17.
- [23] S. Dandil, D.A. Sahbaz, C. Acikgoz, High performance adsorption of hazardous triphenylmethane dye-crystal violet onto calcinated waste mussel shells, *Water Qual. Res. J.* 54 (3) (2019) 249–256.
- [24] Z. Wang, J. Guo, J. Ma, L. Shao, Highly regenerable alkali-resistant magnetic nanoparticles inspired by mussels for rapid selective dye removal offer high-efficiency environmental remediation, *J. Mater. Chem.* 3 (39) (2015) 19960–19968.
- [25] N. Natarajan, R. Susithira, Physico-chemical characteristics of water quality for culturing the freshwater mussel *Lamellidens marginalis* in pond and Laboratory, *IOSR J. Pharm. Biol. Sci.* 11 (1) (2015) 36–42.
- [26] D. Glaser, J.R. Rhea, D.R. Opdyke, K.T. Russell, C.K. Ziegler, W. Ku, L. Zheng, J. Mastriano, Model of zebra mussel growth and water quality impacts in the Seneca River, New York, *Lake Reservoir Manag.* 25 (1) (2009) 49–72.
- [27] A. Bhatnagar, G. Singh, Culture fisheries in village ponds: a multi-location study in Haryana, India, *Agric. Biol. J. N. Am.* 1 (5) (2010) 961–968.
- [28] J.C. Clements, L.A. Comeau, Nitrogen removal potential of shellfish aquaculture harvests in eastern Canada: a comparison of culture methods, *Aquac. Res.* 13 (2019), 100183.
- [29] E. Michaud, G. Desrosiers, R.C. Aller, F. Mermillod-Blondin, B. Sundby, G. Stora, Spatial interactions in the *Macoma balthica* community control biogeochemical fluxes at the sediment-water interface and microbial abundances, *J. Mar. Res.* 67 (1) (2009) 43–70.
- [30] N. Wang, C.G. Ingersoll, D.K. Hardesty, C.D. Ivey, J.L. Kunz, T.W. May, F.J. Dwyer, A.D. Roberts, T. Augspurger, C.M. Kane, R.J. Neves, Acute toxicity of copper, ammonia, and chlorine to glochidia and juveniles of freshwater mussels (Unionidae), *Environ. Toxicol. Chem.: Int. J.* 26 (10) (2007) 2036–2047.
- [31] T. Augspurger, A.E. Keller, M.C. Black, W.G. Cope, F.J. Dwyer, Water quality guidance for protection of freshwater mussels (Unionidae) from ammonia exposure, *Environ. Toxicol. Chem.: Int. J.* 22 (11) (2003) 2569–2575.
- [32] D.S. Cherry, J.L. Scheller, N.L. Cooper, J.R. Bidwell, Potential effects of Asian clam (*Corbicula fluminea*) die-offs on native freshwater mussels (Unionidae) I: water-column ammonia levels and ammonia toxicity, *J. North Am. Benthol. Soc.* 24 (2) (2005) 369–380.
- [33] S. Wang, Y. Wang, X. Feng, L. Zhai, G. Zhu, Quantitative analyses of ammonia-oxidising Archaea and Bacteria in the sediments of four nitrogen-rich wetlands in China, *Appl. Microbiol. Biotechnol.* 90 (2) (2011) 779–787.
- [34] K. Fatema, M. Begum, M. Al Zahid, M.E. Hossain, Water quality assessment of the river Buriganga, Bangladesh, *J. Biodivers. Conserv. Bioresour. Manag.* 4 (1) (2018) 47–54.
- [35] O. Ravera, Cadmium in freshwater ecosystems, *Experientia* 40 (1) (1984) 1–14.
- [36] S. Ray, Bioaccumulation of cadmium in marine organisms, *Experientia* 40 (1) (1984) 14–23.
- [37] Z. Hossain, S. Hossain, N.S. Ema, A.W. Omri, Heavy metal toxicity in Buriganga river alters the immunology of Nile tilapia (*Oreochromis niloticus* L), *Heliyon* 7 (2021), e08285.
- [38] V. Modesto, M. Ilarri, A.T. Souza, M. Lopes-Lima, K. Doua, M. Clavero, R. Sousa, Fish and mussels: importance of fish for freshwater mussel conservation, *Fish Fish* 19 (2) (2018) 244–259.