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Plankton Abundance and its Nexus with Climatic and Water Quality Parameters in the Nile Tilapia (*Oreochromis niloticus*) Broodfish Pond

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ABSTRACT

This study aimed to determine the relationship between the abundance of phytoplankton and zooplankton, climatic variables, and water quality parameters in a tilapia broodfish pond. Water quality parameters were daily collected while plankton abundance was monthly recorded. Daily climatic data were obtained from the local Meteorological Department of Bangladesh. Throughout the study period, fluctuations were detected in both climatic and water quality parameters. Phytoplankton abundance showed annual variations, with the highest value of $10x10^5$/ L recorded in June and the lowest value of $3.5x10^5$/ L in December. Similarly, zooplankton exhibited seasonal fluctuations, with the highest value of $10x10^5$/ L in October and the lowest value of $2.3x10^5$/ L in January. Among the phytoplankton composition, Chlorophyceae accounted for 52% of the total, followed by Bacillariophyceae, Cyanophyceae, and Euglenophyceae. On the other hand, Rotifera constituted 29% of the total zooplankton, followed by Cladocera, Copepoda, and Protozoa. The fluctuations in phytoplankton and zooplankton abundance were influenced by both climatic factors and water quality parameters. The canonical correlations between the pairs of canonical variates were estimated at 1.000 and 0.883, with significance probabilities of 0.054 and 0.631, respectively. The initial canonical function showed a strong correlation of 1.00 (100%) between climatic variables, water quality parameters, and plankton abundance. In addition, this study revealed a negative relationship between plankton abundance and factors, such as air temperature, rainfall, water temperature, pH, and ammonia levels, while a positive correlation was observed with dissolved oxygen (DO) levels. The second canonical function showed a significant correlation of 0.883 (88.3%) between climatic variables, water quality parameters, and plankton abundance. In this context, phytoplankton abundance exhibited a negative correlation with dissolved oxygen and solar intensity, while showing an opposite relationship with water transparency. Similarly, zooplankton abundance showed a positive relationship with water transparency, but an opposite relation with dissolved oxygen and solar intensity.

INTRODUCTION

Climate change has significant global impacts on aquatic organisms, especially due to temperature changes **(Brasil *et al.*, 2020)**. The increasing global temperatures disrupt the thermal conditions that aquatic organisms rely on for their survival and reproductive success **(Nyanti *et al.*, 2018)**. Climate change has profound effects on the structure, function, life cycles, and behaviors of organisms in freshwater ponds. The predominant fish farming method in Bangladesh centers around freshwater pond-based aquaculture, responsible for producing more than 80% of the country's fish. Consequently, this farming system plays a crucial role in the generation of protein-rich food, financial income, and employment opportunities, contributing to both local and international value chains **(Gupta *et al.*, 1994; Haque *et al.*, 2013; Gatzweiler & Von Braun, 2016)**. The climate change effects in freshwater ponds include alterations in structure and function, shifts in seasonal patterns, accelerated biological processes, changes in precipitation, and fluctuations in water availability and quality. Even slight increases in temperature can push species beyond their tolerance limits **(Munday *et al.*, 2008; Rasconi *et al.*, 2017; Masum, 2019; Nahar & Hertini, 2020)**. Extreme weather events worsen the effects of climate change on freshwater pond ecology, causing disturbances, habitat loss, habitat degradation, reduced biodiversity, and decreased ecosystem resilience **(Santos *et al.*, 2011; Gubbins *et al.*, 2013; Jahan, 2018)**. Phytoplankton and zooplankton are essential components of pond ecosystems, playing vital roles in maintaining the health and productivity of the environment **(Pankhurst & Munday, 2011)**. Phytoplankton, which are microscopic photosynthetic algae, are primary producers that convert light, carbon dioxide, and nutrients into organic matter **(Fermin, 1988)**. Micronutrients such as vitamin A, E, C, selenium, zinc, and iron from plankton play a crucial role in reproductive tissue development, hormone level regulation, enhancement of sperm and egg quality, and promotion of larval growth and survival **(Rajendran *et al.*, 2014)**. They form the foundation of the food web and produce oxygen through photosynthesis. Phytoplankton uptake inorganic nutrients and contribute to nutrient cycling when they die or are consumed by zooplankton **(Ensign *et al.*, 2014; Rasconi *et al.*, 2015; Kürten *et al.*, 2019)**. Zooplankton, which are heterotrophic organisms, feed on phytoplankton, regulating their populations and maintaining water clarity **(Ahmed *et al.*, 2016; Rasconi *et al.*, 2017; Horn *et al.*, 2021)**. The interactions between phytoplankton and zooplankton in ponds play a crucial role in providing a vital food source for various organisms, aiding in nutrient recycling, and establishing a balanced ecosystem that supports overall functioning and sustainability **(Buczkowski, 1991; Kürten *et al.*, 2019; Florescu *et al.*, 2022)**.

Climatic variables such as air temperature, humidity, rainfall, and solar intensity all play significant roles in shaping the abundance of phytoplankton and zooplankton in a tilapia broodfish pond **(Siddique *et al.*, 2022)**. Air temperature affects water temperature, which in turn influences phytoplankton growth rates and metabolic activity. Warmer temperatures can lead to increased phytoplankton abundance, as they thrive in these conditions **(Abedin *et al.*, 2017)**. Higher air temperatures increase solar radiation, which promotes photosynthesis in phytoplankton **(Abedin *et al.*, 2017)**. However, warm temperatures can reduce dissolved oxygen levels, potentially limiting phytoplankton growth **(Kumar *et al.*, 2012; Abedin *et al.*, 2017)**. Zooplankton, which feed on phytoplankton, are directly affected by changes in phytoplankton abundance caused by temperature variations **(Yildiz *et al.*, 2010; Horn *et al.*, 2021)**. Humidity indirectly affects phytoplankton and zooplankton by influencing evaporation rates, water temperature, nutrient concentrations, and light availability **(Islam *et al.*, 2016; Karmakar, 2021)**. Higher humidity often leads to increased rainfall, which washes nutrients into the water and stimulates the growth of phytoplankton **(Alfonso *et al.*, 2017; Muringai *et***

***al.*, 2022)**. Rainfall introduces nutrients, such as nitrogen and phosphorus, into the pond, which fuels the growth of phytoplankton **(Brasil *et al.*, 2020; Ines *et al.*, 2022)**. However, heavy rainfall can reduce light availability and disrupt water clarity, which can impact phytoplankton abundance **(Pätynen *et al.*, 2014; Johnson *et al.*, 2018)**. Solar intensity directly affects phytoplankton by providing energy for photosynthesis, which promotes their growth and productivity **(Adebo & Ayelari, 2011; Nahar & Hertini, 2020)**. Excessive solar intensity can result in light limitation and lead to stratification, which can affect nutrient availability and phytoplankton abundance **(Adebo & Ayelari, 2011; Khan & Bari, 2019)**. The specific impacts of these factors on the plankton communities depend on species preferences, interactions with other environmental factors, and the composition of the tilapia broodfish pond ecosystem **(Znachor *et al.*, 2008; Hossain *et al.*, 2016)**. Water temperature directly affects the abundance of phytoplankton and zooplankton in a tilapia broodfish pond **(Rahaman *et al.*, 2019)**. Higher water temperatures accelerate the metabolic rates of these organisms, leading to increased growth and reproduction **(Li *et al.*, 2023)**. Water temperature also affects nutrient availability and vertical stratification, which can influence the abundance of phytoplankton **(Rasconi *et al.*, 2015)**. Additionally, dissolved oxygen levels in the water, influenced by water temperature, play a crucial role in the growth and survival of phytoplankton and zooplankton **(Kumar *et al.*, 2012; Hossain *et al.*, 2016; Abedin *et al.*, 2017; Hosen *et al.*, 2017)**. pH levels in the pond can influence nutrient availability, species preferences, and toxicity, thereby affecting the abundance and composition of planktonic organisms **(Golmarvi *et al.*, 2017; Chikere-Njoku & Njoku, 2019)**. Ammonia concentrations can directly and indirectly impact the abundance of phytoplankton and zooplankton by serving as a nutrient or becoming toxic **(Rahaman *et al.*, 2019)**. Water transparency, which is determined by light availability, affects the growth of phytoplankton and subsequently impacts zooplankton abundance **(Hossain *et al.*, 2016; Chukwu & Afolabi, 2017)**. Maintaining optimal conditions for water temperature, pH, dissolved oxygen, ammonia levels, and water transparency is crucial for supporting the abundance and productivity of phytoplankton and zooplankton in the tilapia broodfish pond **(Schabhüttl *et al.*, 2013)**.

Assessing the impact of climate change on the abundance of phytoplankton and zooplankton in pond water is crucial for several reasons. Phytoplankton and zooplankton play crucial roles in nutrient cycling, energy transfer, and overall ecosystem health **(Kürten *et al.*, 2019; Horn *et al.*, 2021)**. Changes in their abundance can have far-reaching impacts on the entire food web, ecosystem productivity, and stability **(Worm & Myers, 2003)**. Such assessments provide valuable insights into how climate change may influence these vital components and the resulting consequences for ecosystem functioning. Additionally, phytoplankton and zooplankton are essential for commercially important fish species such as tilapia, serving as primary producers and food sources **(Kürten *et al.*, 2019; Nahar & Hertini, 2020)**. Variations in plankton abundance directly affect the availability of food for fish populations, which in turn impacts their growth, reproduction, and overall productivity **(Buczkowski, 1991; Gubbins, 2013; Hasan *et al.*, 2015)**. Moreover, phytoplankton and zooplankton play a crucial role in maintaining water quality by regulating nutrients, oxygen levels, and water clarity **(Dupuis & Hann, 2009; Hossain *et al.*, 2019; Rollwagen-Bollens *et al.*, 2022)**. Changes in their abundance can affect these parameters, potentially leading to degradation of water quality and harmful conditions for aquatic life **(Ahmed *et al.*, 2003;**

Ghosh *et al.*, 2012; Alfonso *et al.*, 2017). Understanding the impact of climate change on plankton abundance facilitates proactive management to maintain optimal water conditions. Moreover, phytoplankton and zooplankton support biodiversity by serving as food sources for various organisms. Alterations in their abundance can disrupt intricate food webs, leading to shifts in species composition and diversity **(Ahsan *et al.*, 2012; Asaduzzaman *et al.*, 2020)**. Monitoring their responses to climate change provides valuable insights into broader ecological shifts, serving as an early warning system for potential ecosystem disruptions **(Asaduzzaman *et al.*, 2020)**. Overall, evaluating the influence of climate change on plankton abundance is essential for addressing the ecological, economic, and societal implications **(Alfonso *et al.*, 2017; Horn *et al.*, 2021)**. It enables the prediction and mitigation of impacts on the health and sustainability of freshwater environments. It also informs effective management strategies and conservation efforts in tilapia broodfish pond systems **(Horn *et al.*, 2021)**. Several previous studies have primarily focused on specific climatic factors, overlooking the combined impact of climatic factors and water quality parameters on plankton abundance in Bangladesh. There is a lack of research using multivariate analysis to understand the individual contributions of these variables within the complex dynamics. Consequently, this study aimed to assess the abundance of plankton in a broodfish pond that manages tilapia (*Oreochromis niloticus*), and to examine its relationship with climatic variables and water quality parameters. By integrating these factors, the research aimed to bridge the knowledge gap and provide insights into the complex dynamics underlying plankton abundance in the specific pond ecosystem.

MATERIALS AND METHODS

1. Ethics statement

This study strictly adhered to animal research guidelines, including the collection of plankton and water quality samples, following an approval from the Animal Welfare and Ethics Committee at Bangladesh Agricultural University (BAU) with the reference code BAURES/ESRC/FISH-11/2022.

2. Study area

The study was conducted in a tilapia broodfish pond situated at Dhala, Trishal, Mymensingh, Bangladesh. The study site is approximately 37km south of Bangladesh Agricultural University, Mymensingh, Bangladesh. The study spanned from February 2021 to January 2022.

3. Preparation of the broodfish pond

Three broodfish ponds, each covering an area of 21 decimals, were chosen as the study site. The ponds were repaired, and their bottoms were properly re-excavated. The average depth of each pond was 5 feet. Lime was applied at a rate of 5 kilograms per decimal on the pond bottom and inside the pond dike. Subsequently, the ponds were filled with water and maintained at an approximate depth of 3.5 feet in each pond. Once the water color turned greenish, broodfish were stocked, and the monitoring of plankton and water quality parameters began.

4. Determination of climatic variables and water quality parameters

Daily data on climatic variables, such as air temperature, humidity, rainfall, and solar intensity, were collected from the Meteorological Department of the local government at

Bangladesh Agricultural University, Mymensingh. Water quality parameters, such as water temperature, dissolved oxygen (DO), pH, ammonia, and water transparency, were measured on a daily basis using specific devices. These included a SMART sensor temperature meter (SMART Sensor AR 867) for water temperature, a DO meter (Lutron DO-5509) for dissolved oxygen, a pocket-sized pH meter (pH-107) for pH measurement, an ammonia test kit for ammonia levels, and a Secchi disk (20cm disk with alternating black and white quadrants) for measuring water transparency. Monthly average data were compiled and presented for further analysis.

5. Assessment of plankton abundance in tilapia broodfish pond

Samples of both phytoplankton and zooplankton were collected using plankton nets with different mesh sizes: 15µm for phytoplankton and 90µm for zooplankton from the surface water layer in the morning. These samples were preserved on-site in 250mL dark sterile plastic bottles containing a 5% formalin solution. Subsequently, the identification and quantitative analysis of both phytoplankton and zooplankton were conducted in the laboratory of the Department of Fisheries Biology and Genetics at Bangladesh Agricultural University. The identification process involved using a compound microscope (Olympus CX 43) equipped with a camera (Olympus EP 50) with magnifications of 16×40 and 16×10, and both bright field and phase contrast illumination. To conduct the quantitative analysis, we used a Sedgewick-Rafter counting chamber (S-R cell). This process involved transferring a 1mL sub-sample from each collected sample to the Sedgewick-Rafter counter, and then counting the cells within 10 randomly selected squares. The resulting cell counts were used to calculate the cell density using specific formulas based on Stirling's estimation.

$$N=(A\times1000\times C)/(V\times F\times L) \quad \text{..................................(1)}$$

where, N= No. of plankton cells or units per liter of original water; A=Total no. of plankton counted; C= Volume of final concentrate of the sample in ml; V= Volume of a field in cubic mm; F= No. of fields counted, and L=Volume of original water in liter.

The identification and enumeration of phytoplankton and zooplankton were conducted up to the genus level using the methods outlined in **APHA (1992)** and **Bellinger, E.G. (1992)**. The average quantity of phytoplankton was measured and expressed in terms of the number per liter of water in the pond.

6. Correlation between the climatic variables, water quality parameters and plankton abundance

To examine the relationship between climatic variables, water quality parameters, and plankton abundance, canonical correlation analysis (CCA) was conducted using SPSS version 23. CCA involves deriving one or more canonical functions, where each function consists of a pair of variables: one serving as an explanatory or independent variable (such as climatic variables and water quality parameters), and the other as a response or dependent variable (phytoplankton and zooplankton abundance). The first canonical function extracted captures the maximum variance between the two sets of variables, representing the highest possible inter-correlation. The second canonical function explains the remaining variance.

Two main criteria were used to select the canonical function for interpretation: the statistical significance level of the function and the magnitude of the canonical correlation. In this study, explanatory variables were described by Y variables in vector c = (c1, c2 , . . . , cY), and response variables were described by X variables in vector k = (k1 , k2 , . . . , kX). Thus, number of observations j can be described by the vectors:

$$\begin{bmatrix} c_1 \\ k_1 \end{bmatrix} \ldots\ldots \begin{bmatrix} c_n \\ k_n \end{bmatrix}$$

with a partitioned sample

$$\bar{x} = \begin{bmatrix} \bar{x}_c \\ \bar{x}_k \end{bmatrix}$$

and a partitioned sample variance

$$S = \begin{bmatrix} S_{cc} & S_{kc} \\ S_{kc} & S_{kk} \end{bmatrix}$$

where,

$$S_{cc} = \frac{1}{n-1}\sum_{j=1}^{n}(c_j - \bar{x}_c)(c_j - \bar{x}_c)'$$

$$S_{kk} = \frac{1}{n-1}\sum_{j=1}^{n}(k_j - \bar{x}_k)(k_j - \bar{x}_k)'$$

and

$$S_{ck} = \frac{1}{n-1}\sum_{j=1}^{n}(c_j - \bar{x}_c)(k_j - \bar{x}_k)'$$

The variance-covariance matrices S_{cc} and S_{kk} consist of variances and covariances within groups for the explanatory and response variables, respectively. On the other hand, the variance-covariance matrices S_{kc} and S_{ck} encompass the covariances between variables from different groups. The canonical functions, represented by vectors s = (s_1, s_2, ..., s_Y) and p = (p_1, p_2, ..., p_X), are obtained through linear combinations of the explanatory and response variables. The s vector contains the climatic variables (explanatory variables) in canonical variates, resulting from the combination of the c vector and the canonical coefficients vector a, expressed as s = a'c. Similarly, the p vector contains the growth parameters (response variables) in canonical variates, resulting from the combination of the k vector and the canonical coefficient vector b, expressed as p = b'k. The estimation of the canonical correlation coefficients a and b is based on the variance-covariance matrices of the original sets of explanatory and response variables, as explained by Eqs. (2) and (3), respectively:

$$S_{cc}^{-1}S_{ck}S_{kk}^{-1}S_{kc}a_i = \lambda_i a_i \qquad (2)$$

$$S_{cc}^{-1}S_{ck}S_{kk}^{-1}S_{kc}b_i = \lambda_i b_i \qquad (3)$$

The pairs of canonical variables (s_i, p_i) resulting from the linear combination, such as s_i = a_i'c and p_i = b_i'k, exhibit stronger correlation and greater independence compared to the pairs of variables (s_i+1, p_i+1) generated by $s_i+1 = a_i+1'c$ and $p_i+1 = b_i+1'k$. This iterative process is repeated until the final pairs of canonical variables, s_Y and p_Y, are obtained. Consequently, canonical correlation analysis (CCA) aims to maximize the correlation between the pairs of canonical variables, $s_1 = a_1'c$ and $p_1 = b_1'k$, while ensuring that the second pair, $s_2 = a_2'c$ and $p_2 = b_2'k$, remains uncorrelated with the values of s_1 and p_1.

7. Statistical analysis

Regular tracking and compilation of data were consistently conducted using Microsoft Excel 2016. Descriptive statistics, such as the maximum, minimum, and average values with standard errors, for climatic variables, water quality parameters, and plankton abundance analysis, were conducted using SPSS version 2023. Moreover, Microsoft Excel 2016 was used to create various graphs that illustrate the results.

RESULTS

1. Determination of climatic variables and water quality parameters

Throughout the study period, there were fluctuations in climatic variables, such as air temperature, humidity, rainfall, solar intensity, as well as water quality parameters including water temperature, dissolved oxygen (DO) levels, pH, ammonia concentration, and water transparency. The observed ranges for the climatic variables were as follows: air temperature ranged from 18.93 to 30.12°C, humidity varied between 75 and 85.8%, rainfall ranged from 0 to 485mm, and solar intensity varied from 3.02 to 7.9 hours. Regarding the water quality parameters, the water temperature fluctuated between 20.81 and 31.23°C, dissolved oxygen (DO) levels ranged from 7.09 to 10.65mg/ L, pH values varied from 7.36 to 10.32, ammonia concentrations ranged from 0 to 0.333mg/ L, and water transparency varied between 15.37 and 27.05cm. Fig. (1) illustrates the monthly variation of selected climatic factors, water quality parameters, and plankton abundance during the study period. Table (1) presents the highest, lowest, and average values (±SE) for each of these variables.

Table 1. The highest, lowest and average (±SE) of climatic variables and water quality parameters of tilapia broodfish pond

Parameter	Highest	Lowest	Average
Air temperature (°C)	30.12	18.93	26.48±1.08
Humidity (%)	85.8	75	80.96±1.15
Rainfall (mm)	485	0	126.52±51.29
Solar intensity (hour)	7.9	3.02	5.20±0.52
Water temperature (°C)	31.23	20.81	28.89±0.90
DO (mg/L)	10.65	7.09	8.20±0.25
pH	10.32	7.36	9.00±0.28
Ammonia (mg/L)	0.33	0	0.08±0.03
Water transparency (cm)	27.05	15.37	20.89±0.95

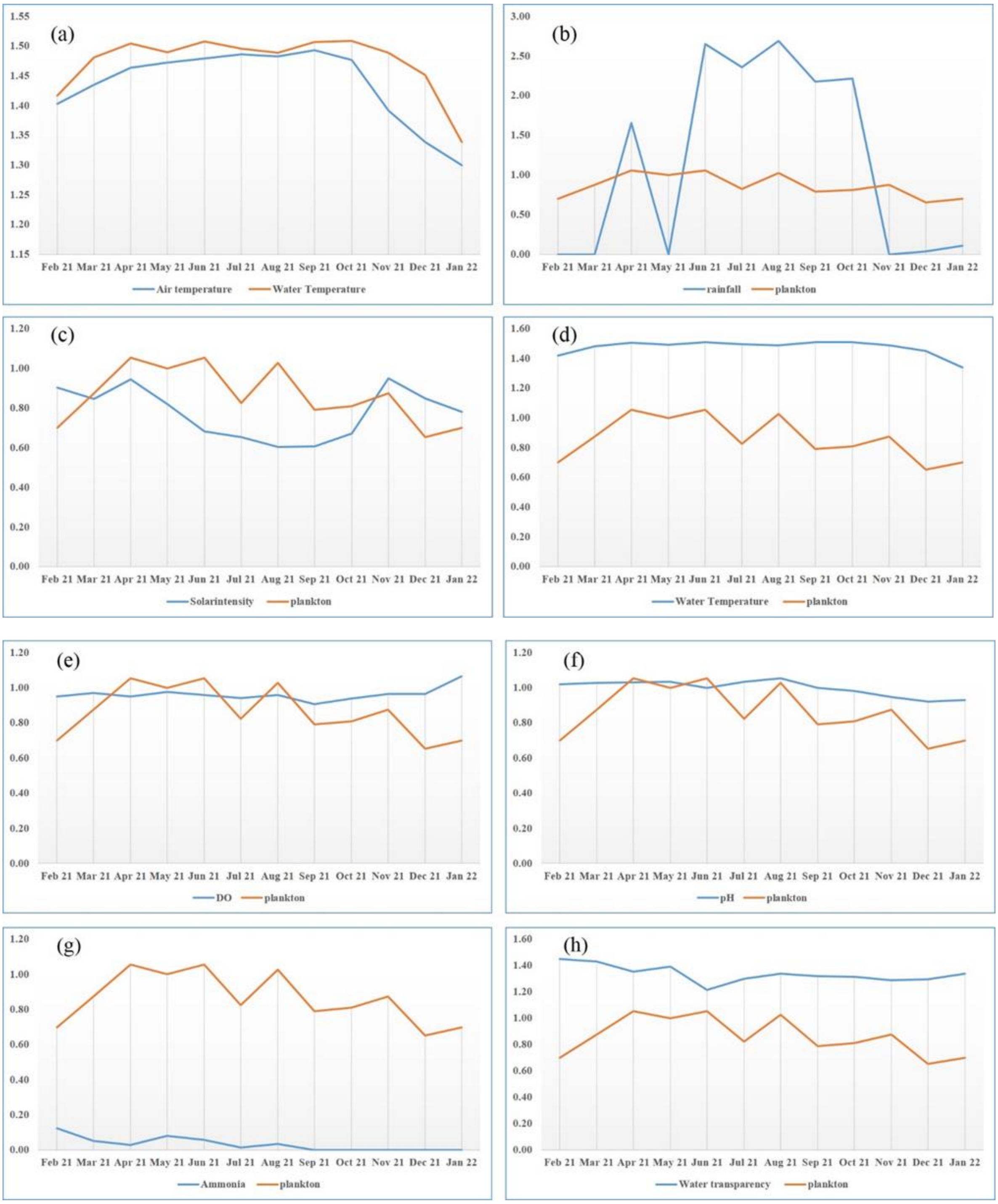

Fig. 1. Monthly variation of selective climatic variables and water quality parameters in relation with plankton abundance; **(a)** Air & water temperature, **(b)** Rainfall & plankton, **(c)** Solar intensity & plankton, **(d)** Water temperature & plankton, **(e)** DO & plankton, **(f)** pH & plankton, **(g)** Ammonia & plankton, **(h)** Water transparency & plankton

2. Assessment of plankton abundance of tilapia broodfish pond

Monthly variations in plankton abundance were observed throughout the study period. The months of April and June exhibited the highest abundance of phytoplankton, with a count of 10.3 x 10^5 cells per liter, while December had the lowest count at 3.5 x 10^5 cells per liter. Regarding specific phytoplankton groups, the highest number of Bacillariophyceae (3.3

x 10^5 cells per liter) was observed in April, whereas December had the lowest count (0.7 x 10^5 cells per liter). For Chlorophyceae, the highest count of 7.2 x 10^5 cells per liter was recorded in June, while the lowest count of 1.0 x 10^5 cells per liter was observed in December. Cyanophyceae exhibited the highest count of 3.0 x 10^5 cells per liter in April, with the lowest count of 0.2 x 10^5 cells per liter occurring in September. Finally, the Euglenophyceae reached its peak count (0.83 x 10^5 cells per liter) in September, while the lowest counts (0.17 x 10^5 cells per liter) were recorded in January and July. Based on the percentage breakdown, Chlorophyceae accounted for 52% of the total, Bacillariophyceae constituted 24%, Cyanophyceae made up 18%, and Euglenophyceae comprised 6% (Fig. 2a). Similarly, the highest number of zooplankton (10.0 × 10^5/ L) was recorded in October, while the lowest (2.8 × 10^5/ L) was recorded in January. Regarding specific zooplankton groups, the highest number of Copepoda (2.7 × 10^5 units per liter) was observed in February, whereas November had the lowest count (0.3 × 10^5 units per liter). For Rotifera, the highest count (3.5 x 10^5 units per liter) was recorded in October and June, while the lowest count (0.5 x 10^5 units per liter) was observed in April. The highest count of Cladocera (2.7 x 10^5 units per liter) was observed in March, while the lowest count (0.3 x 10^5 units per liter) occurred in November. Finally, the highest count of protozoa (4.0 x 10^5 units per liter) was recorded in September, while the lowest counts (0.3 x 10^5 units per liter) were found in June. Table (2) shows the highest, lowest, and average (±SE) numbers of plankton within different groups. Based on the percentage breakdown, Rotifera accounted for 29% of the total, Cladocera constituted 27%, Copepoda made up 24%, and Protozoa comprised 20% (Fig. 2b).

Table 2. The highest, lowest and average (±SE) number of Plankton in tilapia broodfish pond

Parameter	**Highest** (No.X10^5) cells/L	**Lowest** (No.X10^5) cells/L	**Average** (No.X10^5) cells/L
Phytoplankton abundance	10.3	3.5	6.7±0.7
Baciollairophyceae	3.3	0.7	1.6±0.2
Chlorophyceae	7.2	1.0	3.5±0.5
Cyanophyceae	3.0	0.2	1.2±0.2
Euglenophyceae	0.83	0.17	0.4±0.1
Zooplankton abundance	10.0	2.8	5.4±0.6
Copepoda	2.7	0.3	1.3±0.2
Rotifera	3.5	0.5	1.6±0.3
Cladocera	2.7	0.3	1.4±0.2
Protozoan	4.0	0.3	1.1±0.3

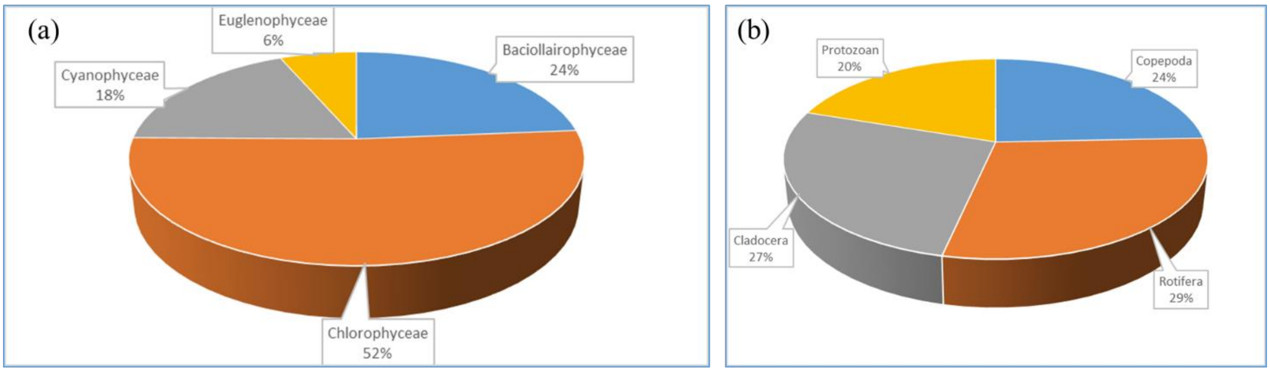

Fig. 2. Percentage breakdown of plankton in different groups; **(a)** Phytoplankton groups, **(b)** Zooplankton groups

3. Canonical correlation analysis between climatic variables, water quality parameters and plankton abundance

To assess the correlations between multivariate sets of variables, we conducted canonical correlation analysis (CCA) and summarized the canonical functions in Table (3). CCA illustrates the pattern of correlations between climatic variables (air temperature, humidity, rainfall, and solar intensity), water quality parameters (water temperature, dissolved oxygen, pH, ammonia, and water transparency), and plankton abundance in a tilapia broodfish pond. Estimated canonical correlations between the pairs of canonical variates were 1.000 and 0.883, with probabilities of significance of 0.054 and 0.631, respectively (Table 3).

Table 3. Canonical correlations analysis among climatic variables, water quality parameters and plankton abundance

Canonical correlations analysis		
Variable	1	2
Independent variable		
Air temperature	−0.871	
Humidity		
Rainfall	−0.456	
Solar intensity		−0.214
Water temperature	−0.729	
DO	0.496	−0.320
pH	−0.793	
Ammonia	−0.427	
Water transparency		0.434
Dependent variable		
Phytoplankton abundance	−0.716	−0.698
Zooplankton abundance	−0.828	0.560
Canonical correlations	1.000	0.883

3.1. Characteristics of canonical function 1

The summary of the first canonical function is presented in Table (3) and Fig. (3), illustrating the correlations between climatic variables (air temperature and humidity) and water quality parameters (water temperature, pH, and dissolved oxygen) and plankton abundance in a tilapia broodfish pond. The first canonical function shows a very strong correlation of 1.00 (100%) between the climatic variables, water quality parameters, and plankton abundance (Fig. 3). The response variables phytoplankton (-0.716) and zooplankton (-0.828) were associated with the explanatory variables: air temperature (-0.871), rainfall (-0.456), water temperature (-0.729), dissolved oxygen (0.496), pH (-0.793), and ammonia (-0.429). In this case, the production of plankton in the broodfish pond is negatively correlated with factors, such as air temperature, rainfall, water temperature, pH, and ammonia levels. Conversely, there is a opposite correlation between plankton production and levels of dissolved oxygen (DO).

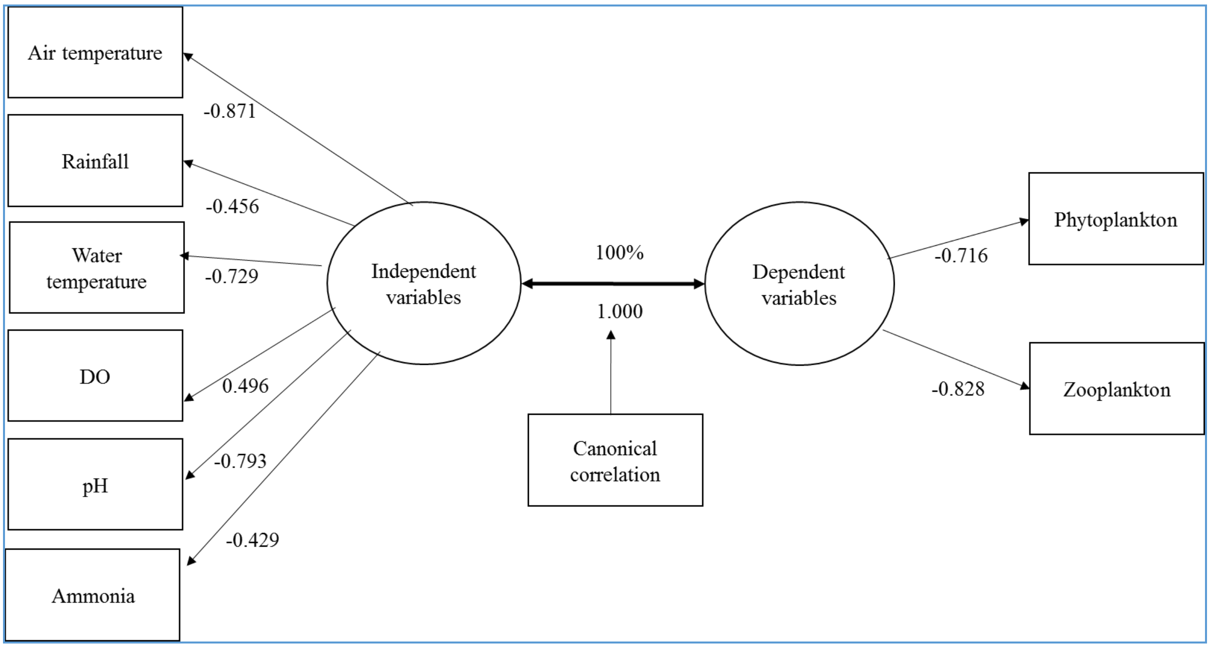

Fig. 3. Canonical correlation 1 (adopted from Table 3) among climatic variables, water quality parameters and plankton abundance

3.2. Characteristics of canonical function 2

The second canonical function revealed a significant correlation of 0.883 (88.3%) between the climatic variables, water quality parameters, and plankton abundance, as presented in Table (3) and illustrated in Fig. (4). Phytoplankton (-0.698) and zooplankton (0.560) were found to be linked to solar intensity (-0.214), dissolved oxygen (DO) (-0.320), and water transparency (0.434). In this context, the abundance of phytoplankton displayed a negative correlation with both dissolved oxygen and solar intensity, while demonstrating a converse association with water transparency. Likewise, the abundance of zooplankton exhibited a favorable correlation with water transparency, but conversely, it displayed an opposite relationship with dissolved oxygen and solar intensity.

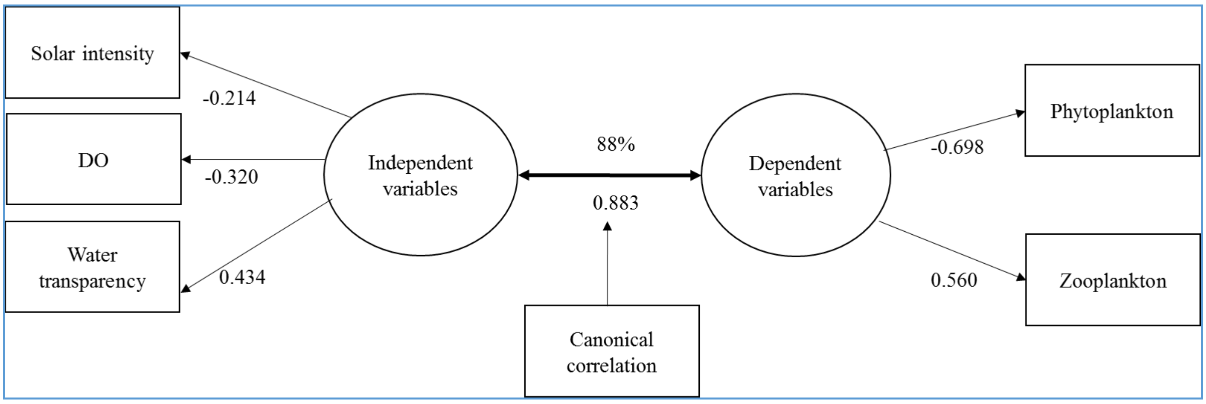

Fig. 4. Canonical correlation 2 (adopted from Table 3) among climatic variables, water quality parameters and plankton abundance

DISCUSSION

The investigation of plankton abundance in tilapia broodfish ponds reveals an intricate relationship with climatic variables and water quality parameters. The investigation examines the effects of temperature, precipitation, and other climatic factors, as well as water quality indicators, on the composition and abundance of plankton in these ponds. Understanding this relationship is crucial for optimizing the environmental conditions that affect plankton dynamics, thereby contributing to the overall health and productivity of tilapia broodfish populations in aquaculture settings **(Haque *et al.*, 2010; Khanom *et al.*, 2020; Alam *et al.*, 2021)**. We observed monthly fluctuations in the abundance of phytoplankton and zooplankton in relation to climatic variables and water quality parameters. The highest phytoplankton count (10.3 x 10^5/ L) occurred in April and June, while the lowest (3.5 x 10^5/ L) was in December. For zooplankton, the highest count (10.0 × 10^5/ L) was in October, and the lowest (2.8 × 10^5/ L) was in January. The dominant phytoplankton groups were Chlorophyceae (7.2 x 10^5 cells/ L), followed by Bacillariophyceae, Cyanophyceae, and Euglenophyceae. Among zooplankton groups, protozoa (4.0 x 10^5 cells/ L) were predominant, followed by rotifers, copepods, and cladocerans. Consistent with previous studies **(Adeogun *et al.*, 2005; Ahsan *et al.*, 2012; Siddika *et al.*, 2013; Hossain *et al.*, 2016)**, the present study found a significant correlation (1.000 and 0.883) between water quality parameters, climatic variables, and plankton abundance in the tilapia broodfish pond. Monthly variations in tilapia production were attributed to seasonal changes, nutrient availability, reproductive cycles, predation, consumption of tilapia broodfish, and water management practices **(Varela *et al.*, 2008; Kim *et al.*, 2019; Asaduzzaman *et al.*, 2020)**. The canonical correlation analysis revealed strong positive correlations (100 and 88%) between plankton abundance and climatic and water quality parameters, highlighting their interdependence. The study's findings align with the influence of physical and chemical properties on aquatic ecosystems, which support diverse life forms **(Hossain *et al.*, 2016)**.

Understanding the abundance, composition, and seasonal variations of plankton is essential for efficient pond management and for optimizing ecosystems to enhance tilapia production **(Hambright and Zohary, 2002; Ahmed *et al.*, 2003)**.

The air temperature ranged from 18.93 to 30.12°C, with an average of 26.48± 1.08°C during our study period. The initial canonical function revealed a negative correlation between air temperature (-0.871) and the abundance of phytoplankton and zooplankton (-0.716 and -0.828), suggesting that lower air temperatures were associated with reduced abundance. The second canonical function suggested a contrasting relationship, indicating that higher air temperatures (0.042) were associated with reduced phytoplankton levels. The study revealed a complex correlation between air temperature and the abundance of phytoplankton and zooplankton, with an indirect influence on their growth and distribution through water temperature in the broodfish pond. Various studies support the significant impact of air temperature on plankton abundance **(Laurel *et al.*, 2008; Hossain *et al.*, 2016)**. Higher temperatures usually lead to increased phytoplankton growth rates, which in turn result in greater overall abundance **(Rahman *et al.*, 2017)** and support larger zooplankton populations due to a more abundant food source. Extremely high temperatures, however, can have detrimental effects on plankton communities, leading to thermal stress and reduced abundance **(Sultana *et al.*, 2017)**. **Kapetsky (2000)** emphasizes the importance of meteorology in fisheries and aquaculture. Solar radiation and air temperature influence water temperature, which in turn affects the natural productivity of both inland and marine waters and the growth of various species involved in fisheries. In accordance with the initial canonical correlation findings of the study, the independent variable of air temperature made a significant contribution, explaining a variance of -0.871 or 87%. This correlation consistently align with the earlier mentioned results for the dependent variables of phytoplankton abundance (-0.716) and zooplankton abundance (-0.828).

Humidity levels ranged from 75 to 85.8%, with an average of 80.96± 1.15% in our study. The first canonical function indicated a negative relationship between humidity (-0.085) and both phytoplankton and zooplankton (-0.716 and -0.828), suggesting that decreased humidity correlated with decreased abundance. The second canonical function revealed an inverse relationship, with humidity (0.029) and both phytoplankton and zooplankton (-0.716 and -0.828), indicating that increased humidity correlated with decreased phytoplankton levels. Overall, the study did not show a strong correlation between humidity and the abundance of phytoplankton and zooplankton. Previous research highlights the indirect influence of plankton abundance on rainfall patterns **(Karmakar, 2021)**. Higher humidity often correlates with increased rainfall, which enhances nutrient inputs into aquatic systems **(Sallam & Elsayed, 2015)**. Climate factors, such as air temperature and relative humidity, have a significant impact on water circulation and lake quality in the Egyptian coastal area of the Nile Delta **(Sallam & Elsayed, 2015)**. Increased nutrient availability stimulates the growth of phytoplankton, which in turn supports larger zooplankton populations. Phytoplankton serves as a valuable biological indicator for evaluating the health and productivity of aquatic ecosystems, especially in nutrient-rich environments **(Rochelle-Newall *et al.*, 2011; Dutkiewicz *et al.*, 2014)**.

Rainfall from May to September in the study area, averaging 126.52± 51.29mm, facilitated the plankton growth in the broodfish pond during the study. The first canonical function (-0.456) showed a negative correlation between the reduced rainfall and lower levels of phytoplankton and zooplankton (-0.716 and -0.828, respectively). The second canonical function supported this relationship. Various studies have indicated that rainfall has a significant impact on plankton dynamics, affecting nutrient runoff and promoting phytoplankton growth **(Tewabe, 2014; Haque *et al.*, 2015; Khan & Bari, 2019; Kürten *et al.*, 2019)**. Studies have noted that rainfall triggers upwelling, which influences fisheries **(Atindana *et al.*, 2019)**. Intense rainfall also affects the composition and biomass of phytoplankton **(Ahn *et al.*, 2002; Hong *et al.*, 2002; Zhou *et al.*, 2012)**. Brownification resulting from rainfall reduces water transparency and primary production **(Ekström *et al.*, 2011; Graneli, 2012)**. Seasonal rainfall patterns impact dam hydrology and alter phytoplankton dynamics **(Znachor *et al.*, 2008)**. Excessive water withdrawal after rainfall alters the composition of phytoplankton in reservoirs **(Rychtecký & Znachor, 2011)**.

Solar intensity during the study showed lower values from June to October, which was attributed to increased rainfall and humidity, ranging from 3.02 to 7.90 hours with an average of 5.20± 0.52 hours. The first canonical function revealed an inverse correlation between solar intensity (0.296) and levels of phytoplankton and zooplankton (-0.716 and -0.828). The second canonical function supported this relationship. Solar intensity, which is crucial for driving photosynthesis in phytoplankton, influences primary production and promotes phytoplankton growth **(Huq *et al.*, 2003; Zhang *et al.*, 2011; Zhou *et al.*, 2012)**. Increased phytoplankton abundance supports zooplankton, potentially leading to higher zooplankton abundance. Temperature significantly affects the growth rates of phytoplankton, especially in relation to the availability of light **(Edwards *et al.*, 2016)**. Phytoplankton growth is less affected by overall temperature due to the presence of light limitation **(Edwards *et al.*, 2016)**.

We observed that the water temperature in the area ranged from 20.81 to 31.23°C, with an average of 28.89± 0.90°C. This was influenced by factors, such as air temperature, humidity, rainfall, and solar intensity. Fluctuations in water temperature were found to have a negative correlation with phytoplankton and zooplankton levels, highlighting their significant influence on the abundance of these organisms in the broodfish pond. Solar intensity also exhibited a negative correlation with plankton levels. Our findings are consistent with studies that highlight the significant influence of water temperature on plankton abundance **(Mohanty *et al.*, 2010; Ghosh *et al.*, 2012; Jerin *et al.*, 2016; Makori *et al.*, 2017)**. Warmer water temperatures promote the growth of phytoplankton, which in turn supports larger zooplankton populations **(Muringai *et al.*, 2022)**. However, extreme temperature fluctuations can disrupt plankton communities and change species composition **(Siddika *et al.*, 2013)**. **Ghosh *et al.* (2012)** investigated the significance of physicochemical parameters in pond water and their correlation with zooplankton fluctuations, which are essential for fish culture and fisheries management. Fish growth is heavily dependent on factors, such as water temperature, pH, dissolved oxygen, free CO2, alkalinity, and salinity **(Nikolsky, 1963; Jhingran, 1985)**. **Kim *et al.* (2019)** emphasize the mesoscale influences on plankton in Korean waters, which are affected by warm currents and nutrient upwelling. This ecological function is supported by previous studies of **Suh *et al.* (1999)**, **Jeong *et al.* (2009)**, **Kim *et al.***

(2010) and **Kim *et al.* (2011)**. **Rasconi *et al.* (2015)** observed that higher temperatures change the structure of plankton communities, favoring smaller species and boosting primary productivity. The comprehensive study suggests that a 3°C temperature rise in low trophic state aquatic ecosystems can lead to a shift toward dominance by fast-growing species **(Rasconi *et al.*, 2015)**.

Dissolved oxygen (DO) levels recorded during our study exhibited a range from 7.09 to 10.65mg/ L, with an average of 8.20± 0.25mg/ L. The complex fluctuations in dissolved oxygen (DO) were influenced by factors, such as air temperature, rainfall, water temperature, pH, ammonia, and plankton abundance. While staying within a safe range, dissolved oxygen significantly impacted plankton abundance. The initial canonical function unveiled an opposite correlation between dissolved oxygen (DO) and both phytoplankton and zooplankton, suggesting that higher levels of DO resulted in lower levels of plankton. Similarly, the second canonical function exhibited a negative association, indicating that a decrease in dissolved oxygen led to decreased plankton levels. These findings emphasize the significant influence of dissolved oxygen (DO) on plankton abundance in the tilapia broodfish pond. Previous studies emphasize the critical role of dissolved oxygen (DO) for the survival and metabolism of phytoplankton and zooplankton **(Ghosh *et al.*, 2012; Hossain *et al.*, 2016; Akter *et al.*, 2018)**. Adequate dissolved oxygen (DO) supports plankton growth, while low levels limit phytoplankton and impact zooplankton **(Smith & Piedrahita, 1988; Alfonso *et al.*, 2017)**. Elevated dissolved oxygen (DO) concentrations can change the composition of phytoplankton **(Abdel-Wahed *et al.*, 2018)**. Dissolved oxygen (DO) serves as the primary oxygen source for aerobic aquatic life, reflecting water quality and metabolic balance, moreover it is crucial for assessing water pollution levels **(Laluraj *et al.*, 2002; Hossain *et al.*, 2016)**. Zooplankton dynamics are influenced by light intensity, food availability, DO levels, and predation **(Hossain *et al.*, 2016)**. In intensive aquaculture, beyond low DO, increased nutrient presence poses concerns **(Sultana *et al.*, 2017)**, leading to phytoplankton blooms and declining pond water quality **(Gilbert *et al.*, 2001)**.

During the study, the pond water pH ranged from 7.36 to 10.32, with an average of 9.00± 0.28. The variation in pH, which is influenced by factors, such as air temperature, rainfall, water temperature, dissolved oxygen (DO), ammonia levels, and plankton abundance, remained within the alkaline range and did not pose any harm. The first canonical function showed a negative correlation between pH and both phytoplankton and zooplankton, indicating that a decrease in pH corresponded to a decrease in plankton levels. Similarly, the second canonical function also revealed a negative relationship, emphasizing the significant impact of pH on plankton abundance in the tilapia broodfish pond. Several previous studies, such as **Moser *et al.* (2012)**, **Siddika *et al.* (2013)** and **Abdel-Wahed *et al.* (2018)** have also shown that pH can affect plankton communities in a water body. It is essential to maintain optimal pH levels for plankton growth, since it can have implications for both phytoplankton and zooplankton populations **(Abdel-Wahed *et al.*, 2018; Talukder *et al.*, 2018)**. The decomposition of unutilized feed in aquaculture ponds, as observed by **Moser *et al.* (2012)**, **Shifat *et al.* (2018)**, and others, can result in increased bio-available nitrogenous and phosphorus compounds, higher CO2 concentrations, and reduced DO, pH, and alkalinity. These changes can impact fish feeding habits, grazing behavior, and growth **(Naser, 2018)**.

In one study, it was suggested that the total alkalinity levels should be above 40ppm, as recommended by **Talukder *et al.* (2018)** and **Asaduzzaman *et al.* (2020)**. This is consistent with the findings of the current study. Moreover, in feed and weed-based pond polyculture, relatively high total alkalinity levels were observed by **Hossain (2016)** and **Asaduzzaman *et al.* (2020)**. These levels could be linked to lower dissolved oxygen levels and increased free CO2 production with growing fish biomass **(Talukder *et al.*, 2018)**. Additionally, ocean acidification, as found by **Moser *et al.* (2012)**, can negatively impact shell and skeleton formation in planktonic and benthic organisms, including mollusks and corals.

Ammonia is an essential nutrient for phytoplankton, providing support for increased productivity and zooplankton abundance **(Domingues *et al.*, 2011)**. However, excessive levels can be toxic, with 0.1mg/ L considered the highest acceptable concentration **(Meade, 1985)**. In our study, ammonia concentrations in the pond varied from 0 to 0.33mg/ L, with an average of 0.08± 0.03mg/ L, influenced by various factors, including air temperature, humidity, rainfall, solar intensity, water temperature, dissolved oxygen (DO), pH, and plankton abundance. Canonical functions indicated a negative correlation between ammonia and both phytoplankton and zooplankton. This finding is consistent with a previous study by **Domingues *et al.* (2011)**, which examined the impact of pH on plankton. Nitrate and ammonium are crucial sources of nitrogen for phytoplankton growth, with their utilization varying **(Anderson & Davis, 2013; Hasan *et al.*, 2015; Horn *et al.*, 2021)**. While elevated ammonium levels can boost phytoplankton productivity, it challenges the belief that nitrate is always preferred **(Yoshiyama & Sharp, 2006; Domingues *et al.*, 2011)**.

Water transparency during the study fluctuated, ranging from 15.37 to 27.05cm, with an average of 20.89± 0.95cm. These variations are attributed to the abundance of plankton and the availability of nutrients. Canonical functions revealed a negative relationship between water transparency and both phytoplankton and zooplankton, highlighting the impact of these organisms on pond clarity. The abundance of phytoplankton demonstrated a negative correlation with both dissolved oxygen and solar intensity, while displaying an opposite association with water transparency. In parallel, the abundance of zooplankton indicated a positive correlation with water transparency, yet exhibited a opposite relationship with dissolved oxygen and solar intensity. Clearer water allows for greater light penetration, facilitating photosynthesis and increasing phytoplankton abundance **(Adeogun *et al.*, 2005; Pinto-Coelho *et al.*, 2005; Alfonso *et al.*, 2017; Chukwu & Afolabi, 2017; Vasconcelos *et al.*, 2018)**. Higher phytoplankton abundance benefits zooplankton, potentially enhancing fish productivity **(Dhawan & Kaur, 2002)**. The impact of filter-feeding fish, such as tilapia, on phytoplankton biomass and water transparency is controversial **(Rivera Vasconcelos *et al.*, 2018)**. Despite their efficient consumption of phytoplankton, tilapia's ability to suppress algal blooms and improve water transparency is considered low **(Hambright *et al.*, 2002; Turker *et al.*, 2003; Rivera Vasconcelos *et al.*, 2018)**. The relationship between plankton abundance and environmental factors can vary, emphasizing the need for long-term monitoring and additional research for a more precise understanding **(Turker *et al.*, 2003)**.

Therefore, it is essential to recognize that the relationship between plankton abundance and climatic variables, as well as water quality parameters, may vary depending on the particular ecosystem, geographical location, and interactions with other factors. Achieving a comprehensive understanding of the effects of these variables on phytoplankton and zooplankton communities requires long-term monitoring and research.

CONCLUSION

In conclusion, the relationship between the abundance of phytoplankton and zooplankton and climatic variables, as well as water quality parameters, was determined to be complex and constantly changing. Monthly fluctuations in plankton abundance were observed as a result of changes in climatic conditions and water quality parameters in the tilapia broodfish pond. Canonical correlation analysis revealed strong positive correlations between plankton abundance and climatic and water quality variables. The first canonical function exhibited a high correlation coefficient of 1.000 (100%), signifying a significant relationship. Similarly, the second canonical function showed a significant association with a correlation coefficient of 0.883 (88.3%). Factors such as air temperature and solar intensity play key roles in promoting the growth of phytoplankton, which leads to increased food availability and supports larger populations of zooplankton. Humidity and rainfall had direct or indirect effects on plankton abundance by stimulating nutrient inputs, promoting phytoplankton growth, and potentially benefiting zooplankton populations. Water temperature influences plankton abundance, as higher temperatures promote the growth of phytoplankton and provide a larger food source for zooplankton. Sufficient levels of dissolved oxygen (DO) supported plankton growth, while low DO levels restricted the populations of phytoplankton and zooplankton. Optimal pH levels are necessary for phytoplankton productivity, which in turn affects both phytoplankton and zooplankton. Ammonia serves as a nutrient for phytoplankton, enhancing productivity and potentially benefiting zooplankton. However, excessive levels could be toxic. Water transparency allows for increased light penetration, which promotes photosynthesis and potentially supports larger populations of phytoplankton and zooplankton. These findings emphasize the complex relationships between climatic variables, water quality parameters, and plankton abundance, emphasizing the importance of ongoing monitoring, research, and sustainable management practices to preserve the health and functionality of aquatic ecosystems.

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