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Water quality and phytoplankton structure and functional classification in Tadlac Lake, Philippines

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Abstract. *Rodil MSP, Banaag C, Velasco EJT, Elazegui EP. 2024. Water quality and phytoplankton structure and functional classification in Tadlac Lake, Philippines. Biodiversitas 25: 2769-2782.* Following the ban on aquaculture enforced from December 1999 to February 2000, the local government of Tadlac Lake, Los Baños, Laguna, Philippines, is currently developing ecotourism projects in the lake. This necessitates the assessment of water quality and phytoplankton to ensure the sustainability of the lake, supporting both ecological preservation and visitor satisfaction. This present study unveils the current ecological condition of Tadlac Lake, while advancing knowledge of phytoplankton's responses to different environmental conditions and adaptation mechanisms through their functional classifications. Our study revealed that except for phosphate during the dry period, water quality parameters adhered to the standards for class C waters. Phytoplankton species are grouped into Phaeophyta, Cyanobacteria, and Chlorophyta. Bacillariophyceae was the most dominant class with 15 species. The persistent presence of *Stephanodiscus hantzschii, Synedra affinis, Synedra tabulata, Achnanthes lanceolata, Navicula placentula, Neidium affine*, *Synechocystis aquatilis, Oscillatoria limosa*, and *Chlorococcum humicola* indicate that the lake's recovery from past deterioration remains incomplete. Shannon-Weiner and Pielou evenness index suggested that the lake exhibits a state of light pollution. The Wilcoxon signed rank test reveals significant seasonal variations in environmental factors, including temperature, total dissolved solids, salinity, electrical conductivity, pH, dissolved oxygen, phosphates, and total coliform counts, which directly impact the structure and functional classification of phytoplankton communities. Spearman correlation coefficients and canonical correspondence analysis further establish significant correlations between individual phytoplankton species and these environmental parameters, providing additional evidence. The results emphasize the need for seasonally tailored environmental management strategies.

Keywords: Ecological health, phytoplankton community structure, phytoplankton functional classification, seasonal variability, water quality indicators

Abbreviations: BOD: Biological oxygen demand; CCA: Canonical correspondence analysis; EC: Electrical conductivity; DO: Dissolved oxygen; DS: Dominant status; E: Eudominant, Max: Maximum; Min: Minimum; J': Pielou's Evenness Index; R: Recedent, RA: Relative abundance; H': Shannon-Wiener index; D: Simpson index; Std Dev: Standard deviation, SD: Subdominant, SR: Subrecedent; TDS: Total dissolved solids; Temp: Temperature

INTRODUCTION

Freshwater lakes occupy a pivotal role within ecosystems, primarily acting as centers of fish production. Nevertheless, the threats of water pollution and poor management methods lead to a series of physiological changes that have an impact on the development and even survival of aquatic organisms. This phenomenon appears in Tadlac Lake, one of the 79 lakes in the Philippines. Tadlac Lake is among the eight small lakes of the Laguna de Bay Region and is recognized for its potential in ecotourism and blueprint for the development of small water bodies in the Philippines. Tadlac Lake is classified as Class C, a water designated for the nurturing of fish and other aquatic resources.

Tilapia fish cage culture began in Tadlac Lake in 1986, with an initially approved area of 30,000 m² or 12% of the total surface area of the lake. However, this allocation was exceeded, leading to nearly full occupation of the lake by fish cages. Due to limited oversight and a focus on the larger nearby Laguna de Bay, regulations were insufficiently enforced until 1992, when the Laguna Lake Development Authority (LLDA) attempted to reduce the fish cage area. This effort was not fully realized due to the fisher folks' appeal for a reasonable period to recover their investment. The rapid growth of aquaculture negatively affected water quality and jeopardized sustainability through fecal matter, unconsumed feed, and organic materials in the lake environment (Brillo 2017). In 1999, a massive fish kill occurred during the lake's annual overturn, resulting in the loss of all fish stocks and serving as a catalyst for halting aquaculture activities in the lake. The Barangay Council, led by the Barangay Chairman and supported by the Fisheries and Aquatic Resources Management Council (FARMC), engaged in discussions with the fish cage operators. They made a formal appeal for the operators to allow the lake a period of respite, to enable it to recover and restore its ecological balance. Despite this intervention, not many assessments of the lake's trophic status and water quality, which are essential for assessing its recovery, have been carried out. In a study by Villaruel and Camacho (2022), it was revealed that as of 2018, the lake remains eutrophic and exhibits signs of moderate pollution.

In 2023, the local government of Tadlac plans to promote ecotourism in the area following the ban on aquaculture, thus there is a need to ensure the ecological health and sustainability of the lake. In biodiversity hotspots, ecotourism is growing in popularity because of its ability to improve rural livelihoods while still protecting the environment. It can help reduce poverty, which is deeply ingrained in many facets of society (Makindi 2016). However, ecotourism cannot exist if the environment is neglected; as a result, before any tourism development can take place, an efficient conservation strategy must be put in place (Rivera et al. 2022). This strategy respects and preserves the environment while protecting biodiversity, supporting visitor satisfaction and fostering economic possibilities for nearby populations. By combining the results of a thorough study on water quality into conservation and management strategies, the local government can support responsible ecotourism development while reducing the ecological issues facing the lake.

The summation of the physical, chemical, biological, and aesthetic characteristics that together influence the potential usefulness of water is known as water quality (Dickens and O'Brien 2021). Water quality, which is controlled by various anthropogenic pressures and stressors, as well as by climatic conditions, dictates the functioning and balance of aquatic ecosystem (Akhtar et al. 2021). For example, water quality is the primary driver of the successional processes that control phytoplankton diversity and distribution (Djumanto et al. 2017; Sharma et al. 2018; Song et al. 2022) and water quality degradation brought on by land use changes can have a broad impact on phytoplankton community composition (Kakouei et al. 2021; Peng et al. 2021; Yang et al. 2022). In response to changes in their habitats, both biological and physical, their densities, biomasses, and compositions alter quickly (Guo et al. 2019; Shoener et al. 2019; Graco-Roza et al. 2021). Because plankton species react swiftly to disturbances and are highly sensitive to changes in their environment, they are utilized as indicators of water quality (Zhang et al. 2021); they exemplify susceptibility to water contamination. While analyzing water quality solely can occasionally fall short, using phytoplankton as bioindicator appears as a tactical advantage, strengthening monitoring efforts. The phytoplankton composition not only depicts current conditions but also its historical conditions (Banoo et al. 2022).

The main objective of this study was to assess the water quality and phytoplankton structure and functional classification of Tadlac Lake in Los Baños, Laguna, Philippines, taking into account both the wet and dry sampling seasons. Additionally, it aimed to provide a description of the environmental preferences of different phytoplankton species which can guide environmental management and policy decisions, helping to maintain water quality and support sustainable practices in local lakes. By incorporating the findings of this water quality study into conservation and management initiatives, the local government can effectively address and mitigate the ecological concerns that threaten the health of Tadlac Lake while promoting sustainable tourism development.

MATERIALS AND METHODS

Study area

Tadlac Lake, also known as Alligator Lake, is a volcanic crater lake located in Brgy. Tadlac, Los Baños, Laguna, Philippines, just 50 m from the broad coastlines of Laguna de Bay. The lake has a surface area of 248,000 m^2 and an average depth of 27 m. Tadlac Lake flourished as one of the oligotrophic lakes dotting the Laguna terrain before the presence of aquaculture. The lake's distinct character is further defined by yearly Lake Overturns or Limnic eruptions, a rare type of natural catastrophe, which takes place during the cold months of the year specifically from December to February. Figure 1 shows the location of Tadlac Lake and indicates three sampling sites, each predicated upon the level of anthropogenic influences. The first location, located at 14°10'50''N 121°12'16''E, is close to a busy resort abounding with recreational opportunities. The second is situated at 14°10'55''N 121°12'31''E and has a fishing-related domain. Last is a place isolated from human-environment interactions. It is located at 14°11'04''N 121°12'19''E. Each sampling site is further segmented into three sampling points.

Data collection procedures

Samples were taken at each sampling site in October 2021 and March 2022, representing the wet and dry periods, respectively.Temperature, pH, total dissolved solids (TDS), electrical conductivity (EC), and salinity were measured in situ using 5 in 1 Water Quality Tester while dissolved oxygen (DO) was determined using JPB-70A DO Meter. Three trials at each sampling point for the three sampling sites were performed.

For ex situ analysis including Biological Oxygen Demand (BOD), total coliform count, phosphate and nitrate analysis, water samples were collected using composite sampling from the three sampling points. The samples were held in an ice chest at 20°C and were transported immediately to a chemical laboratory for analysis. BOD was analyzed using the 5-Day BOD Test. The phosphate and nitrate concentrations were measured using UV-VIS Hitachi Spectrometer via stannous chloride method at a wavelength of 650 nm and screening method in the ultraviolet range at wavelengths of 220 nm and 275 nm, respectively. The total coliform count was determined using Multiple Tube Fermentation Technique.

The phytoplankton species were collected via two methods: vertical and horizontal. In vertical method, the phytoplankton was collected by submerging the plankton net with a mesh size of 20 µm 5 m below the water surface. The net was lifted at a speed of 0.3 ms^{-1}. On the other hand, in horizontal method, the plankton net was put just below the water surface and was dragged horizontally 100 m away from the sampling site for 6 min. The collected water samples were placed in the plankton bottles with a 10% formalin solution. The samples were decanted and treated with Rose Bengal for staining. It was transferred to Sedgewick Rafter Counting Chamber then counted using binocular microscope. Taxonomic identification of the phytoplankton species was performed using international resources such as AlgaeBase (Guiry 2021) and reference texts like Bellinger and Sigee (2015).

Data analysis

Environmental data are given as the mean, standard deviation (Std Dev), minimum (Min) and maximum (Max) after performing the descriptive analysis (IBM SPSS version 26.0). Mean values were compared with the water quality standards for class C waters based on the Department of Environment and Natural Resources Administrative Order No. 2016-08, to investigate the suitability of the water for fish and aquatic life. A Wilcoxon Signed Rank Test was performed to evaluate the differences in water quality between the wet and dry periods. Additionally, a Kruskal-Wallis one-way ANOVA was employed to compare water quality across the three selected sites.

Relative abundance and dominance of each phytoplankton species were determined based on Engelmann's scale (Engelmann 1978). The functional classification of the phytoplankton species was based on the Standard Methods for the Examination of Water and Wastewater (Baird and Bridgewater 2023). Phytoplankton species were classified as filter- and screen-clogging algae, clean water algae, water pollution algae, taste and odor algae, surface water algae, and algae growing on surfaces. Spearman's rho correlation was used to analyze the relationship between the abundance of each phytoplankton and various water quality parameters, with significance levels set at 0.01 and 0.05. Canonical Correspondence Analysis (CCA) was conducted to further explore the phytoplankton-environment relationships.

Shannon-Wiener Index (H'), Pielou's Evenness Index (J') and Simpson index (D) were used to evaluate the phytoplankton structure. The formulas are as follows:

Shannon-Wiener Index (H') = $-\Sigma p_i \times \ln(p_i)$

Where: i means the proportion of the species i phytoplankton in total individuals.

The result of diversity index was used to determine pollution status with range H′ values of 0-1; 1-2; 2-3 and >3 correspond to heavy, moderate, light and no pollution (Zhu et al. 2021).

Pielou's Evenness Index (J') $= H'/H_{max}$
$H_{max} = \ln S$

Where:
H' : Shannon-Wiener Index;
H_{max} : maximum value of Shannon-Wiener Index;
S : total number of phytoplankton species

J values of 0-0.3; 0.3-0.5 and >0.5 correspond to heavy, moderate and light or no pollution (Zhu et al. 2021).

Simpson index of diversity (D) $=1- (\Sigma(n_i \times (n_i - 1)) / (N * (N - 1)))$

Where:
n : the total number of individuals of a particular species;
N: the total number of individuals of all species

D values of 0.00; 0.01-0.4; 0.41-0.6; 0.61-0.8; 0.81-0.9; and 1.00 correspond to absence, low, moderate, moderately high, high and absolute diversity (Batugedara and Senanayake 2022).

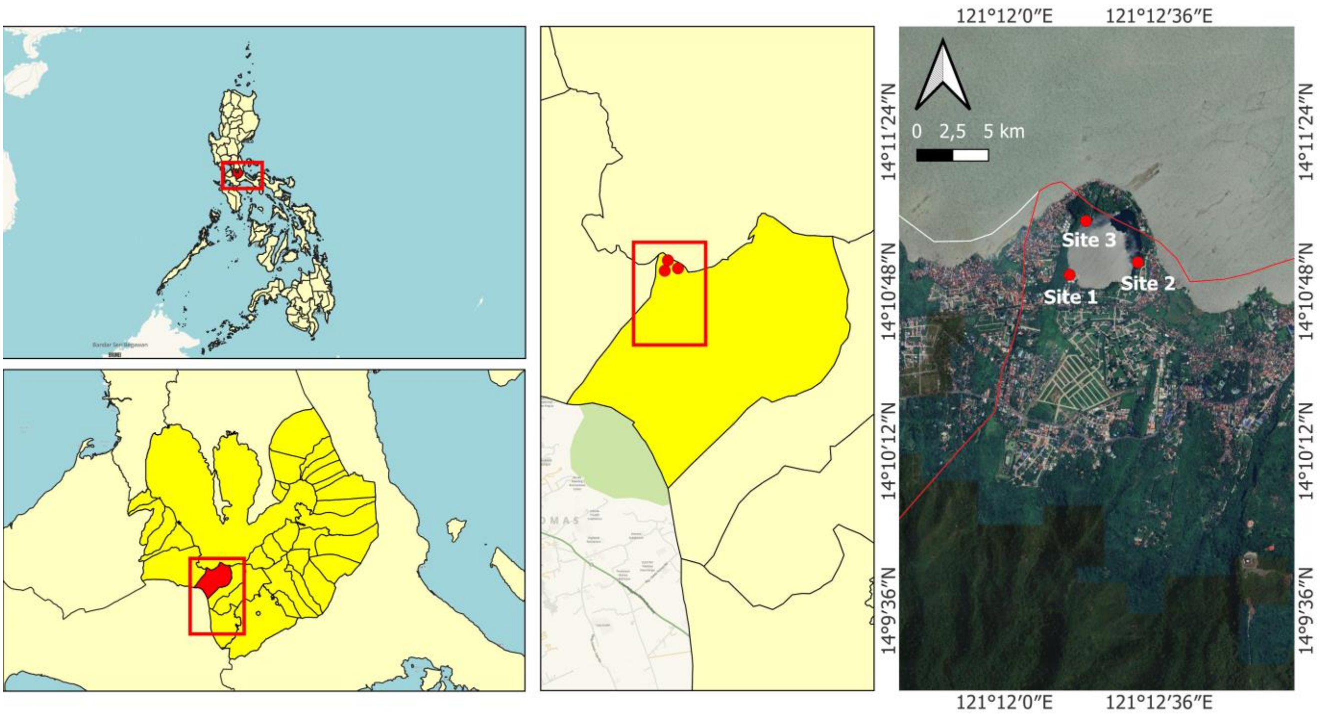


Figure 1. Map of study location in Tadlac Lake, Los Baños, Laguna, Philippines indicating three sampling sites

RESULTS AND DISCUSSION

Water quality of Tadlac Lake

Table 1 displays the physico-chemical characteristics of water in Tadlac Lake across different periods, while Tables 2 and 3 provide statistical analyses that evaluate variations in these parameters across different seasons and sampling sites. Most of the water quality metrics showed higher values during the dry month compared to the wet month. In terms of temperature, the mean temperature spanned from 29.90°C to 32.20°C during wet period and it ranged from 28.20°C to 30.60°C during dry period. Seasonal changes in air temperatures and the influence of cool, dry North-East winds contributed to the recorded temperature variations, as indicated by the significant difference in temperature of water collected during wet and dry period ($p<0.05$).

Table 1. Water quality of Tadlac Lake, Los Baños, Laguna, Philippines during wet and dry months

Water parameter	DENR standard	Site	Wet sampling month				Dry sampling month			
			Mean	Std Dev	Min	Max	Mean	Std Dev	Min	Max
Temperature (°C)	3 (max. rise in °C)	1	29.90	0.17	29.70	30.20	28.20	0.58	27.90	29.60
		2	30.90	0.59	30.00	31.70	29.20	0.37	28.70	30.00
		3	32.20	0.39	31.80	33.10	30.60	1.84	28.50	33.60
TDS (mg L^{-1})		1	468.72	3.09	466.05	473.85	483.17	3.63	475.15	487.50
		2	462.87	2.95	458.90	466.70	480.78	2.43	477.10	484.90
		3	462.87	3.12	457.60	466.05	484.12	2.61	480.35	486.85
Salinity (mg L^{-1})		1	360.56	2.50	358.50	364.50	371.67	3.53	363.00	375.00
		2	356.05	2.40	353.00	359.00	369.83	3.31	363.00	373.00
		3	356.06	2.20	352.00	358.50	368.41	2.34	369.50	374.50
EC (µS cm^{-1})		1	721.11	4.76	717.00	729.00	743.00	5.59	731.00	750.00
		2	712.11	4.54	706.00	718.00	739.67	3.74	734.00	746.00
		3	712.11	4.81	704.00	717.00	744.83	4.02	739.00	749.00
pH	6.50-9.00	1	7.51	0.03	7.44	7.55	6.88	0.02	6.85	6.90
		2	7.40	0.02	7.38	7.43	6.92	0.02	6.91	6.94
		3	7.42	0.02	7.38	7.45	6.92	0.05	6.80	6.95
DO (mg L^{-1})	>5.00	1	6.30	0.13	6.10	6.50	7.32	0.25	7.00	7.70
		2	8.34	0.53	7.60	9.40	6.86	0.22	6.50	7.10
		3	7.17	0.28	6.80	7.60	7.03	0.51	6.30	7.70
BOD (mg L^{-1})	<7.00	1	3.00	1.00	2.00	4.00	2.00	1.00	1.00	3.00
		2	2.00	1.00	1.00	3.00	<2.00	1.00	1.00	3.00
		3	<2.00	1.00	1.00	3.00	<2.00	1.00	1.00	3.00
Nitrates (mg L^{-1})	<7.00	1	1.63	0.83	1.13	2.59	1.91	0.09	1.80	1.97
		2	3.08	0.68	2.33	3.70	1.92	0.09	1.83	2.01
		3	0.71	0.05	0.65	0.74	0.78	0.05	0.74	0.84
Phosphates (mg L^{-1})	0.50	1	0.29	0.08	0.24	0.39	0.61	0.09	0.52	0.69
		2	0.08	0.01	0.07	0.09	0.76	0.03	0.73	0.79
		3	0.04	0.04	0.01	0.09	0.78	0.05	0.74	0.84
Total coliform (MPN per 100 mL)		1	2400.00	400.00	2000.00	2800.00	130.00	10.00	120.00	140.00
		2	2400.00	100.00	2300.00	2500.00	240.00	10.00	230.00	250.00
		3	1600.00	100.00	1500.00	1700.00	540.00	20.00	520.00	560.00

Table 2. Result of Wilcoxon Signed Test analysis to compare the quality of water collected in the two periods (per site)

Water parameter	Site 1		Site 2		Site 3	
	p-value	Remarks	p-value	Remarks	p-value	Remarks
Temperature	0.01	Significant	0.01	Significant	0.05	Significant
TDS	0.01	Significant	0.01	Significant	0.02	Significant
Salinity	0.01	Significant	0.01	Significant	0.01	Significant
EC	0.01	Significant	0.01	Significant	0.02	Significant
pH	0.01	Significant	0.01	Significant	0.01	Significant
DO	0.01	Significant	0.01	Significant	0.40	Not Significant
BOD	0.11	Not Significant	0.11	Not Significant	0.11	Not Significant
Nitrates	0.29	Not Significant	0.11	Not Significant	0.11	Not Significant
Phosphates	0.01	Significant	0.01	Significant	0.01	Significant
Total coliform	0.01	Significant	0.01	Significant	0.01	Significant

Table 3. Results of Kruskal Wallis analysis to compare the quality of water collected in the three sites (per period)

Water parameter	Wet period		Dry period	
	p-value	Remarks	p-value	Remarks
Temperature	0.04	Significant	0.25	Not Significant
TDS	0.31	Not Significant	0.97	Not Significant
Salinity	0.19	Not Significant	0.90	Not Significant
EC	0.30	Not Significant	0.84	Not Significant
pH	0.79	Not Significant	0.27	Not Significant
DO	0.03	Significant	0.83	Not Significant
BOD	1.00	Not Significant	1.00	Not Significant
Nitrates	0.04	Significant	0.19	Not Significant
Phosphates	0.06	Not Significant	0.06	Not Significant
Total coliform	0.07	Not Significant	0.03	Significant

In Tadlac Lake, the concentration of TDS averaged between 462.87-468.78 mg L^{-1} during the wet month and 480.78-484.12 mg L^{-1} during the dry month, falling within the typical range of TDS concentrations found in natural freshwater, which generally ranges from about 20 to 1000 mg L^{-1} (Boyd 2020). Likewise, freshwater contains minimal salts, generally less than 1000 mg L^{-1} (Li et al. 2020). Salinity levels of Tadlac Lake were within this range, with average readings of 356.05-360.56 mg L^{-1} during the wet month and 368.41-371.67 mg L^{-1} during the dry month at various sampling sites. These consistent TDS and salinity measurements indicate that Tadlac Lake maintains a relatively low salinity level typical of freshwater bodies. The slight variations observed between wet and dry months suggest seasonal influences on water quality parameters. On the other hand, the EC, which is a function of temperature and salinity of water, recorded an average value of 721.11 µS cm^{-1}, 712.11 µS cm^{-1}, and 712.11 µS cm^{-1} during wet month and 743.00 µS cm^{-1}, 739.67 µS cm^{-1} and 744.83 µS cm^{-1} during dry month for Site 1, Site 2 and Site 3, respectively. The TDS, salinity, and electrical conductivity exhibited significant changes with seasonal variations ($p<0.05$) based on the results of Wilcoxon Signed Rank analysis.

For Class C waters like Tadlac Lake, the recommended pH range is 6.50 to 9.00. The three sites experienced seasonal pH variations, as shown in Table 2 ($p<0.05$). During the wet season, pH was slightly alkaline (7.40 to 7.51), but during the dry month, it shifted slightly towards acidity (6.88 to 6.92). This change is linked to the annual limnic eruption, typically between December and February, which releases carbon dioxide from deeper lake levels. This released carbon dioxide forms carbonic acid, lowering the pH. Nevertheless, the recorded pH levels consistently fell within the recommended limits, ensuring they met safety and regulatory standards.

DO levels consistently met the 5 mg L^{-1} threshold for Class C waters. As shown in Table 2, DO exhibits significant seasonal changes in all sites except Site 3 ($p=0.40$). During the dry month, DO values were generally lower due to the limnic eruption phenomenon, except for Site 1, which had the lowest total coliform levels, contributing to higher DO levels. Total coliform levels correlate with BOD, reflecting microbial activity from organic matter decomposition. Meanwhile, the BOD concentrations in the three sampling sites did not exceed the 7 mg L^{-1} Class C threshold, indicating consistently low and comparable levels of organic contamination across all sites. No significant seasonal fluctuation in BOD concentration was recorded in any of the sites ($p=0.11$).

Nitrate, an inorganic form of nitrogen in lakes, is essential for growth but can degrade water quality via eutrophication when present in excess (Singh et al. 2022). The Department of Environment and Natural Resources sets the standard at 7.00 mg L^{-1}. In Tadlac Lake, nitrate levels at Sites 1 to 3 ranged from 0.71 to 3.08 mg L^{-1} during the wet month and 1.78 to 1.92 mg L^{-1} during the dry month. These levels steady met the Class C standard, with no significant seasonal variations recorded ($p>0.05$), as indicated in Table 2. Phosphate is also important in aquatic ecosystem, however, in excess phosphates in lakes can lead to eutrophication by promoting excessive algae growth, which reduces water clarity and oxygen levels, posing risks to aquatic life and water quality (Akinnawo 2023). Significant seasonal variations in phosphate concentration were observed in Tadlac Lake ($p=0.01$), influenced by water volume fluctuations during the wet months caused by annual flooding. This influx dilutes phosphates, contributing to levels consistently below the 0.50 mg L^{-1} Class C limit. Conversely, during the dry period, phosphate levels exceeded this limit due to limnic eruptions. Carbon dioxide release reduces dissolved oxygen, converting ferric phosphate to ferrous phosphate, which is more soluble and releases phosphate from sediment. This mixing typically occurs during cool, windy weather before sampling.

Microorganism levels serve as key indicators of water quality, with coliforms specifically used to assess fecal pollution. During the wet month, counts ranged from 1600.00 to 2400.00 MPN per 100 mL, while in the dry month, they varied from 130.00 to 540.00 MPN per 100 mL across Sites 1 to 3, indicating lower levels compared to the wet season. These counts demonstrate the presence of pollution from human or animal feces. Runoff from precipitation carries fecal debris but reflects minimal human impact. These levels show variation across different sampling periods, reflecting dynamic changes in microbial presence influenced by seasonal factors ($p=0.01$).

Based on the Kruskal-Wallis analysis, which compares the quality of samples collected across three distinct sites, each selected for their varying levels of anthropogenic influence, most water quality parameters did not show significant differences during wet period, indicating a general uniformity in water quality despite the different levels of human activities. However, notable exceptions were observed in temperature, DO, and nitrate levels, all of which exhibited significant variation at the 0.05 significance level. Specifically, temperature was found to be relatively lower in Site 1, while DO and nitrate levels were notably higher in Site 2. Conversely, during the dry period, total coliform levels exhibited variability among the three sites, indicating distinct microbial contamination profiles across these locations. Site 1 which is close to a busy resort, exhibited the lowest total coliform levels which are likely due to a combination of effective waste management, strict regulatory compliance, and a strong emphasis on public health and safety.

Composition of phytoplankton community

Table 4 presents the distribution, relative abundance, and dominance status of each phytoplankton across the three sites. As shown, twenty-five species of phytoplankton were identified during both wet and dry sampling periods. These species are categorized into three major divisions: Phaeophyta (brown algae), Cyanobacteria (blue-green algae), and Chlorophyta (green algae). Phytoplankton species were divided into four classes: Bacillariophyceae, Cyanophyceae, Chlorophyceae, and Zygnematophyceae, comprising a total of 15, 3, 4, and 3 taxa, respectively. Figure 2 graphically presents the seasonal distribution of phytoplankton species across the three sites, while Figure 3 depicts the relative density of each class.

Bacillariophyceae were highly represented in Lake Tadlac, followed by Cyanophyceae, Chlorophyceae and Zygnematophyceae. Among the 15 taxa within the Bacillariophyceae group, six species comprising *S. hantzschii*, *S. affinis*, *S. tabulata*, *A. lanceolata*, *N. placentula*, and *N. affine* demonstrated their resilience by appearing in both wet and dry months. The *S. hantzschii*, recognized as an indicator species, holds a dominant presence in eutrophic lakes (Rott and Kofler 2021). Members of Bacillariophyta like *Navicula* and *Synedra* exhibit a propensity to thrive in environments contaminated with organic pollutants (Barinova and Mamanazarova 2021; Khalil et al. 2021). Cyanophyceae was represented by *S. aquatilis*, *O. limosa*, and *O. formosa*. Presence of *S. aquatilis* is closely linked to elevated nutrient levels and is often associated with the development of unpleasant odors and water discoloration (Tito and Luna 2020).

Table 4. Distribution, relative abundance and dominance status (Engelmann's scale 1978) of phytoplankton species at the three sampling sites in Tadlac Lake, Los Baños, Laguna, Philippines

Phytoplankton species	Site 1				Site 2				Site 3			
	Wet		Dry		Wet		Dry		Wet		Dry	
	RA	DS	RA	DA	RA	DS	RA	DS	RA	DS	RA	DS
Bacillariophyceae												
Stephanodiscus hantzschii Grunow	12.61	D	6.06	SD	15.52	D	6.84	SD	13.62	D	3.31	SD
Nitzschia subrostrata Hust.	-		4.04	SD	-		2.87	R	-		2.89	R
Melosira granulata (Ehr.) Ralfs	-		6.46	SD	-		5.96	SD	-		6.19	SD
Melosira islandica (Cleve) Euler	-		5.45	SD	-		6.84	SD	-		6.19	SD
Synedra affinis Kütz.	10.43	D	4.04	SD	9.48	SD	4.86	SD	11.06	D	4.96	D
Synedra tabulata Kütz.	7.83	SD	4.04	SD	6.90	SD	3.11	R	8.94	SD	2.89	R
Synedra ulna Nitzsch	-		4.64	SD	-		5.74	SD	-		2.48	R
Achnanthes lanceolata Bory	10.00	SD	3.23	SD	9.05	SD	3.75	SD	10.21	D	4.96	SD
Navicula placentula (Ehr.) Kütz.	10.00	SD	4.44	SD	10.35	D	4.42	SD	9.79	SD	7.02	SD
Neidium affine Ehr.	13.91	D	5.86	SD	12.50	D	4.42	SD	10.21	D	2.48	R
Stauroneis anceps Ehr.	-		4.64	SD	-		5.96	SD	-		5.78	SD
Cymbella ventricosa Agardh	-		4.04	SD	-		2.65	R	-		3.31	SD
Surirella elegans Ehr.	-		3.84	SD	-		3.09	R	-		5.37	SD
Surirella robusta Ehr.	-		2.83	R	-		2.65	R	-		1.65	R
Surirella elegans var. *acuminata* Skvortzov & Noda	-		3.43	SD	-		3.09	R	-		2.89	R
Cyanophyceae												
Synechocystis aquatilis Sauv.	10.87	D	4.65	SD	10.78	D	5.08	SD	14.04	D	6.20	SD
Oscillatoria limosa Agardh ex Gomont	8.26	SD	3.23	SD	9.91	SD	2.65	R	9.36	SD	2.48	R
Oscillatoria formosa Bory ex Gomont	-		4.04	SD	-		3.31	SD	-		2.89	R
Chlorophyceae												
Chlorella variegata Beig.	-		4.44	SD	-		5.52	SD	-		6.20	SD
Chlorococcum humicola (Nag.) Rabenh.	16.09	D	-		15.51	D	-		12.77	D	-	
Scenedesmus dimorphus (Turpin) Kütz.	-		4.24	SD	-		3.31	SD	-		2.07	R
Lyngbya birgei Smith	-		3.43	SD	-		2.87	R	-		2.48	R
Zygnematophyceae												
Spirogyra ionia Wade	-		3.23	SD	-		2.87	R	-		7.02	SD
Closterium moniliforme Bory	-		2.83	R	-		4.19	SD	-		5.37	SD
Closterium calosporum Wittrock	-		2.83	R	-		2.65	R	-		1.65	R

Note: RA: Relative abundance; DS: Dominant status; SR: Subrecedent; R: Recedent; SD: Subdominant; D: Dominant; Eudominant; RA 1%: Subrecedent; 1.1-3.1%: Recedent; 3.2-10%: Subdominant; 10.1-31.6%: Dominant and <31.7%: Eudominant; (-): Not recorded; 0: Below 1% RA

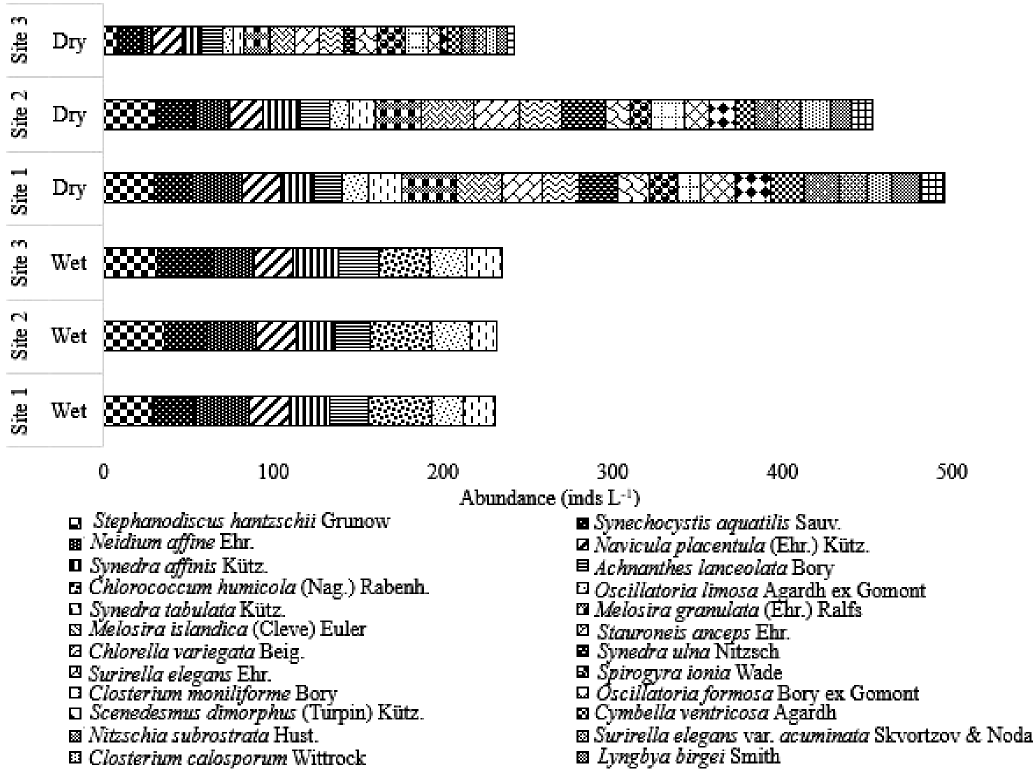
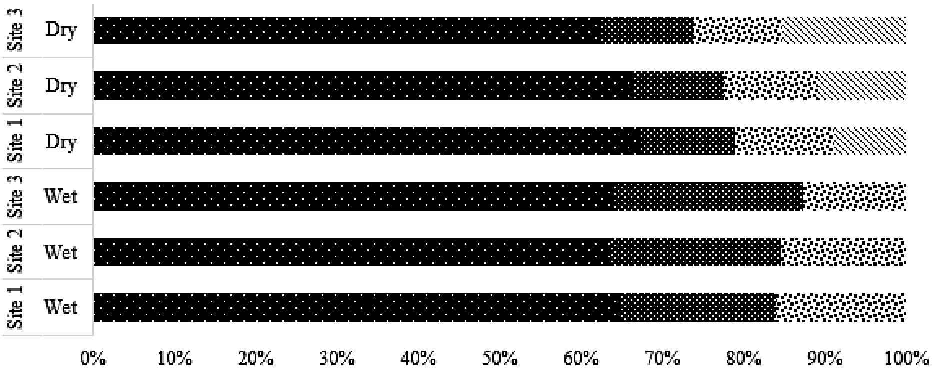


Figure 2. Seasonal distribution of phytoplankton species across the three sites in Tadlac Lake, Los Baños, Laguna, Philippines



	Site 1 Wet	Site 2 Wet	Site 3 Wet	Site 1 Dry	Site 2 Dry	Site 3 Dry
Bacillariophyceae	149	148	150	332	301	151
Cyanophyceae	44	48	55	59	50	28
Chlorophyceae	37	36	30	60	53	26
Zygnematophyceae	0	0	0	44	49	37

Abundance (Inds L^{-1})

Figure 3. Relative density of phytoplankton groups at the three sampling sites in Tadlac Lake, Los Baños, Laguna, Philippines

Oscillatoria can also thrive in eutrophic conditions, causing the growth of other invasive algae and damaging the balance of aquatic ecosystems (Masithah and Islamy 2023), and can be used as marker species or indicator of water pollution (Devi and Bhatnagar 2024). The *O. limosa* and *O. formosa* are species of cyanobacteria which are tolerant to organic pollution (Rishi and Awasthi 2015). Under Chlorophyceae, *C. variegata*, *S. dimorphus*, *L. birgei* and *C. humicola*, being the most dominant, are recorded. *C. humicola* is pollution-tolerant coccoid green microalga known for its resilience in contaminated environments. This species can survive and even thrive in conditions with high levels of pollutants, making it valuable indicator of water quality and potential agent for bioremediation (Upadhyay et al. 2021; Morsi et al. 2023). Zygnematophyceae was constituted of filter clogging algae such as *Spirogyra ionia*, *Closterium moniliforme* and *C. calosporum*.

Among the phytoplankton species identified in the lake, *S. hantzschii, N. affine, S. aquatilis, C. humicola* were the dominant species in the three sampling sites during wet period. The identification of phytoplankton species in the three sampling sites during dry period accounted 24 species. Species *N. subrostrata, M. granulata, M. islandica, S. ulna, S. anceps, C. ventricosa, S. elegans, S. robusta, S. elegans* var. *acuminate, O. formosa, C. variegata, S. dimorphus, L. birgei, S. ionia, C. moniliforme* and *C. calosporum* were seen only during this period. *Nitzschia*, *Synedra*, and *Oscillatoria* species often signal eutrophication, reflecting nutrient-rich conditions typically caused by agricultural runoff or sewage discharge. Their presence implies that while there is some pollution in the water, it is not severe, as evidenced by the co-occurrence of species indicative of good water quality. *S. anceps* and Surirella species are reliable bioindicators of clean, high-quality water. *Surirella* species are sensitive to pollution and environmental changes, making them excellent indicators of unpolluted conditions (Barinova and Mamanazarova 2021).

The One-way Analysis of Similarities (ANOSIM), employing the Bray-Curtis Similarity Index (p=0.87; r=-0.44), demonstrated no statistically significant differences in phytoplankton abundance across the sampling stations. This outcome aligns with the water quality analysis results, which also indicated that most water quality parameters did not differ significantly at the 0.05 level of significance. This suggests that the various land use activities along the lake's shoreline do not significantly affect the density of phytoplankton species in the adjacent waters. In contrast, the species composition of phytoplankton in Tadlac Lake showed marked variation between the two sampling periods, as detailed in Table 4, indicating a dynamic biological shift. ANOSIM revealed a significant variation in overall phytoplankton abundance between the two sampling periods ($p<0.05$; r=1.00). The Similarity Percentage (SIMPER) analysis showed a 57.73% dissimilarity, highlighting the considerable change in species composition over time. The taxa that contributed most to the observed variation were *C. humicola* (5.58%), *M. granulata* (3.78%), *M. islandica* (3.74%), *S. anceps* (3.30%) and *C. variegata* (3.23%). The analysis presented in Table 2 highlights significant changes in environmental factors affecting Tadlac Lake, including temperature, TDS, salinity, conductivity, pH, DO, phosphates, and total coliform counts. These variations emphasize the critical role of these environmental parameters in shaping the abundance and distribution of phytoplankton species in the lake.

Environmental factors influencing phytoplankton abundance

Table 5 reveals the Spearman correlation coefficients between each phytoplankton species and water quality parameters. The results demonstrate a notable correlation between phytoplankton species and temperature, TDS, salinity, EC, pH, DO, phosphates, and total coliform counts, which further substantiates the influence of these environmental factors on phytoplankton dynamics in Tadlac Lake.

Table 5. Matrix of Spearman's rho correlation for each phytoplankton and environmental parameters in Tadlac Lake, Los Baños, Laguna, Philippines

Phytoplankton species	Temp	TDS	Salinity	EC	pH	DO	BOD	Nitrate	Phosphate	Total coliform
Stephanodiscus hantzschii Grunow	-0.03	-0.60	-0.39	-0.59	0.47	0.32	0.07	0.61	-0.61	0.39
Nitzschia subrostrata Hust.	-0.82*	0.77	0.89*	0.77	-0.92**	0.03	-0.42	0.21	0.70	-0.96**
Melosira granulata (Ehr.) Ralfs	-0.82*	0.77	0.89*	0.77	-0.92**	0.03	-0.42	0.21	0.70	-0.96**
Melosira islandica (Cleve) Euler	-0.76	0.71	0.96**	0.71	-0.83*	-0.15	-0.42	0.27	0.76	-0.89*
Synedra affinis Kütz.	0.46	-0.84*	-0.54	-0.84*	0.81	-0.20	0.40	-0.23	-0.81*	0.54
Synedra tabulata Kütz.	0.14	-0.52	-0.41	-0.52	0.29	0.26	0.13	-0.31	-0.77	0.58
Synedra ulna Nitzsch	-0.76	0.71	0.96*	0.71	-0.83*	-0.15	-0.42	0.27	0.76	-0.89*
Achnanthes lanceolata Bory	0.48	-0.90*	-0.80	-0.90*	0.90*	0.00	0.44	0.14	-0.89*	0.78
Navicula placentula (Ehr.) Kütz.	0.17	-0.80	-0.68	-0.79	0.73	0.32	0.28	0.51	-0.84*	0.68
Neidium affine Ehr.	-0.19	-0.55	-0.40	-0.54	0.56	0.11	0.45	0.55	-0.61	0.52
Stauroneis anceps Ehr.	-0.75	0.88*	0.97**	0.89*	-0.94**	-0.17	-0.42	-0.01	0.88*	-0.93**
Cymbella ventricosa Agardh	-0.83*	0.85*	0.90*	0.86*	-0.90*	-0.07	-0.40	0.02	0.76	-0.90*
Surirella elegans Ehr.	-0.75	0.94**	0.96**	0.95**	-0.98**	-0.11	-0.44	-0.10	0.88*	-0.95**
Surirella robusta Ehr.	-0.84*	0.83*	0.90*	0.84*	-0.89*	-0.07	-0.39	0.05	0.75	-0.89*
Surirella elegans var. *acuminata* Skvortzov & Noda	-0.82*	0.86*	0.94**	0.87*	-0.91*	-0.11	-0.41	0.04	0.80	-0.92*
Synechocystis aquatilis Sauv.	0.44	-0.77	-0.63	-0.76	0.66	0.09	0.09	0.01	-0.80	0.46
Oscillatoria limosa Agardh ex Gomont	0.36	-0.89*	-0.76	-0.88*	0.79	0.38	0.20	0.42	-0.93**	0.73
Oscillatoria formosa Bory ex Gomont	-0.84*	0.83*	0.92*	0.84*	-0.89*	-0.09	-0.39	0.06	0.77	-0.90*
Chlorella variegata Beig.	-0.74	0.91*	0.98**	0.92*	-0.96**	-0.17	-0.43	-0.04	0.90*	-0.95**
Chlorococcum humicola (Nag.) Rabenh.	0.59	-0.95**	-0.94**	-0.95**	0.99**	0.16	0.51	0.25	-0.92**	0.98**
Scenedesmus dimorphus (Turpin) Kütz.	-0.85*	0.78	0.88*	0.79	-0.84*	-0.07	-0.37	0.11	0.70	-0.86*
Lyngbya birgei Smith	-0.83*	0.83*	0.92**	0.84*	-0.89*	-0.09	-0.39	0.06	0.77	-0.90*
Spirogyra ionia Wade	-0.62	0.97**	0.93**	0.98**	-0.98*	-0.14	-0.44	-0.22	0.94**	-0.93**
Closterium moniliforme Bory	-0.67	0.92**	0.97**	0.93**	-0.96**	-0.19	-0.44	-0.09	0.94**	-0.94**
Closterium calosporum Wittrock	-0.77	0.84*	0.95**	0.85*	-0.90*	-0.16	-0.41	0.04	0.84*	-0.91*

Note: *: Correlation is significant at the 0.05 level; **: Correlation is significant at the 0.01 level

Several species showed significant and negative correlations with temperature. For example, *N. subrostrata*, *M. granulata*, *S. robusta*, *S. elegans* var. *acuminata*, *S. dimorphus, C. ventricosa*, *O. formosa* and *L. birgei* all have negative correlations with temperature at 0.05 level of significance. This suggests that these species may thrive in cooler water conditions. Their ability to thrive in lower temperatures reflects their evolutionary adaptations and ecological strategies to optimize growth and survival in specific environmental conditions. For example, through internal resource allocation changes, phytoplankton may adjust to low temperatures. Because of this adaptation, which helps them offset some of the metabolic reactions that are most sensitive to temperature, they are able to carry out vital processes, develop, and reproduce even in areas that are colder (Sherman et al. 2016).

Various phytoplankton species exhibit positive correlations with TDS, salinity, and EC (Goswami et al. 2018) including *S. anceps, C. ventricosa*, *S. elegans*, *S. robusta*, S. *elegans* var. *acuminata*, *O. formosa*, *C. variegata*, *L. birgei*, *S. ionia*, *C. moniliforme*, and *C. calosporum*. While these species typically thrive in freshwater environments, this indicates that these species exhibit notable adaptability to elevated levels than other freshwater phytoplankton primarily through osmoregulation, reduced competition, optimized nutrient utilization, and avoidance of certain predators. More than half of the identified phytoplankton species exhibited significant negative correlations with pH levels. Jia et al. (2022) similarly found that Bacillariophyta, Cyanobacteria, Chlorophyta, and overall phytoplankton abundance showed significant negative relationships with pH. Phytoplankton have physiological mechanisms to cope with varying pH levels. Species that show negative correlations with pH likely have adaptations that allow them to maintain cellular processes and metabolic functions within their optimal pH range, avoiding stress or impairment in less favorable pH conditions.

Surirella elegans, *C. variegata*, as well as *S. ionia* responded positively and significantly to increased phosphate levels, indicating their presence in nutrient-rich habitats. Phosphates are substances that are needed and affect the process and development phytoplankton (Nindarwi et al. 2021). In high phosphate habitats, some species are more competitive or exhibit faster growth, making them effective indicators of nutrient-rich environment. *S. hantzschii*, O. *limosa*, *C. humicola* and *Navicula* species are also frequently found in eutrophic environments (Halder 2017; Kock et al. 2019; Ray et al. 2020; Rott and Kofler 2021). *Achnanthes* species are found in a wide range of hydrological conditions from clean to nutrient-rich substrates, including eutrophic waters or water contaminated by organic wastes (Barinova and Mamanazarova 2021). Their negative associations with phosphate concentration could be the result of nutrient imbalances, competition, and other environmental factors that inhibit them from growing even in the presence of high phosphate concentrations. Numerous biotic (such as predation pressure and resource supply) and abiotic (such as temperature, light, nutrients, heat wave) variables influence the phytoplankton community structure in aquatic environments (Filiz et al. 2020; Gjoni et al. 2023). The structure of phytoplankton is influenced by both internal (nutrients and grazing) and external (wind-driven vertical mixing and storm impacts) factors (Stockwell et al. 2020; Hopkins et al. 2021). Despite the overall preference of *S. anceps* and *C. moniliforme* for low-nutrient habitats (Bellinger and Sigee 2015; Barinova and Mamanazarova 2021), these species had a positive correlation with phosphate which could be attributed to their adaptation to shifting conditions, wherein moderate increases in phosphate may temporarily enhance their growth. Additionally, these species might be outcompeting others under specific conditions in the lake, leading to a relative increase in their populations even with higher phosphate levels.

Phytoplankton species such as *S. hantzschii*, *N. subrostrata, M. granulata, M. islandica*, and others exhibited a range of correlations with total coliform. Negative correlations, as observed for many species, suggest that as phytoplankton abundance or environmental conditions favorable to phytoplankton increase (e.g., higher pH, dissolved oxygen, or nutrient levels), while total coliform bacteria populations decrease. This inverse relationship can be attributed to competition for nutrients, alterations in water quality parameters, and ecological dynamics within the aquatic ecosystem.

While correlation shows the strength and direction of relationships between each environmental parameter and phytoplankton species, CCA was done to explore further the species-environment relationships, showing how different species respond to various environmental factors. Figure 4 shows the ordination of the phytoplankton assemblages from the lake around two main CCA axes. The plot features two axes (Axis 1 and Axis 2) that represent the primary gradients in the data. Axis 1 accounts for 92.98% of the variance, with an eigenvalue of 0.435, while Axis 2 accounts for 4.425% of the variance, with an eigenvalue of 0.01988. The positions of species and environmental variables along these axes indicate their relationships. Each black point represents a different species of plankton. The upper left quadrant indicates the influence of mineral-rich runoff, leading to moderate nutrient enrichment (higher EC and TDS, elevated phosphate levels, and low to moderate salinity) while experiencing lower organic pollution levels, slightly acidic to neutral water conditions and cooler to warm temperatures. Many dominant species flourish in this environment including *S. ulna, S. robusta, O. formosa, N. subrostrata, L. birgei, C. calosporum*, and *C. ventricosa*. Additionally, species such as *M. granulata* is located in the upper left quadrant, albeit it is nearer the middle. According to EC, TDS, and moderate phosphate nutrient levels, this species has adapted to conditions that provide a balance between nutrition availability and mineral content. On the other hand, the lower left quadrant is characterized by significantly elevated TDS, EC, and phosphate levels-levels that are much greater than those seen in the upper left quadrant. These regions are also distinguished from other quadrants by comparatively lower pH, temperature, and dissolved oxygen levels, as well as low to moderate salt levels. CCA indicates that some species, including *C. variegata S. anceps, S. elegans* as well as *C. moniliforme* are well-adapted to these conditions.

Lower right quadrant indicates alkaline, warmer, highly nutrient-rich environment with active decomposition processes and high levels of organic contaminants which is conducive for species like *S. tabulata, N. affine, S. hantzschii* as well as *O. limosa*. On the other hand, balanced nutrient levels, ideal dissolved oxygen concentration, and moderate pH and BOD characterize the upper right quadrant. These characteristics point to a healthier aquatic habitat but minimal organic pollution favorable for phytoplankton species such as *A. lanceolata* and *N. placentula*.

Functional classification of phytoplankton

Understanding the ecological roles and responses of phytoplankton to environmental changes depends on the classification of these organisms based on their functional features. This functional classification is shown in Figure 5. The phytoplankton species were methodically divided into many groupings, such as the algae that clog filters and screens and serve as a substrate for bacteria, fungus, and protozoa. Algae that thrive on surfaces, commonly found along the shoreline or in lake areas that are connected to soil, were also thoroughly identified. These included clean water algae, which are responsible for absorbing nitrogen and phosphorus, water pollution algae linked to septic system leakage and industrial discharges, taste and odor algae that produce compounds affecting the taste and smell of water, making it unpleasant, and surface water algae that exist as free-floating entities on or near the water's surface, and algal blooms on surfaces.

There is a notable increase in the counts of all phytoplanktons' functional classification during the dry season across all sites. This may be due to factors like reduced water flow and increased nutrient concentration. Filter- and Screen-Clogging Algae show the most dramatic increase during the dry season, particularly in Site 1 and Site 2. Water pollution Algae also show significant increases, potentially impacting water quality and usability.

Figure 6 shows the ordination of the functional classification of phytoplankton from the lake around two main CCA axes. Axis 1 accounts for 82.55% of the variance, with an eigenvalue of 0.0175, while Axis 2 accounts for 11.63% of the variance, with an eigenvalue of 0.00246. Clean water algae in upper right quadrant exhibit a notable positive correlation with elevated levels of dissolved solids, conductivity, and salinity. Despite being higher than other sites in the study, the salinity at this location remains very low and is more characteristic of freshwater rather than saline water. These conditions indicate mineral-rich or slightly saline waters that are favorable for clean water algae. Upper left quadrant is characterized by conditions commonly associated with polluted water, such as higher biochemical oxygen demand, elevated temperatures, and increased levels of coliform bacteria. Water pollution algae thrive in these conditions, which typically occur in environments with organic pollution, warm temperatures, and potentially higher microbial activity. Because the organic matter supplies nutrients to sustain their growth, algae that are growing on surfaces also flourish in these conditions. Enough substrates, like rocks or submerged structures, together with warm temperatures provide the perfect conditions for adhesion and colonization.

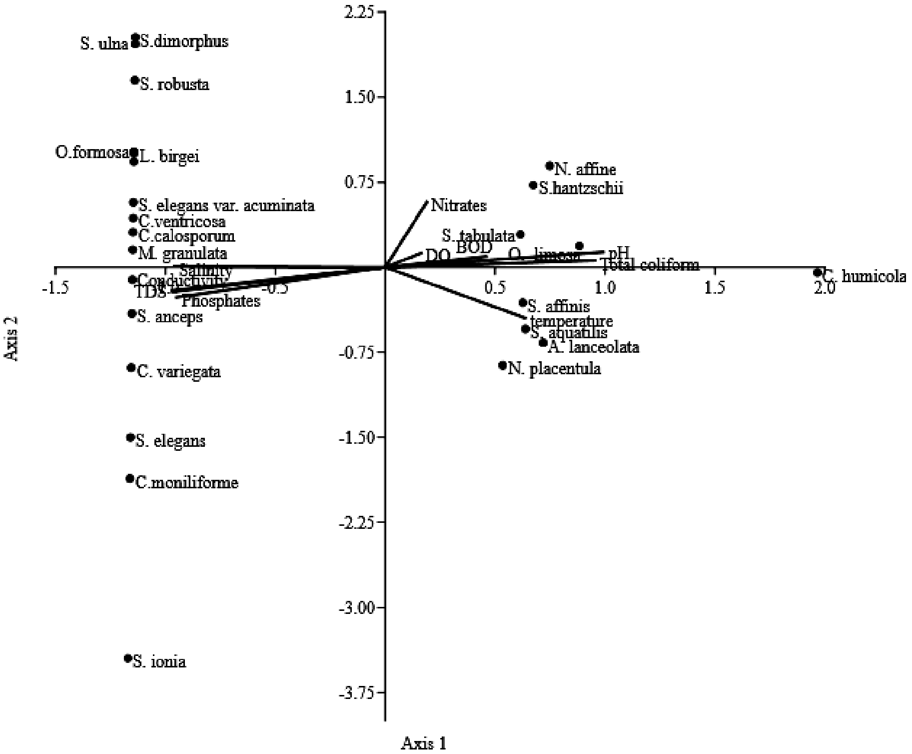
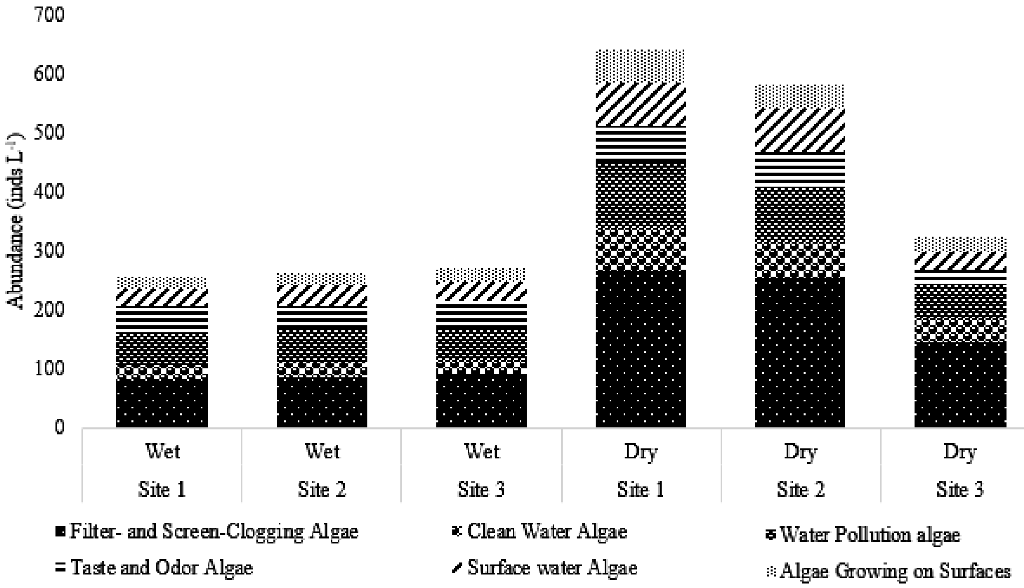


Figure 4. Canonical correspondence analysis based on the abundance of phytoplankton and environmental parameters at the three sampling sites in Tadlac Lake, Los Baños, Laguna, Philippines



Filter- and Screen-Clogging Algae		Clean Water Algae	Water Pollution Algae	Taste and Odor Algae	Surface water Algae	Algae Growing on Surfaces
Melosira granulata (Ehr.) Ralfs	*Chlorella variegata* Beig.	*Surirella robusta* Ehr.	*Oscillatoria formosa* Bory ex Gomont	*Synedra tabulata* Kütz.	*Stephanodiscus hantzschii* Grunow	*Cymbella ventricosa* Agardh
Spirogyra ionia Wade	*Melosira islandica* (Cleve) Euler	*Surirella elegans* var. *acuminata* Skvortzov & Noda	*Oscillatoria limosa* Agardh ex Gomont	*Synedra affinis* Kütz.	*Stauroneis anceps* Ehr.	*Achnanthes lanceolata* Bory
Synedra affinis Kütz.	*Synedra tabulata* Kütz.	*Navicula placentula* (Ehr.) Kütz.	*Spirogyra ionia* Wade	*Synedra ulna* Nitzsch	*Scenedesmus dimorphus* (Turpin) Kütz.	*Lyngbya birgei* Smith
Closterium calosporum Wittrock	*Synedra ulna* Nitzsch	*Surirella elegans* Ehr.	*Chlorococcum humicola* (Nag.) Rabenh.			
Oscillatoria formosa Bory ex Gomont	*Closterium moniliforme* Bory		*Chlorella variegata* Beig.			
Cymbella ventricosa Agardh	*Oscillatoria limosa* Agardh ex Gomont		*Lyngbya birgei* Smith			
Navicula placentula (Ehr.) Kütz.			*Nitzschia subrostrata* Hust.			

Figure 5. Functional classification of phytoplankton species across the three sites in Tadlac Lake, Los Baños, Laguna, Philippines

Lower pH values are linked to algae in the lower left quadrant, suggesting more acidic settings. In conditions where acidity can affect water chemistry and result in undesirable tastes and aromas in the water, taste and odor algae as well as surface water algae frequently flourish. Acid rain, deteriorating organic debris, and industrial discharges are a few of the causes of these conditions. Moreover, this quadrant is less susceptible to bacterial contamination, elevated temperatures, and organic pollutants. They may be present in waters where organic waste has not had a significant influence. Nitrates and phosphates, two common markers of nutrient-rich or eutrophic waters, are linked to higher amounts of algae in the lower right quadrant. A surplus of filter- and screen-clogging algae may grow under these conditions.

Table 6 presents an overview of the diversity indices for the phytoplankton species observed in this study. These indices provide valuable insights into the species richness, evenness, and overall biodiversity within the sampled aquatic ecosystems.

High H' suggests a rich diversity and therefore a healthier ecosystem (less pollution), whereas a low H′ value implies poor diversity and thus a less healthy ecosystem (more pollution). Shannon-Wiener diversity index of 2.17 to 3.15 in this study revealed a light pollution. Pielou evenness index is constrained between 0 and 1. The less evenness in communities between the species, the lower the J is. Pielou evenness index (J') ranged from 0.97 to 0.99 and these results suggested high balance or evenness of phytoplankton species in the ecosystem. Based on the association between the diversity index and the level of water pollution, the lake exhibited a state of light pollution. Similarly, the value of Simpson index of Diversity (D) ranges between 0 (absence of diversity) and 1 (absolute diversity). Based on the results, Simpson index of diversity (D) of 0.89 to 0.96 indicated that the lake manifests high to absolute diversity. These attributes draw attention to the lake's remarkable biodiversity, which reflects a diverse and well-balanced community of phytoplankton species. This abundant diversity highlights the lake's ecological adaptability and its capacity to harbor a variety of species, which supports the general health of the ecosystem.

Table 7 shows the variability of water quality in Tadlac Lake across multiple years, including periods before the aquaculture ban and before the ecotourism initiatives, which is the focus of the present study.

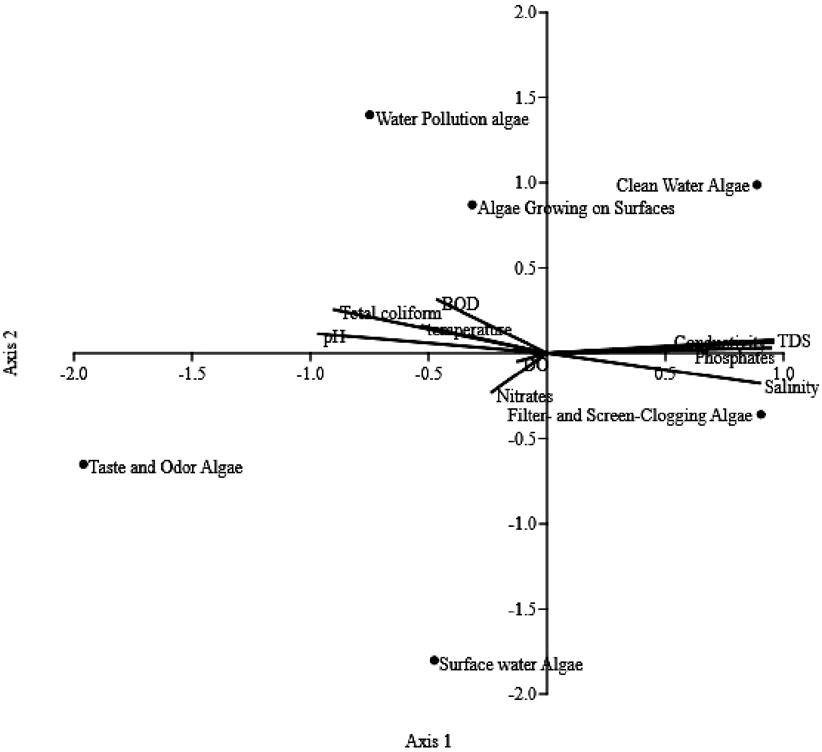


Figure 6. Canonical correspondence analysis based on the abundance of each phytoplanktons' functional classification and environmental parameters at three sampling sites in Tadlac Lake, Los Baños, Laguna, Philippines

Table 6. Diversity indices of phytoplankton at three sampling sites in Tadlac Lake, Los Baños, Laguna, Philippines

Diversity indices	Site 1		Site 2		Site 3	
	Wet	Dry	Wet	Dry	Wet	Dry
Total individuals	230	495	232	453	235	242
Shannon Weiner index (H')	2.17	3.15	2.17	3.13	2.18	3.09
Pielou's evenness (J')	0.99	0.99	0.99	0.98	0.99	0.97
Simpson index (D)	0.89	0.96	0.89	0.96	0.89	0.96

Table 7. Temporal variability in water quality of Tadlac Lake, Los Baños, Laguna, Philippines across multiple years

Water parameter	Before aquaculture ban (Gonzales and Flavier 1996)	2017-2018 (Villaruel and Camacho 2022)	Before ecotourism initiatives (Present study)	DENR Water Quality Guidelines and General Effluent Standards of 2016
Temperature	26.60	29.97	30.16	3 max. rise in °C
Conductivity	421.16	919.18	728.66	
pH	7.97	8.87	7.18	6.5-9.0
DO	2.64	6.17	7.17	> 5 mg L^{-1}
BOD	2.63	2.06	2.17	< 7 mg L^{-1}
Nitrates	0.14	0.02	1.67	< 7 mg L^{-1}
Phosphates	0.03	0.03	0.43	0.50 mg L^{-1}
Pollution index	High	Moderate	Low	

Tadlac Lake's water quality has fluctuated according to several studies conducted from the date before an aquaculture ban until the present. Temperature, conductivity, pH, dissolved oxygen, and levels of nutrients are among the variables that have changed; dissolved oxygen has shown to be particularly improved. Notwithstanding, certain obstacles persist, such as phosphates, which suggest potential sources of pollution.

In the present study, after the cessation of aquaculture activities on the lake since 1999, massive efforts were conducted to ensure the lake recovery. Government agencies with the supervision of Laguna Lake Development Authority implemented policies including apprehending violators of fishery laws. Due to minimal anthropogenic activities on the lake and strict implementation of conservation policies, the lake exhibited a better water condition.

In conclusion, phytoplankton species found in the study belonged to three major divisions: Phaeophyta (brown algae), Cyanobacteria (blue-green algae), and Chlorophyta (green algae), as well as four classes. The rank shows characteristics in the order of Phaeophyta> Cyanobacteria> Chlorophyta and the dominant species are *S. hantzschii, S. affinis, S. tabulata, A. lanceolata, N. placentula*, and *N. affine*. Fifteen species were categorized as Filter- and Screen-Clogging Algae and water pollution algae. The existence of these species serves as a reminder that Tadlac Lake remains in a state of incomplete recuperation from its earlier deterioration, characterized by a significant historical burden of organic pollution and eutrophication. The biological evaluation results of the phytoplankton diversity index show that the water quality exhibits a state of light pollution. The physical, chemical and bacteriological analyses show good agreement with the results of the phytoplankton index evaluation. While some parameters suggest positive trends, ongoing monitoring and management are crucial to sustain and enhance water quality in Tadlac Lake. Remedial actions are essential to support sustainable ecotourism emphasizing the need for seasonally tailored environmental management strategies. Through the integration of the findings from this water quality study into conservation and management plans, the local government can encourage sustainable tourist growth while mitigating the ecological problems that the lake faces.

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REFERENCES

Akhtar N, Syakir Ishak MI, Bhawani SA, Umar K. 2021. Various natural and anthropogenic factors responsible for water quality degradation: A review. Water J 13: 2660. DOI: 10.3390/w13192660.

Akinnawo SO. 2023. Eutrophication: Causes, consequences, physical, chemical and biological techniques for mitigation strategies. Environ Chall 12: 100733. DOI: 10.1016/j.envc.2023.100733.

Baird R, Bridgewater L. 2023. Standard Methods for the Examination of Water and Wastewater. 24th Edition. APHA Press, Washington DC.

Banoo S, Acharya C, Behera RR, Satapathy DR, Panda CR. 2022. Phytoplankton population dynamics in relation to environmental variables at Paradip Port, East Coast of India. Thalassas 38 (6): 1135-1153. DOI: 10.1007/s41208-022-00443-3.

Barinova S, Mamanazarova K. 2021. Diatom algae-indicators of water quality in the lower Zarafshan river, Uzbekistan. Water J 13 (3): 358-375. DOI: 10.3390/w13030358.

Batugedara I, Senanayake I. 2022. Plankton diversity in coastal waters near Kalu Ganga River Mouth; Sri Lanka. KDU J Multidiscip Stud 4 (2): 7-20. DOI: 10.4038/kjms.v4i2.47.

Bellinger EG, Sigee DC. 2015. Freshwater Algae: Identification, Enumeration and Use as Bioindicators. 2nd Edition. Wiley, New Jersey. DOI: 10.1002/9781118917152.

Boyd CE. 2020. Water Quality: An Introduction. Springer, Cham. DOI: 10.1007/978-3-030-23335-8_5.

Brillo BB. 2017. Intricacies, challenges and implications: The governance of Tadlac Lake, Los Banos, Laguna, Philippines. Intl J Water 11 (4): 376-394. DOI: 10.1504/IJW.2017.088047.

Department of Environment and Natural Resources. 2016. Water Quality Guidelines and General Effluents Standards of 2016. DAO-2016-08. emb.gov.ph

Devi P, Bhatnagar A. 2024. Comparative analysis of phytoplankton dynamics and water quality assessment in selected lentic water bodies of Haryana, India. Environ Conserv J 25 (1): 62-73. DOI: 10.36953/ECJ.24582661.

Dickens C, O'Brien G. 2021. Water quality: Standards and indicators. In: Leal Filho W, Azul AM, Brandli L, Lange Salvia A, Wall T (eds). Clean Water and Sanitation. Encyclopedia of the UN Sustainable Development Goals. Springer, Cham. DOI: 10.1007/978-3-319-70061-8_111-1.

Djumanto, Rasul E, Inoue T, Aoki S. 2017. Phytoplankton distribution in Mikawa Bay of Japan in relation to temperature and salinity variables. Bonorowo Wetlands 7: 16-25. DOI: 10.13057/bonorowo/w070105.

Engelmann HD. 1978. Zur Dominanzklassifizierung von Bodenarthropoden. Pedobiologia 18: 378-380. DOI: 10.1016/s0031-4056(23)00612-1.

Filiz N, Işkın U, Beklioğlu M, Öğlü B, Cao Y, Davidson TA, Søndergaard M, Lauridsen TL, Jeppesen E. 2020. Phytoplankton community response to nutrients, temperatures, and a heat wave in shallow lakes: An experimental approach. Water J 12: 3394. DOI: 10.3390/w12123394.

Gjoni V, Glazier DS, Wesner JS, Ibelings BW, Thomas MK. 2023. Temperature, resources and predation interact to shape phytoplankton size-abundance relationships at a continental scale. Glob Ecol Biogeogr 32 (11): 2006-2016. DOI: 10.1111/geb.13748.

Gonzales S, Flavier M. 1996. Water Quality of Tadlac Lake. [Undergraduate Thesis]. University of the Philippines Los Baños, Los Baños, Laguna. [Philippines]

Goswami K, Das Trakroo M, Kumar S, Mishra A. 2018. Impact of physico-chemical parameters on primary productivity of Lake Nainital. J Entomol Zool Stud 6 (4): 647-652.

Graco-Roza C, Soininen J, Corrêa G, Pacheco FS, Miranda M, Domingos P, Marinho MM. 2021. Functional rather than taxonomic diversity reveals changes in the phytoplankton community of a large dammed river. Ecol Indic 121: 107048. DOI: 10.1016/j.ecolind.2020.107048.

Guiry MD. 2021. AlgaeBase: A global database for algae. Curr Sci 121: 10-11. DOI: 10.18520/CS/V121/I1/10-11.

Guo K, Wu N, Wang C, Yang D, He Y, He J, Chai Y, Duan M, Huang X, Riis T. 2019.Trait dependent roles of environmental factors, spatial processes and grazing pressure on lake phytoplankton metacommunity. Ecol Indic 103: 312-320. DOI: 10.1016/j.ecolind.2019.04.028.

Halder N. 2017. Taxonomy and biodiversity of the Genus *Oscillatoria* Vauch. ex Gom. (Cyanoprokaryota: Oscillatoriales) with ecological notes from hooghly in West Bengal, India. Braz J Biol 4: 89-101. DOI: 10.21472/bjbs.040710.

Hopkins JE, Palmer MR, Poulton AJ, Hickman AE, Sharples J. 2021. Control of a phytoplankton bloom by wind-driven vertical mixing and light availability. Limnol Oceanogr 66: 1926-1949. DOI: 10.1002/lno.11734.

Jia J, Chen Q, Ren H, Lu R, He H, Gu P. 2022. Phytoplankton composition and their related factors in five different lakes in China: Implications for lake management. Intl J Environ Res Pub Health 19 (5): 3135-3147. DOI: 10.3390/ijerph19053135.

Kakouei K, Kraemer BM, Anneville O, Carvalho L, Feuchtmayr H, Graham JL, Higgins S, Pomati F, Rudstam LG, Stockwell JD, Thackeray SJ, Vanni MJ, Adrian R. 2021. Phytoplankton and cyanobacteria abundances in mid-21st century lakes depend strongly on future land use and climate projections. Glob Chang Biol 27: 6409-6422. DOI: 10.1111/ gcb.15866.

Khalil S, Mahnashi MH, Hussain M, Zafar N, Waqar-Un-Nisa, Khan FS, Afzal U, Shah GM, Niazi UM, Awais M, Irfan M. 2021. Exploration and determination of algal role as bioindicator to evaluate water quality-Probing fresh water algae. Saudi J Biol Sci 28 (10): 5728-5737. DOI: 10.1016/j.sjbs.2021.06.004.

Kock A, Taylor JC, Malherbe W. 2019. Diatom community structure and relationship with water quality in Lake Sibaya, KwaZulu-Natal, South Africa. S Afr J Bot 123: 161-169. DOI: 10.1016/j.sajb.2019.03.013.

Li C, Gao X, Li S, Bundschuh J. 2020. A review of the distribution, sources, genesis, and environmental concerns of salinity in groundwater. Environ Sci Pollut Res 27 (33): 41157-41174. DOI: 10.1007/s11356-020-10354-6.

Makindi SM. 2016. Local communities, biodiversity conservation and ecotourism: A case study of the Kimana Community Wildlife Sanctuary, Kenya. Afr J Hosp Tour Leis 5 (3): 1-15.

Masithah ED, Islamy RA. 2023. Checklist of freshwater periphytic diatoms in the midstream of Brantas River, East Java, Indonesia. Biodiversitas 24 (6): 3269-3281. DOI: 10.13057/biodiv/d240621.

Morsi H, Mostafa ES, Eladel H, Altuwajiri M. 2023. Screening the pollution-tolerant *Chlorococcum* sp. (Chlorophyceae) grown in municipal wastewater for simultaneous nutrient removal and biodiesel production. Water J 15 (9): 1723-1734. DOI: 10.3390/w15091723.

Nindarwi D, Samara S, Santanumurti M. 2021. Nitrate and phosphate dynamics of phytoplankton abundance in Kanceng River, Sepuluh, Bangkalan, East Java, Indonesia. IOP Conf Ser: Earth Environ Sci 679 (1): 012063. DOI: 10.1088/1755-1315/679/1/012063.

Peng X, Zhang L, Li Y, Lin Q, He C, Huang S, Li H, Zhang X, Liu B, Ge F, Zhou Q, Zhang Y, Wu Z. 2021. The changing characteristics of phytoplankton community and biomass in subtropical shallow lakes: Coupling efects of land use patterns and lake morphology. Water Res 200: 117235. DOI: 10.1016/j.watres.2021.117235.

Ray JG, Santhakumaran P, Kookal S. 2020. Phytoplankton communities of eutrophic freshwater bodies (Kerala, India) in relation to the physicochemical water quality parameters. Environ Dev Sustain 23: 259-290. DOI: 10.1007/s10668-019-00579-y.

Rishi V, Awasthi AK. 2015. Seasonal variation of genus *Oscillatoria* (Vaucher) in River Ganga at Kanpur. Biosci Trends 8: 3347-3351.

Rivera JP, Gutierrez E, David I, Newsome D. 2022. Implementing an effective ecotourism strategy for the Philippines. In: Aquino RS, Porter BA (eds.) Tourism in the Philippines. Perspectives on Asian Tourism. Springer, Singapore. DOI: 10.1007/978-981-19-4497-0_2.

Rott E, Kofler W. 2021. Planktonic centric diatoms from the Eastern Alps: Morphology, biogeography and ecology. Plant Fungal Syst 66 (1): 1-36. DOI: 10.35535/pfsyst-2021-0001.

Sharma AK, Malik DS, Bargali H. 2018. Food and feeding habits of *Schizothorox Richordsonii* (Gray, 1832) inhibiting Bhagirathi River, Tehri Garhwal, India. Intl J Sci Res 9 (4): 25562-25565. DOI: 10.24327/ijrsr.2018.0904.1882.

Sherman E, Moore JK, Primeau F, Tanouye D. 2016. Temperature influence on phytoplankton community growth rates. Glob Biogeochem Cycles 30 (4): 550-559. DOI: 10.1002/2015gb005272.

Shoener BD, Schramm SM, Béline F, Bernard O, Martínez C, Plósz BG, Snowling S, Steyer J-P, Valverde-Pérez B, Wágner D. 2019. Microalgae and cyano-bacteria modeling in water resource recovery facilities: A critical review. Water Res X 2: 100024. DOI: 10.1016/j.wroa.2018.100024.

Singh S, Anil AG, Kumar V, Kapoor D, Subramanian S, Singh J, Ramamurthy PC. 2022. Nitrates in the environment: A critical review of their distribution, sensing techniques, ecological effects and remediation. Chemosphere 287: 131996. DOI: 10.1016/j.

Song Y, Guo Y, Liu H, Zhang G, Zhang X, Thangaraj S, Sun J. 2022. Water quality shifts the dominant phytoplankton group from diatoms to dinofagellates in the coastal ecosystem of the Bohai Bay. Mar Pollut 183: 114078. DOI: 10.1016/j.marpolbul.2022.114078.

Stockwell JD, Doubek JP, Adrian R et al. 2020. Storm impacts on phytoplankton community dynamics in lakes. Glob Change Biol 26 (5): 2756-2784. DOI: 10.1111/gcb.15033.

Tito JCR, Luna LMG. 2020. Trophic status of twenty-four water reservoirs in the eastern of Cuba. Revista Cubana de Química 32 (1): 136-153.

Upadhyay AK, Singh R, Singh DV, Singh L, Singh DP. 2021. Microalgal consortia technology: A novel and sustainable approach of resource reutilization, waste management and lipid production. Environ Technol Innov 23: 101600. DOI: 10.1016/j.eti.2021.101600.

Villaruel MJS, Camacho MVDC. 2022. Phytoplankton Community Dynamics in Tadlac Lake, Los Baños, Laguna, Philippines. J Fish Environ 46 (3): 55-71.

Yang Y, Chen H, Al MA, Ndayishimiye JC, Yang J, Isabwe A, Luo A, Yang J. 2022. Urbanization reduces resource use efciency of phytoplankton community by altering the environment and decreasing biodiversity. J Environ Sci 112: 140-151. DOI: 10.1016/j.jes.2021.05.001.

Zhang Y, Gao W, Li Y, Jiang Y, Chen X, Yao Y, Messyasz B, Yin K, He W, Chen Y. 2021. Characteristics of the phytoplankton community structure and water quality evaluation in autumn in the Huaihe River (China). Intl J Environ Res Public Health 18 (22): 12092-12106. DOI: 10.3390/ijerph182212092.

Zhu H, Liu XG, Cheng SP. 2021. Phytoplankton community structure and water quality assessment in an ecological restoration area of Baiyangdian Lake, China. Intl J Environ Sci Technol 18: 1529-1536. DOI: 10.1007/s13762-020-02907-6.