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Research Article

Dynamics of Phytoplankton in Bangladesh's Largest Freshwater Lake: Seasonal Shift and Environmental Drivers

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Abstract

This study examines the seasonal shift of the phytoplankton assemblage of Kaptai Lake, Bangladesh, to elucidate the underlying drivers and ecological integrity. In 2020 and 2021, phytoplankton and physiochemical parameters were collected. There were found to be 59 genera of phytoplankton, with the pre-monsoon Zygnematophyceae having the highest seasonal dominance, followed by the monsoon Cyanophyceae and post-monsoon Chlorophyceae. The range of abundance was 0.89-2.95×10^6 cells/L, respectively. Alpha diversity indices revealed the phytoplankton community was highly diversified. Zygnematophyceae, Dinophyceae, and Bacillariophyceae were identified by SIMPER analysis as major contributors to community variation. Significant correlations were found between temperature, total dissolved solids, alkalinity, conductivity, and transparency, indicating their impact on the dynamics of phytoplankton with seasonal changes. These results demonstrate how the phytoplankton community of Kaptai Lake is rich and dynamic, influenced by seasonal variations in temperature and the resulting changes in the water's chemistry. This information helps to build successful conservation plans and offers an insightful understanding of the ecology of freshwater lakes.

Introduction

Phytoplankton is the basis of most lake food webs, and fish production relies on it [1]. They play an indispensable role in ecology as well as climate change [2]. Phytoplankton dynamics, community structure, and diversity are influenced by several physico-chemical factors; which cause seasonal and spatial variations of plankton diversity. Moreover, Phytoplankton density is directly correlated with the productivity of an aquatic environment [3], as they play an essential role as primary producers and thus can affect higher trophic levels by providing nutritional bases for zooplankton and, as a result, other invertebrates, shellfish, and finfish [4]. Ecology links phytoplankton diversity to productivity [5]. Phytoplankton shows wide variation in distribution due to changes in physico-chemical parameters and also provides good insight into water quality [6].

Kaptai Lake is the largest artificial freshwater resource in Bangladesh and was formed by damming the river Karnaphuli in 1961 [7]. The lake surface area covers 68,800 ha with an average depth of 9m and a maximum width of 4 km [7,8]. The quantity, distribution, diversity, growth, reproduction, and migration of aquatic species are all significantly influenced by the interplay between the chemical and physical characteristics of the water [9]. Temporal variation of water quality, trophic state index, macrobenthic fauna, and zooplankton abundance have been studied in Kaptai Lake [10-14]. These studies have reported: (i) the mesotrophic condition of the lake, (ii) that physicochemical parameters were within the permissible limit, and (iii) the dominance of *Melosira*, *Pediastrum*, and *Staurastrum*.

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However, despite the importance of phytoplankton as a primary producer, no such studies on phytoplankton diversity and community structure have been studied in Kaptai Lake.

Kaptai Lake significantly contributes to the local economy and fisheries sector. This lake contributes to fisheries, navigation, flood control, agriculture, and many household activities. In 1965/66, commercial fishing started with 1200 MT in this lake [12]. In 2021-22, the fish yield is about 17,937MT [15]. Thus, understanding the dynamic environmental parameters and their influence on phytoplankton productivity is crucial, given its pivotal role in the lake's ecological food web. This study aims to evaluate the seasonal variations in phytoplankton abundance and diversity indices and examine the relationship between environmental factors and phytoplankton classes in Kaptai Lake, Bangladesh. Insights from this research will enhance the assessment of water quality and contribute to a deeper understanding of freshwater ecosystem dynamics.

Materials and methods

Sampling sites and duration

Kaptai Lake including the sampling points is shown in Figure 1. But in recent days, the KL's total fish production was largely attributed to two notable clupeid species: kechki (*Corica soborna*) and chapila (*Gudusia chapra*), which accounted for more over 30% and 31% of the total, respectively. The locals use the lake as a navigational and agricultural route. Two streams, the Chengi in the north and the Rainkhyong in the south, feed the Rangamati-Kaptai. Two inflowing streams feed the Langodu: the Kassalong and Miyani on the northern side, and the Karnaphuli River laterally feeds Barkal. The area surrounding the lake is devoid of industries.

The samples were taken from four sampling spots [Rangamati Sadar (S1), Barkal (S2), Langadu (S3), and Kaptai (S4),] away from the discharge point of rivers, but the major fishing area of the Kaptai Lake. Monthly samplings were carried out for 1 year from July 2020 to June 2021. The year was classified as monsoon (August-October'20), post-monsoon (December 20-February'21), and pre-monsoon (March-May'21) as the season pattern of Bangladesh.

Physiochemical variables

A portable multiparameter (HANNA HI 98194) was used at each sampling site to test the water's temperature, conductivity, salinity, Total Dissolved Solids (TDS), and pH. A portable Dissolved Oxygen (DO) meter (HANNA HI 9146) was used to quantify DO, and a Secchi disk was used to measure water transparency (SD). Total alkalinity and free CO_2 were determined using the standard methods mentioned in APHA [16] and Strickland and Parsons [17].

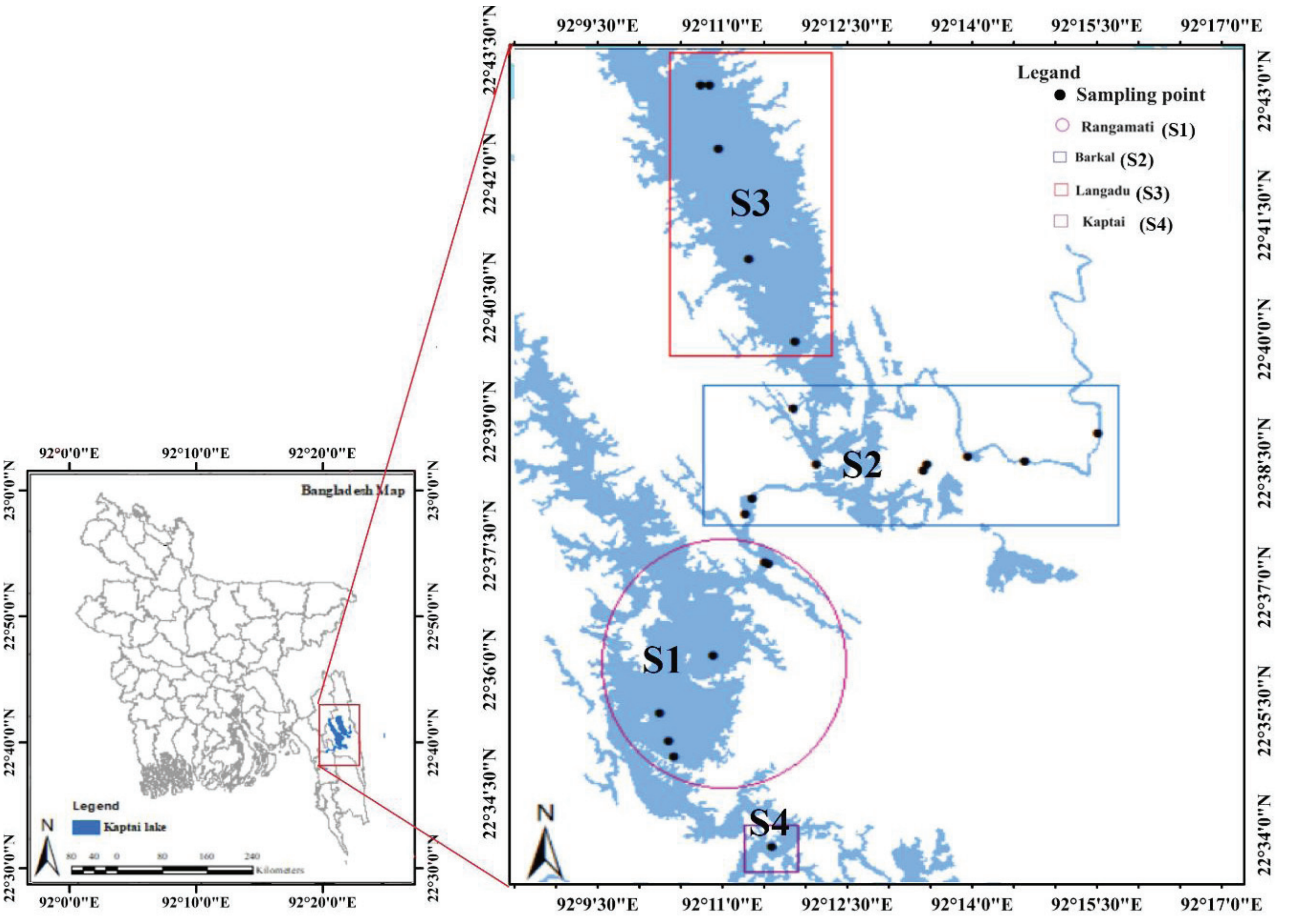

Figure 1: The sampling sites of Kaptai Lake, Bangladesh.

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Plankton collection, identification, and counting

Plankton sampling was done by filtering 40 liters of water samples by 25µ mesh size plankton net. Filtered water samples were stored in the sample bottle and taken to the laboratory for primary observation, then preserved with 5% buffered formalin and stored in the refrigerator at 4 °C temperature. The samples were brought to be identified and classified under a binocular light microscope (OLYMPUS, Model: CX22LED, Japan) by using the Sedgwick-Rafter (S-R) cell and identification book [18-20].

The abundance of each phytoplankton was calculated. Plankton abundance is the number of individuals or cells per unit volume. Phytoplankton abundance was calculated using the following formula [21]:

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

Here,

N=Number of plankton cells or units L^{-1} of original water; A=Total number of plankton counted; C=Volume of the final concentration of the sample in ml; V=Volume of a field =1 cu mm; F=Number of the field counted and L= Volume of original water in liter.

Alpha diversity indices

The univariate analysis approach explained some ecological indicators through the alpha diversity Indices. Phytoplankton alpha diversity indices were evaluated using the Shannon-Weaver diversity index [22], the Margalef richness index [23], the Simpson index [24] and the Pielou evenness index [25] with the following formula:

Shannon- Weaver diversity index: $H' = -\sum_{i=1}^{S} Pi \times \ln Pi$

Margalef richness index: d=$(s-1) / \ln N$

Simpson index: $D = 1 - \sum_{i=1}^{S} Pi^2$

Pielou evenness index: $J' = H' / \ln S$

Where N is the total number of all species in the sample, S is the total species in the sample, and Pi is the total individual numbers in species i.

Statistical analysis

The study employed statistical methodology to examine seasonal changes in physicochemical parameters and phytoplankton abundance. Descriptive statistics, encompassing mean values and their Standard Errors (SE), were computed using IBM SPSS 25.0 software. A one-way ANOVA, followed by the Kruskal-Wallis test, was utilized to determine significant differences ($p < 0.05$) in physicochemical variables across various seasons. To address issues of variance heterogeneity, data on physicochemical variables and phytoplankton abundance underwent ln (x + 1) transformation. Pearson correlation analysis was performed to evaluate the relationships between physicochemical factors and the abundance of different phytoplankton groups. Canonical Correspondence Analysis (CCA) was conducted to investigate the connections between physicochemical parameters and phytoplankton classes. To mitigate multicollinearity among environmental factors, Variance Inflation Factors (VIFs) were kept below 10. The environmental factors influencing the composition of the phytoplankton were selected by 999 Monte Carlo permutation tests at the significant level ($p < 0.01$) to confirm the existence of variation among physiochemical parameters and phytoplankton classes [26]. Both Canonical Correspondence Analysis (CCA) and Pearson correlation analysis were performed using the PAST software package (PAST, v2.02). Furthermore, a two-way Similarity Percentage Analysis (SIMPER) was carried out to determine which specific phytoplankton classes made significant contributions to seasonal similarities.

Results

Physiochemical variables

The physiochemical variables (mean ± SE) with seasonal variation are shown in Table 1. Physiochemical variables showed significant variation only for air temperature ($p < 0.05$). Average air temperature varied between 25.38 and 33.26 °C, higher in the pre-monsoon and lower in the post-monsoon season. The highest values of water temperature (30.45 ± 1.91°C), DO (7.31 ± 0.83 mg/L), conductivity (110.00 ± 7.70 µS/cm) and TDS (55.00 ± 3.80 mg/L) were recorded in the pre-monsoon season; the lowest values of water temperature (25.38 ± 1.92°C), DO (4.64 ± 0.70mg/L) were recorded in the pre-monsoon season while lowest values of conductivity (103.83 ± 8.72µS/cm), alkalinity (69.00 ± 2.08mg/L) and TDS (55.00 ± 3.80 mg/L) were found in post-monsoon and the monsoon season exhibited the highest alkaline pH (8.18±0.25) and lowest salinity (0.03±0.005 ppt). Alkalinity (73.19±5.82 mg/L), free carbon dioxide (13.51±0.78 mg/L), and transparency (1.94±0.44 m) were highest in the post-monsoon season.

Seasonal variation of abundance

Phytoplankton abundance over the study period is summarized in Figure 2. Results revealed phytoplankton

Table 1: Mean values ± standard error (SE) and significance of one-way ANOVA of physiochemical variables in the temporal dimension (Pre-monsoon, Monsoon, and Post-monsoon) from the sampling sites in the Kaptai Lake.

Physiochemical variables	Pre-monsoon	Monsoon	Post-monsoon	p - value
	Mean ± SE	Mean ± SE	Mean ± SE	
Air temp. (°C)	33.26±2.40	30.88±1.49	25.38±1.92	0.04*
Water temp. (°C)	30.45±1.91	29.29±1.38	27.85±1.47	0.06
DO (mgL^{-1})	7.31±0.83	4.89±1.09	4.64±0.70	0.25
pH	8.16±0.12	7.18±0.25	7.61±0.12	0.19
Conductivity (µS/cm)	110.00±7.70	100.83±8.72	108.31±9.16	0.21
Alkalinity (mgL^{-1})	70.50±3.37	69.00±2.08	73.19±5.82	0.15
Free CO_2 (mgL^{-1})	7.87±0.96	10.78±0.77	13.51±0.78	0.09
Salinity (ppt)	0.05±0.005	0.03±0.005	0.05±0.004	0.16
Transparency (m)	1.67±0.26	1.17±0.30	1.94±0.44	0.19
TDS (mgL^{-1})	55.00±3.80	52.67±4.17	54.56±4.82	0.25

Tem: temperature; DO: Dissolved Oxygen; TDS: Total Dissolved Solids. Significant differences are indicated with the asterisk (*). * $p < 0.05$.

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abundance ranged from 0.89-2.95×10⁶ cells/L during the study period. The highest abundance occurred during the pre-monsoon (2.95×10⁶ cells/L), while the lowest was recorded in the monsoon (0.89×10⁶ cells/L). There was no significant seasonal variation ($p > 0.05$).

Diversity and distribution

The abundant and common species recorded during the study period are summarized in Table 2. Phytoplankton diversity varied considerably with seasons. A total of 59 genera belonging to Cyanophyceae (15), Chlorophyceae (14), Zygnematophyceae (5), Dinophyceae (4), Bacillariophyceae (9), Xanthophyceae (1), Trebouxiophyceae (3), Euglenophyceae (4), Ulvophyceae (1) and Chrysophyceae (1). The highest number of genera, 42, was recorded in the post-monsoon season, especially Cyanophyceae, which were found to be a more dominant group

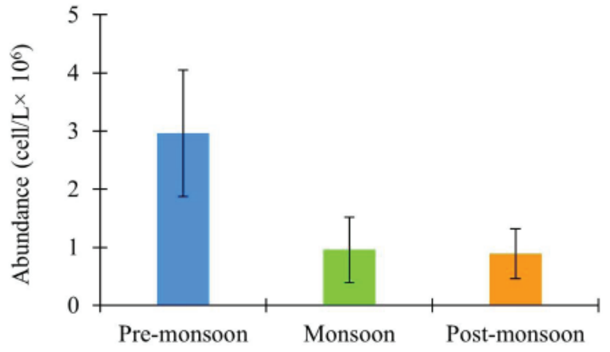

Figure 2: Phytoplankton abundance of Kaptai Lake during the study period.

Table 2: Checklist of dominant phytoplankton genera surveyed during the study period.

No	Class	Pre-monsoon	Monsoon	Post-monsoon
	Cyanophyceae			
1	*Anabaena*	++	-	++
2	*Aphanocapsa*	+	++	+++
3	*Aphanothece*	++	+++	++
4	*Coelosphaerium*	-	++	++
5	*Chlorococcus.*	-	++	+++
6	*Chlorogloea*	++	+++	++
7	*Gloeocapsa.*	+	+++	++
8	*Microcystis*	-	++	++
9	*Merismopedia*	+++	++	-
10	*Nostoc*	+	-	++
11	*Nodularia.*	-	++	++
12	*Oscillatoria*	-	++	-
13	*Planktothrix*	-	-	++
14	*Phormidium.*	+	+++	++
15	*Synechocystis*	-	++	-
	Chlorophyceae			
1	*Ankistrodesmus*	+	-	++
2	*Coelastrum.*	++	++	++
3	*Chlorella*	++	++	++
4	*Eudorina*	-	++	-
5	*Kirchneriella*	+	++	++
6	*Pleodorina*	++	++	++
7	*Protococcus*	++	++	++
8	*Pediastrum*	++	-	++
9	*Sorastrum*	-	++	-
10	*Scenedesmus*	++	++	-
11	*Tetraspora*	++	-	-
12	*Tetraedron*	+	-	-
13	*Volvox*	+	-	-
14	*Westella*	-	-	++
	Zygnematophyceae			
1	*Cosmarium*	+++	++	++
2	*Closterium*	++	++	++
3	*Mougeotia*	-	-	++
4	*Staurastrum*	+++	++	+++
5	*Spirogyra*	-	++	-
	Dinophyceae			
1	*Ceratium*	++	-	++
2	*Dinophysis*	+	++	++
3	*Gymnodinium*	+++	+++	++
4	*Peridinium*	++	+++	++
	Bacillariophyceae			
1	*Fragilaria*	++	++	++
2	*Gyrosigma*	-	-	++
3	*Lioloma*	-	-	++
4	*Melosira*	-	++	++
5	*Navicula*	-	++	-
6	*Nitzschia*	+	-	-
7	*Pseudo-nitzschia*	+	+	-
8	*Synedra*	++	+++	+++
9	*Tabellaria*	-	++	++
	Xanthophyceae			
1	*Tribonema*	+	-	++
	Trebouxiophyceae			
1	*Actinastrum*	+	++	++
2	*Crucigenia*	-	-	++
3	*Dictyosphaerium*	+	-	++
	Euglenophyceae			
1	*Euglena*	++	++	++
2	*Phacus*	+	++	++
3	*Strombomonas*	+++	++	-
4	*Trachelomonas*	-	++	-
	Ulvophyceae			
1	*Ulothrix*	-	-	++
	Chrysophyceae			
1	*Dinobryon*	-	++	++

Note: (-): 0 cell/L; (+): 1-10000 cell/L; (++): 10001-100000 cell/L; (+++): >100001 cell/L.

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than the others. The species composition of phytoplankton was less diverse (36 genera), and Chlorophyceae was the dominant group during the pre-monsoon season.

Phytoplankton abundance (%) was summarized in Figure 3. During the study period, phytoplankton distribution was not evenly distributed, whereas in the pre-monsoon season, the Zygnematophyceae was high in abundance (39%). In the monsoon season, Cyanophyceae was dominant (33%), while the Dinophyceae and Bacillariophyceae were almost similar, 23% and 25%, respectively. The Chlorophyceae showed the highest percentage of abundance (54%) compared to others during the post-monsoon season.

Alpha diversity indices

The phytoplankton alpha diversity showed no significant seasonal variation ($p > 0.05$). (Figure 4). The Shannon-Weaver diversity index (H') was higher in the post-monsoon (3.20), followed by the monsoon (2.95) and pre-monsoon (2.75) seasons, respectively. The Margalef richness index (d) recorded the highest diversity (2.87) during the post-monsoon, followed by the pre-monsoon (2.49) and the monsoon (2.38), respectively. The Simpson (dominance) index (D) and the Pielou evenness index (J') vary from 0.89-0.93 and 0.44-0.58, respectively, with the highest value in the post-monsoon season. Overall, in the post-monsoon season, all the alpha diversity indices reached the highest value in Kaptai Lake.

Seasonal succession of dominant phytoplankton genera

The phytoplankton and dominant genera identified in different seasons in the study areas are shown in Figure 5. Water temperature was high in pre-monsoon; Zygnematophyceae (*Staurastrum*) and Cyanophyceae (*Merismopedia, Aphanothece*) were dominant. The monsoon season with high temperatures (29.29±1.38 °C) showed a high abundance of Cyanophyceae (*Planktothrix* and *Gloeocapsa*) and Bacillariophyceae (*Synedra*). In the post-monsoon, the Chlorophyceae (*Pleodorina*) predominated with various genera. According to SIMPER analysis, the average degree of dissimilarity among seasons was 41.87 %, with Zygnematophyceae, Dinophyceae, and Bacillariophyceae accounting for most of the difference (36.57%, 18.41% and 15.8%, respectively) (Table 3).

Canonical correspondence analysis

Important physiochemical variables responsible for the phytoplankton community changes were identified with CCA and are represented in Figure 6. Axis 1 explained 61.51%, and Axis 2 explained 38.49% of the variability in the biplot (Figure 7). The first axis showed positive correlations with pH (r = 0.67), air temperature (r = 0.41), water temperature (r = 0.25) and strong negative correlations with alkalinity (r = -0.88), salinity (r = -0.98), conductivity (r = -0.98), transparency (r = -0.99), TDS (r = -0.93) and DO (r = -0.19). Chlorophyceae and Xanthophyceae phytoplankton groups responded positively to

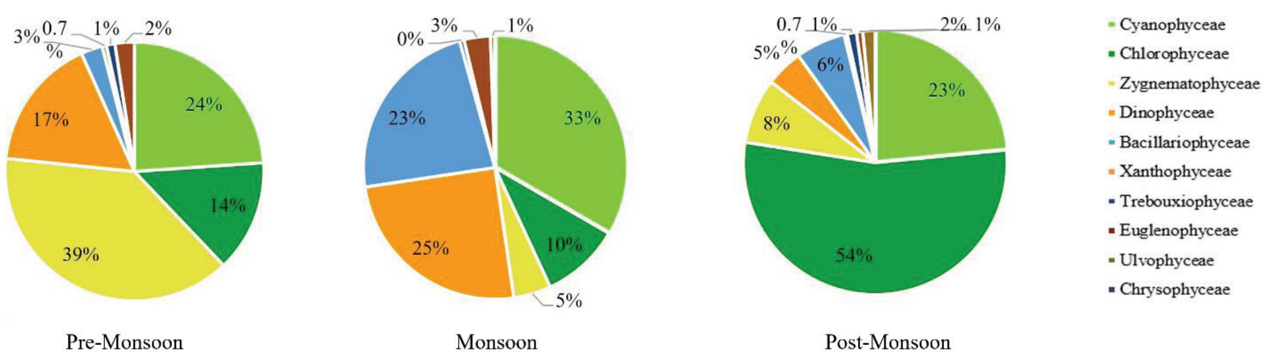

Figure 3: Phytoplankton abundance (%) of Kaptai Lake in three different seasons.

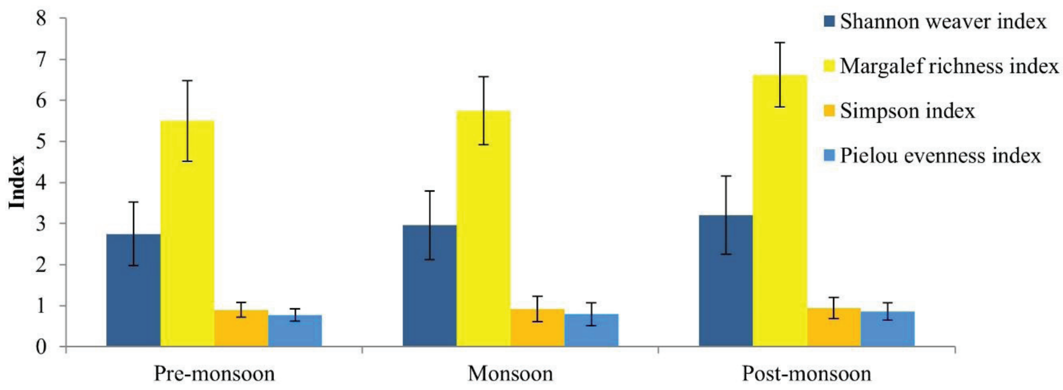

Figure 4: Phytoplankton alpha diversity indices in Kaptai Lake during the study period.

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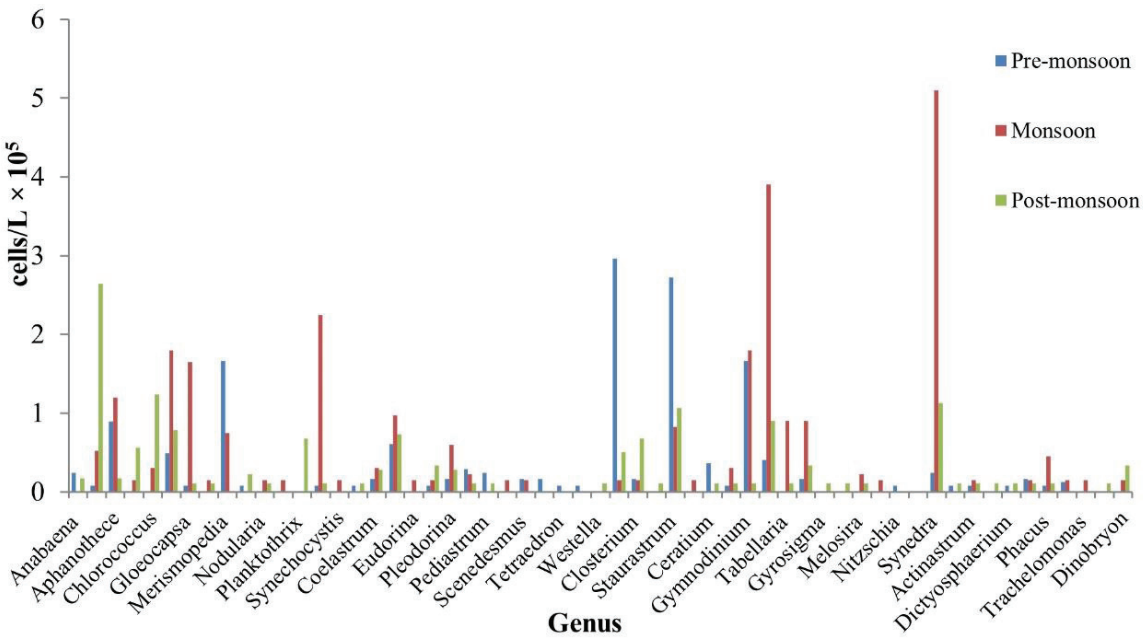

Figure 5: Identified dominant genera of phytoplankton during the study period.

Table 3: SIMPER results for phytoplankton in Kaptai Lake during the study period. Overall average dissimilarity = 41.87%.

Taxon	Av. dissimilarity	Contribution %
Zygnematophyceae	15.31	36.57
Dinophyceae	7.71	18.41
Bacillariophyceae	6.61	15.8
Cyanophyceae	6.05	14.46
Chlorophyceae	3.55	8.45
Euglenophyceae	0.84	2.02
Chrysophyceae	0.75	1.80
Trebouxiophyceae	0.71	1.69
Xanthophyceae	0.19	0.47
Ulvophyceae	0.12	0.27

Av. dissim. = Average dissimilarity; Contrib. = Contribution.

pH, air temperature, and water temperature. Chrysophyceae, Zygnematophyceae, and Dinophyceae responded positively to salinity, TDS, DO, and conductivity in the pre-monsoon season.

The second axis showed strong positive correlations with DO (r = 0.99), water temperature (r = 0.91), and strong negative correlations with CO_2 (r = -0.95). Chrysophyceae, Zygnematophyceae, and Dinophyceae responded positively to salinity, TDS, DO, and conductivity. Ulvophyceae and Bacillariophyceae showed affinity with alkalinity and free CO_2 during the post-monsoon. Cyanophyceae, Trebouxiophyceae, and Euglenophyceae responded negatively to pH and water temperature in the monsoon.

Interaction between phytoplankton and physiochemical parameters

The correlation between the water quality parameters and the phytoplankton is demonstrated in Figure 7. Cyanophyceae was strongly positively correlated with transparency (r = 0.82) and negatively correlated with air and water temperature, pH, and free CO_2. Chlorophyceae showed a moderate positive relation with Cyanophyceae (r = 0.68). On the contrary, transparency showed a positive relation with Zygnematophyceae (r = 0.88), Bacillariophyceae (r = 0.95), and Ulvophyceae (r = 0.84). Xanthophyceae was positively correlated (r = 0.70) with salinity. Whereas, pH and salinity revealed a strong negative relation ($p < 0.01$) with Trebouxiophyceae, Euglenophyceae, Ulvophyceae and Chrysophyceae.

Discussion

Seasonal shift of physiochemical parameters and phytoplankton community

The physiochemical parameters influence plankton abundance and diversity [27]. Air temperature showed significant temporal variation ($p < 0.05$), and the rest of the parameters were the same throughout the year. The findings almost coincide with the previous studies of Kaptai Lake [7,12,13].

Plankton is a biological parameter influenced by other biological factors and is a crucial link in the chain that sustains the existence of other creatures [28]. Multiple environmental factors and physiological characteristics impact the amount of phytoplankton. Physical, chemical, and biological changes in the environment will change the composition and abundance of phytoplankton at different levels [29].

The current study site is an inland closed-basin lake; the study was anticipated to uncover the current status of the phytoplankton community and seasonal variation. However, except for air temperature, no seasonal variation may be due to the well-mixed waters in the lake [30]. The pre-monsoon maxima and post-monsoon minimums can be caused by the

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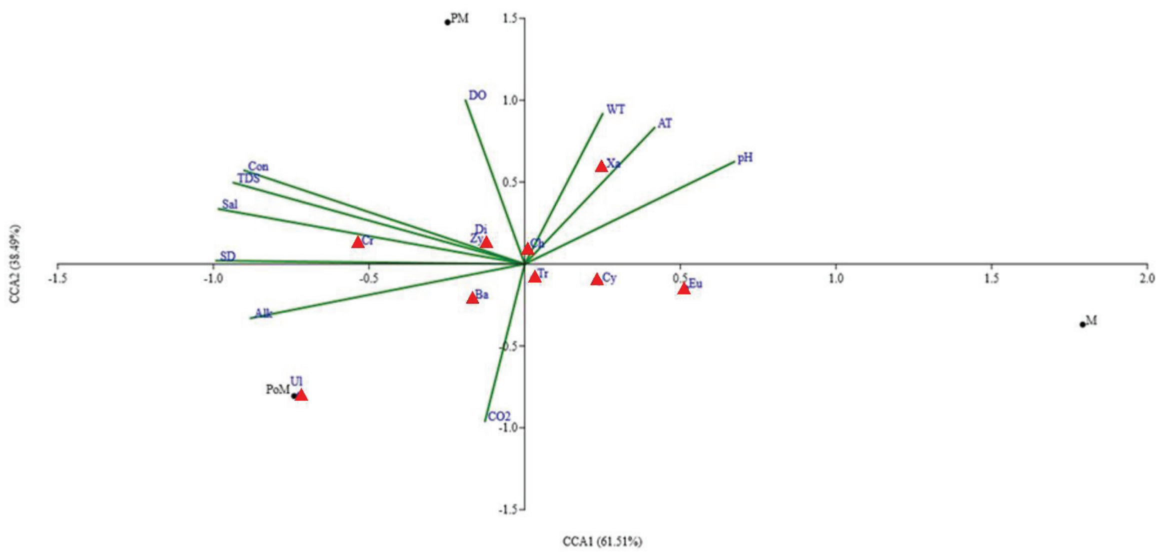

Figure 6: CCA biplot shows the seasonal variation between phytoplankton class and environmental parameters. Environmental variables are depicted by long arrows and classes are given in code words. The correlation between phytoplankton classes and environmental variables is explained by the length of the arrows. DO: dissolved oxygen; TDS: Total Dissolved Solids; WT: Water Temperature; AT: Air Temperature; Con: Conductivity; Alk: Alkalinity; Sal: Salinity; SD: Transparency; Red triangle: Phytoplankton class; Di: Dinophyceae; Zy: Zygnematophyceae; Ch: Chlorophyceae; Ul: Ulvophyceae; Eu: Euglenophyceae; Cy: Cyanophyceae; Tr: Trebouxiophyceae; Ba: Bacillariophyceae; Xa: Xanthophyceae; Cr: Chrysophyceae; Black dot: Season; PM: Pre-monsoon; M: Monsoon; PoM: Post-monsoon.

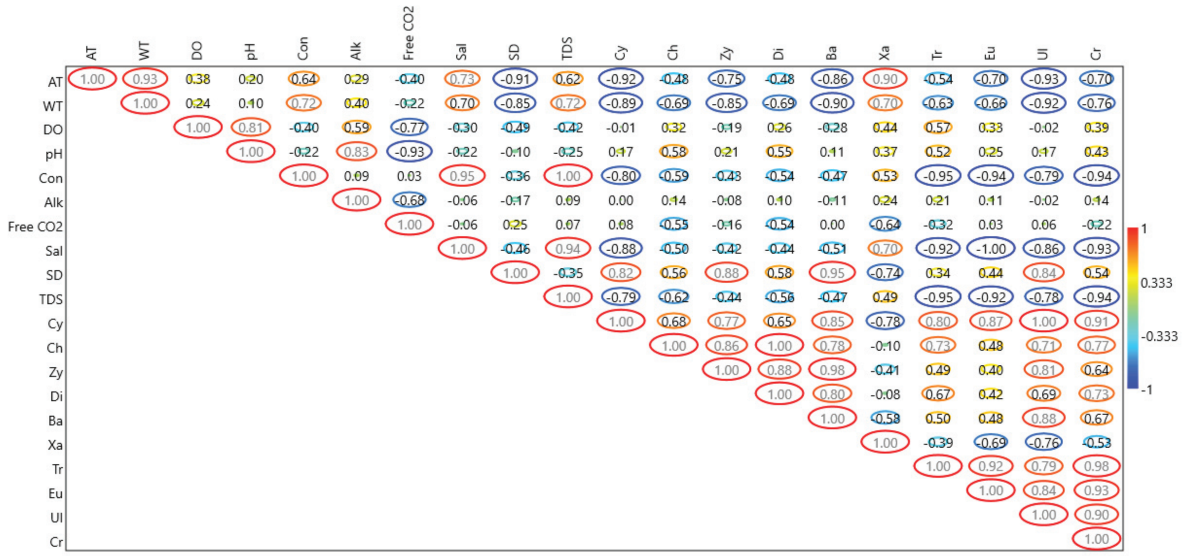

Figure 7: Pearson correlation coefficients of physiochemical variables with phytoplankton classes in Kaptai Lake. Negative correlations are shaded blue; positive correlations are shaded red. The strength of the correlation is indicated by the oval size. ($p < 0.01$). AT: Air Temperature; WT: Water Temperature; DO: Dissolved Oxygen; Con: Conductivity; Alk: Alkalinity, Sal: Salinity; SD: Transparency; TDS: Total Dissolved Solids; Cy: Cyanophyceae; Ch: Chlorophyceae; Zy: Zygnematophyceae; Di: Dinophyceae; Ba: Bacillariophyceae; Xa: Xanthophyceae; Tr: Trebouxiophyceae; Eu: Euglenophyceae; Ul: Ulvophyceae; Cr: Chrysophyceae.

temperature of plankton production and water dilution in the monsoon month. Arumugam & Furtado [31] and Sreenivasan [32] reported large amounts of phytoplankton in some tropical lakes in the summer [31,32]. Bharadwaja [33] also pointed out temperature and light as the causes of phytoplankton population growth. Similarly, Pearson correlation analysis results confirmed different phytoplankton classes were positively and negatively correlated with air temperature (Figure 3). Mustafa & Ahmed [34] recorded the lowest amount of phytoplankton in monsoon months. In the monsoon season, phytoplankton production is reduced due to heavy rainfall, high turbidity, low pH and low nutrients, along with the consumption of phytoplankton by zooplankton and fishes, etc. [35]. Varma [36] have reported phytoplankton density in different seasons in order of summer > winter > monsoon, which supports these findings. These observations agree with the results of the present study.

The study recorded a higher percentage of Zygnematophyceae (39%), Cyanophyceae (33%), and Chlorophyceae (54%) in

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the pre-monsoon, monsoon, and post-monsoon seasons. According to the Plankton Ecology Group (PEG) model of freshwater systems, cryptophytes and chlorophytes dominate in the post-monsoon due to the available nutrients and low temperatures [37]. Moreover, Kosten, et al. [38] and Gillett, et al. [39] found that Cyanophyceae occur as the dominant plankton in warmer water temperatures with flushing of nutrients in the monsoon season.

In this study, the diversity indices popularly used, including species diversity index (H'), species richness index (d), evenness index (J'), and dominance index (D) were considered as explanatory variables of eutrophication levels, which to some degrees are interrelated. The results of the calculated ecological indexes of the Kaptai Lake (Figure 6) reflected changes in the phytoplankton community structure due to the impact of the monsoon climate. The Shannon diversity index (H') varied from 2.75 to 3.20. At the same time, the lowest phytoplankton structure stability during the pre-monsoon season and the highest stability of this structure was detected in the post-monsoon which corresponded to a moderate productive trophic status of the lake [40,41]. The dominance index (D), which determines the criteria of species diversity used to identify the habitats' main floral and faunal structures [42], was of the highest value in the post-monsoon period and immediately decreased in the monsoon season. The species richness index (d) was highest during the post-monsoon period, which correlated with maximal species richness of the phytoplankton community [25]. The evenness index (J') revealed a maximum value in the post-monsoon season. Authors such as [43-45] also recorded similar values of these studies in the Songhua River, China; Lake Matano, Indonesia; and the Santragachi Lake, India. The Kaptai Lake is identified as a diversified and integrated plankton community based on alpha diversity indices, which are similar [41].

Seasonal succession of phytoplankton genera

Throughout the sampling period, the phytoplankton community structure in Kaptai Lake showed significant seasonal succession. Cyanophyceae (*Planktothrix* and *Gloeocapsa*) and Bacillariophyceae (*Synedra*) were the most dominant genera in the monsoon season. Numerous field studies and statistical analyses have demonstrated that the dominance of Cyanophyta was directly related to the high temperatures [46,47]. Bacillariophyta may grow well and reproduce successfully in high temperatures, as demonstrated by Beliveau and Hickman [48]. Tsukada, et al. [49] found that Bacillariophyta grows better below 32°C. Bacillariophyta favors low temperatures and thrives in summer due to their favorable physiological conditions. In the post-monsoon, Chlorophyceae (*Pleodorina*) was dominant. Sreenivasan, et al. [32] presented the rich phytoplankton community in Bhavanisagar Lake, where green blooms occurred with seasonal variations.

Interaction of phytoplankton classes physiochemical variables

The results revealed that Zygnematophyceae dominated during the pre-monsoon season, while the dominant period of Cyanophyceae was in the monsoon and Chlorophyceae was in the post-monsoon. CCA results showed that the Zygnematophyceae was positively correlated with DO, and DO was highest in the pre-monsoon (Table 1). A similar result was also found in the Loumbila reservoir in Western Africa. They stated this was due to the ecological characteristics of this algae to grow in less polluted water [50]. Coesel [51] and Nygaard [52] marked this class for water quality assessments for the sensitivity to water quality. However, with the increase in rainfall, pH decreases in the monsoon season, and the CCA result showed Cyanophyceae was negatively correlated with pH and temperature. The optimum growth temperature for Cyanophyceae is 25–30 °C [53]. Most cyanobacteria grow in neutral to alkaline environments, where the optimal pH ranges from 7.5 to 10 [54,55]. It has been reported that Chlorophyceae was positively correlated with pH and water temperature in the post-monsoon season. The optimal temperature and pH for Chlorophyceae growth is 20 to 30 °C and pH 7-9 [56]. The SIMPER analysis showed that Zygnematophyceae, Dinophyceae, and Bacillariophyceae classes were responsible for seasonal dissimilarities. All those classes were positively correlated with transparency and negatively correlated with temperature (Figure 7). In this study, the most crucialphysico–chemical variables structuring the phytoplankton community in Kaptai Lake are TDS, conductivity, alkalinity, transparency, air temperature, and water temperature (Figure 6).

The community structure of phytoplankton, and zooplankton, their interaction, and water nutrients data can exhibit the complete scenario of plankton diversity, which were not taken into account in this study due to the limitation of facilities. The current study examined phytoplankton with physicochemical variables although the data employed in this study was insufficient in terms of sampling sites (close and away from the discharge point of feeding rivers). Regardless, this study provides information concerning the current status of phytoplankton and their interaction with physicochemical variables in Kaptai Lake. For further analysis of the Kaptai Lake fisheries, parameters that were not considered, as well as a large number of sampling areas, should be suggested. The current study serves as a benchmark for ecosystem management of Kaptai Lake fisheries.

Conclusion

In this study, the concept of phytoplankton community structure was assessed to better understand their seasonal variation in the largest lake of Bangladesh. In general, the abundance of phytoplankton was abundant compared to other freshwater lakes. Based on the diversity index, Kaptai Lake is blessed with a diverse and integrated phytoplankton community. Seasonally, the main phytoplankton groups are Zygnematophyceae, Dinophyceae, and Bacillariophyceae which cause the seasonal variation. Water temperature varied significantly with the season; other physicochemical variables remained almost the same. Although TDS, conductivity, transparency, temperature, and alkalinity are responsible for the changes. The study revealed that Zygnematophyceae prevailed in the pre-monsoon when TDS and conductivity were high due to high evaporation. While, in the monsoon, Dinophyceae was

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dominant and influenced by the pH and transparency of the water. In the post-monsoon, Bacillariophyceae prevailed and were influenced by alkalinity. The phytoplankton abundance is high to support fish growth. This study reveals the importance of physicochemical variables in influencing phytoplankton groups and identifies that Kaptai Lake is blessed with a diverse and integrated phytoplankton community. Future research is needed to study the spatio-temporal pattern of plankton communities with the availability of fish in significant fishing areas. The findings can lead to an understanding of the enriched ecosystem of Kaptai Lake.

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Author contributions

Rabina Akther Lima: Conceptualization, Data Collection, Writing Original Draft, Analysis; Azhar Ali: Conceptualization, Data Collection, Review & Editing; Md. Khaled Rahman: Data Collection, Data Analysis, Review & Editing; B.M. Shahinur Rahman: Data Collection, Data curing; Md. Lipon Mia: Data Collection, Methodology; Ehsanul Karim: Conceptualization, Experimental design, Review & Editing, and Yahia Mahmud: Monitoring, Review & Editing.

Ethical statement

This study adhered to ethical research practices during field sampling and data collection. No permits were required for collecting phytoplankton samples from Kaptai Lake, as Bangladesh does not have specific regulations for environmental sampling in freshwater bodies. During sample collection, care was taken to minimize disturbance to the lake ecosystem. All collected samples were preserved following standard protocols to ensure their integrity for analysis.

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