

Phytoplankton as Bio-Indicators of Water Quality of Lake Mboandong, Cameroon

Miranda Egbe Awo^{1*}, Parfait Gildas Ndjouondo², Charleine Sob Djouego¹,
Beatrice Ambo Fonge¹

¹Department of Plant Science, University of Buea, Southwest Region, Buea, Cameroon

²Department of Biology, Higher Teacher Training College, The University of Bamenda, Bambili, Cameroon

Email: *awo.miranda@ubuea.cm

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Abstract

Water quality and phytoplankton community structure of a tropical lake in Cameroon (Lake Mboandong) were evaluated using phytoplankton and environmental factors. Water samples were collected from 4 sampling sites, in January (dry season) and August (rainy season) in 2024 at the top 10 cm and analysed for physicochemical parameters. Algal identification was done with the light microscope at different magnifications, using relevant identification manuals. Results of the physicochemical characteristics of this study showed that the lake's water was poorly oxygenated in the dry (2.35 mg/l) than the rainy season (3.78 mg/l), lower temperatures in the rainy ($18.38^{\circ}\text{C} \pm 0.52^{\circ}\text{C}$) than dry season ($19.04^{\circ}\text{C} \pm 0.44^{\circ}\text{C}$). Water pH was neutral to slightly basic, 7.49 ± 0.28 and 8.66 ± 0.07 in the rainy and dry seasons respectively. Higher turbidity occurred during the rainy season (10.93 ± 3.82 NTU) than in the dry season 6.56 ± 0.44 NTU. Nitrates were higher in the rainy (1.92 ± 0.99 mg/l) than in the dry season (0.52 ± 0.2 mg/l). Orthophosphate was rather higher in dry (3.08 ± 1.87 mg/l) than rainy season (1.53 ± 0.5 mg/l). A total of 77 phytoplankton were identified from 7 divisions. Bacillariophyta (18 taxa), Chlorophyta (23 taxa) and Cyanophyta (11 taxa) were the major groups. Total dry season abundance (7600 cells/L) was higher than that of the rainy season (3586 cells/L). Shannon-Weiner diversity was higher during the rainy (3.41) than during the dry season (2.51). Cyanobacteria contributed the largest (56.31% and 28.13%) in dry and rainy seasons respectively, mainly dominated by *Microcystis aeruginosa* and *Synechococcus* sp. *Chlorella* sp, *Tetraedron caudatum*, *Selenastrum* sp and *Pediastrum duplex* were common chlorophytes while *Aulocoseira granulata* and *Cocconeis pediculus* were common diatoms. The lake is a mildly polluted but productive lacustrine ecosystem that supports high phytoplankton diversity. The primary source of the pollution is the entry of inorganic and organic wastes from surrounding farmlands around the lake, as well as possible

excessive nutrient levels due to the lake's geological background.

Keywords

Lake Mboandong, Phytoplankton, Water Quality, Shannon-Weiner Diversity

1. Introduction

As a result of exposure to natural events and seasonality, algal communities pass through several successions, and because some species have different ecological tolerance limits, they could either be rare or abundant at certain periods of the year (Madzivanzira et al., 2023; Salmaso, 2003). In some other scenarios, both rare and abundant species could coexist in which case they all compete for the same nutrients, whose concentrations could be limiting at some periods of the year (Djouego et al., 2024; Hassan et al., 2023), thus influencing the diversity of algal communities. Other factors such as retention time, light attenuation, nutrients and a wide range of biotic interactions such as competition, predation, grazing, etc., are also known to influence algal diversity (Anyinkeng et al., 2016; Awo et al., 2020).

Algal succession in tropical aquatic systems is characterized by two distinct seasons; the dry and rainy seasons with specific algal taxa dominating. According to Salmaso (2003), temporal changes in phytoplankton composition can reflect a complex environmental gradient, capable of driving annual algal succession patterns. Lung'Ayia et al. (2000) reported the dominance of Cyanophyta and Bacillariophyta in Lake Victoria. Studies by Descy et al. (2005), found Cyanophyta and Chlorophyta as dominant taxa in Lake Tanganyika.

A plethora of environmental factors may act synergistically, favouring the growth and development of species that share similar ecological requirements as conferred by their genotypes (Sarmiento & Descy, 2008). Multivariate analyses have revealed algal succession along anthropogenic gradients where different land use and land cover characteristics prevail (Fai et al., 2023). Irrespective of the succession patterns, algae play vital roles in maintaining high productivity in the aquatic ecosystems (Stevenson, 2014). They are the primary producers, sustaining the other levels of the aquatic food chain.

Lake Mboandong, which is an elliptical lake situated behind Mount Cameroon, secluded from settlement and bordered by vast expanses of cocoa farms plays a unique role in supplying neighbouring villages with different species of fishes, amongst the other ecosystem services. Despite its long existence and diverse ecosystem services, very little has been documented on this lake. Studies have focused on the geochemical and palynological aspects of the lake sediments (Bessa et al., 2024; Richards, 2021). Studies on the water quality of neighbouring Lake Barombi Kotto, another volcanic crater lake around the vicinity revealed that the lake usually experiences eutrophication, characterized by large densities of cyanobacteria,

mainly *Microcystis aureginosa* and *M. flosaquae* typically driven by high nutrient loads (Awo et al., 2020).

To demonstrate the influence of seasonality and environmental variables on the composition of phytoplankton species in Lake Mboandong, an ecological study was carried out, the study aimed to determine the influence of season and some environmental parameters on the diversity and distribution of the phytoplankton community in Mboandong Lake.

2. Materials and Methods

2.1. Description of the Study Area

Lake Mboandong (4° 45'N and 9° 26'E, 120 m altitude) is an elliptical crater lake of about 25 hectares, with an average depth of 5 m, lying in the rain shadow of Mt. Cameroon, with very close proximity to Lake Barombi Kotto (Figure 1). Its bottom is relatively flat at 5 m with a characteristically thick layer of organically-rich mud and silty clay (Richards, 2021). It has a tropical climate, with an average annual temperature of 26.6°C and an annual precipitation of 3216 mm. Precipitation is highest in July and August, while January and February are known to be the driest months (Campbell et al., 2017). The vegetation is made up of secondary forests where cocoa and oil palms are cultivated together with staples like cassava, plantains and cocoyams (Awo et al., 2020; Richards, 2021).

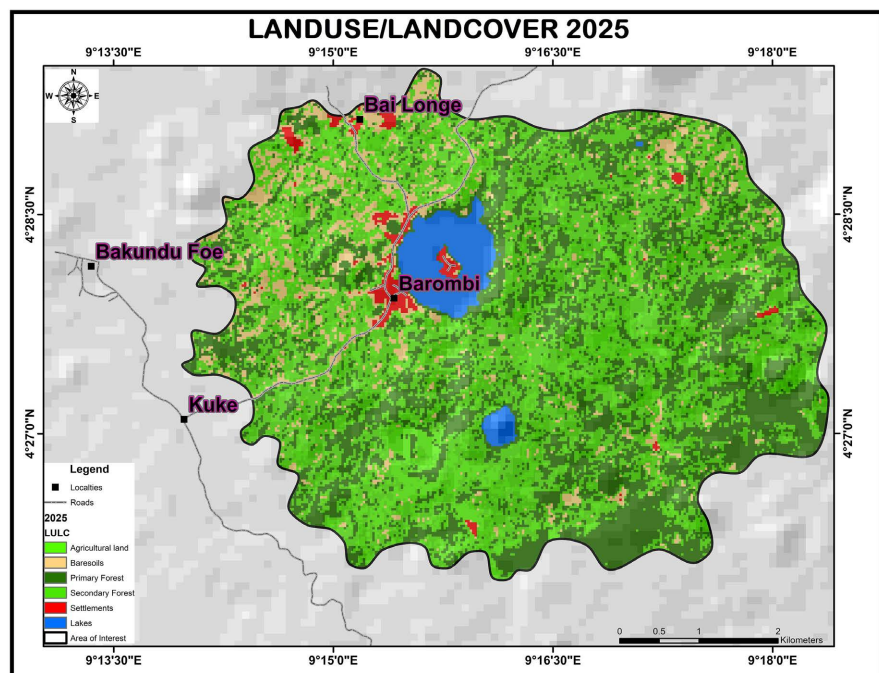


Figure 1. Map showing Lake Mboandong, adjacent Lake Barombi Kotto and the land uses in 2025.

2.2. Field Sampling

Field sampling was done in two seasons (dry and rainy), with samples collected at

the 4 cardinal points, from Stations 1 to 4 (**Table 1**). Water samples were collected within 1 m depth using a Van Don Water sampler and transferred to 1 litre plastic bottles. This was repeated twice to collect 3 replicates per sampling point. These bottles were immediately put in coolers containing ice blocks after three drops of Lugol's iodine were added to each of these plastic bottles to preserve the algae.

Physicochemical parameters were determined very early in the morning between 6 and 7 a.m. before sunrise to avoid the influence of the sunlight on water temperature. Water temperature, total dissolved solids, Hydrogen potential (pH), and electrical conductivity, were determined *in situ* using a Hanna HI 98,494 multi-parameter probe. A different set of water samples were labelled and put in a cooler containing ice blocks, parcelled and sent to the Hydrobiology and Environmental Laboratory of the University of Yaoundé 1 within 24 hours for the analysis of seven nutrients and anions and cations (Phosphates, magnesium, nitrates, nitrites, potassium, sodium, and ammonium ions) following standard methods (APHA, 2005).

2.3. Identification and Counting of Phytoplankton

Samples were preserved in a 5% formalin solution (Suthers et al., 2019), and taken to the Plant Science Laboratory of the University of Buea for identification and counting of the phytoplankton cells, using a Sedgwick-Rafter counting chamber under a compound microscope equipped with a micrometre. The identification was done using comparative morphology based on phytoplankton identification keys (Bellinger & Sigee, 2010, 2015; Suthers et al., 2019; van Vuuren et al., 2006; Verlecar & Desai, 2004). Algal abundance was expressed in cells/L.

Table 1. Sampling points and GPS coordinates.

Sampling Point	Latitude	Longitude	Altitude (m)
Site 1	4.450218013	9.270626059	147
Site 2	4.448661926	9.268162601	139.1
Site 3	4.450818252	9.267024738	145.3
Site 4	4.453048689	9.269713685	138

2.4. Data Analysis

Data was keyed into Microsoft Excel Version 2021 and analysed with the R package for statistical computing version 4.2 (R Core Team, 2024). Various ecological indices (species occurrence, abundance, richness, evenness and Shannon-Weiner diversity index) were used to elucidate species composition, structure and diversity across sites and seasons. The dissimilarity between study sites was assessed using Jaccard's dissimilarity index. Pearson's correlation analysis was used to shed light on the relationship between phytoplankton diversity and water physicochemical parameters. Principal component analysis was used to sim-

plify the complexity of the dataset, uncover patterns, and identify relationships between variables and the key variables driving the dynamics of the system.

2.5. Determination of Some Ecological Indices

Shannon-Weiner diversity index (H'): $H' = -\sum_{i=1}^s P_i \ln P_i$,

with $P_i = n_i/N$; n_i was the number of individuals belonging to a species i and N corresponded to the total number of species.

H' takes into account species abundance and it is sensitive to species with low frequencies. Typical values usually range between 1.5 and 3.5 bits in most ecological studies, and rarely more than 4 in most ecological studies. It increases as both the richness and the evenness of the community increase (Fai et al., 2023; Inyang & Wang, 2020).

Pielou Evenness Index (J) was computed according to Pielou (1975). The value of J varies between 0 (one species dominates) and 1 (all the species tend to have the same abundance). $J = H'/\log_2 S$, where: S is the total number of species or taxonomic richness.

3. Results and Discussion

3.1. Phytoplankton Community Structure in Lake Mboandong

A total of 77 phytoplankton species were identified from seven algal divisions (Table 2). These included Bacillariophyta (18 species), Charophyta (7 species), Chlorophyta (23 species), Chrysophyta (5 species), Cyanophyta (11 species), Dinophyta (6 species), and Euglenophyta (7 species). Amongst these, Chlorophyta exhibited the highest species diversity, encompassing 23 different species. There were differences in the phytoplankton abundance across seasons, with higher abundances recorded in the dry season than during the rainy season. Concerning the distribution of algal groups, Cyanophyta was the most dominant in both seasons (56.31% and 28.13% in the dry and rainy seasons respectively). The composition of Cyanophyta was higher in both seasons relative to the other algal divisions. Dry season algal composition was in the following order: Cyanophyta > Bacillariophyta > Chlorophyta > Euglenophyta > Dinophyta > Chrysophyta and Charophyta while rainy season composition was Cyanophyta > Chlorophyta > Bacillariophyta > Euglenophyta > Dinophyta > Chrysophyta > Charophyta.

3.2. Diversity of Phytoplankton in Mboandong Lake during the Study Period

Higher phytoplankton was recorded during the rainy season than in the dry season (Table 3). Species diversity ranged from 1.69 to 2.48 bits, with S3 and S4 having the lowest and highest algal diversities respectively. During the rainy season, diversity ranged from 2.35 in S1 to 2.83 bits in S4. Differences in diversity across sites were equally recorded in both the dry and rainy seasons. Site 4 (S4) had the highest phytoplankton diversity during the dry season (2.48 bits) while the lowest was in S3 (1.63 bits).

Table 2. Phytoplankton composition across sites and seasons in Lake Mboandong during the study period.

Division	Class	Order	Family	Species	Dry season				Rainy season				
					S1	S2	S3	S4	S1	S2	S3	S4	
Bacillariophyta	Bacillariophyceae	Achnanthes	Achnanthesiaceae	<i>Achnanthes minutissimum</i>	10	0	10	0	0	27	0	0	
			Cocconeidae	<i>Cocconeis pediculus</i>	80	77	150	0	0	0	13	0	
		Aulacoseirales	Aulacoseiraceae	<i>Aulacoseira granulata</i>	293	177	0	27	253	107	43	40	
			Cymbellales	Cymbellaceae	<i>Cymbella cistula</i>	33	0	0	43	0	0	0	0
		<i>Cymbella</i> sp.			0	0	0	0	0	33	0	0	
		<i>Navicula amphora</i>			30	0	0	0	0	0	0	0	
		Naviculales	Naviculaceae	<i>Navicula</i> sp.	0	0	123	0	0	0	0	0	
				Pinnulariaceae	<i>Pinnularia</i> sp.	0	0	0	0	0	53	0	0
		Pleurosigmales	Pleurosigmales	Pleurosigmales	<i>Pinnularia viridis</i>	0	0	0	0	0	0	33	0
					<i>Gyrosigma acuminatum</i>	0	0	0	30	0	0	0	0
		Bacillariales	Bacillariales	Bacillariaceae	<i>Nitzschia palea</i>	17	17	0	0	0	7	0	47
					<i>Urosolenia gracilis</i>	0	0	17	0	0	0	0	0
		Rhizosoleniales	Rhizosoleniales	Rhizosoleniaceae	<i>Urosolenia eriensis</i>	0	0	0	0	0	0	10	0
					<i>Melosira varians</i>	13	0	10	10	0	0	0	0
		Coccinodiscophyceae	Coccinodiscophyceae	Melosirales	Melosiraceae	<i>Meridion circulare</i>	10	0	0	0	0	0	0
						<i>Synedra ulna</i>	17	67	0	0	13	20	0
Fragilariophyceae	Fragilariophyceae	Fragilariiales	Fragilariaceae	<i>Asterionella formosa</i>	0	10	0	0	0	0	10	73	
				<i>Tabellaria flocculosa</i>	0	0	0	20	7	27	0	0	
Charophyta	Zygnematophyceae	Closteriales	Closteriaceae	<i>Closterium</i> sp.1	0	0	60	0	10	0	0	0	
				<i>Closterium</i> sp.2	0	0	0	0	0	0	0	13	
				<i>Cosmarium contractum</i>	0	0	0	7	0	0	0	0	
		Desmidiales	Desmidiaceae	<i>Cosmarium minutum</i>	0	0	0	0	0	0	20	0	
				<i>Micrasterias</i> sp.	0	0	0	0	0	0	13	0	
		Zygnematales	Zygnematales	Zygnemataceae	<i>Spirogyra</i> sp.	0	0	0	0	3	0	0	0
<i>Mougoetia</i> sp.	0				0	0	0	0	0	0	50		
Chlorophyta	Allomalorhagida	Anomoirhaga	Cateriidae	<i>Cateria</i> sp.	27	0	0	0	0	0	0	0	
				Trebouxiophyceae	Chlorellales	Chlorellaceae	<i>Chlorella</i> sp.	100	0	160	0	60	7
	Oedogoniales	Oedogoniaceae	<i>Oedogonium</i> sp.	0			100	0	0	0	0	0	0
			<i>Oedogonium</i> sp.	0	0	0	0	30	0	0	0		
	Chlorophyceae	Chlorophyceae	Scenedesmaceae	<i>Scenedesmus quadricauda</i>	53	0	0	0	0	0	37	0	
				<i>Scenedesmus obliquus</i>	0	0	0	0	0	0	0	17	
	Sphaeropleales	Sphaeropleales	Hydrodictyceae	<i>Tetraedron caudatum</i>	20	97	73	0	0	0	73	0	
				<i>Pediastrum duplex</i>	0	0	20	0	20	47	0	0	
				<i>Lagerthemia</i> sp.	0	0	10	0	0	0	0		

Continued

				<i>Tetraedron caudatum</i>	0	0	0	0	0	0	23	37
				<i>Tetraedron</i> sp.	0	0	0	33	0	0	0	0
			Selenastraceae	<i>Ankistrodesmus</i> sp.	0	0	0	0	0	13	17	0
				<i>Selenastrum</i> sp.	0	0	183	0	0	60	27	30
			Sphaeropleaceae	<i>Ankyra</i> sp.	0	0	0	0	13	0	0	0
			Chlamydomonadaceae	<i>Chlamydomonas</i> sp.	0	0	0	0	17	47	27	27
				<i>Chlorogonium</i> sp.	0	0	0	0	63	0	0	0
		Chlamydomonadales	Haematococcaceae	<i>Haematococcus</i> sp.	0	0	0	0	33	0	40	37
				<i>Haematococcus pluvialis</i>	37	0	0	27	0	0	0	0
			Volvocaceae	<i>Pandorina</i> sp.	0	77	0	0	0	0	0	17
	Chlorophyceae	Chlorococcales	Dictyosphaeraceae	<i>Dictyosphaerium</i> sp.	0	27	0	0	0	0	0	0
	Ulvophyceae	Cladophorales	Clodophoraceae	<i>Cladophora fracta</i>	0	0	0	0	0	0	60	0
	Trebouxiophyceae	Chlorellales	Chlorellaceae	<i>Chorella vulgaris</i>	0	0	0	57	0	0	0	0
			Oocystaceae	<i>Oocystis lacustris</i>	0	0	0	50	0	0	0	0
				<i>Dinobryon cylindricum</i>	10	0	0	0	0	0	0	0
		Chromulinales	Dinobryaceae	<i>Dinobryon divergens</i>	3	0	0	7	17	0	0	0
	Chrysophyceae			<i>Mallomonas</i> sp.	43	0	0	0	0	0	0	0
		Synurales	Mallomonadaceae	<i>Synura</i> sp.	0	0	0	0	0	33	0	0
		Pyrenomonadales	Pyrenomonadaceae	<i>Rhodomonas</i>	0	0	0	0	0	0	0	40
			Aphanizomenonaceae	<i>Aphanizomenon flos-aquae</i>	37	0	0	0	0	0	0	0
				<i>Anabaena circinalis</i>	0	23	13	0	7	0	0	37
		Nostocales	Nostocaceae	<i>Anabaena</i> sp.	0	0	0	20	0	0	0	0
			Gloeotrichiaceae	<i>Gloeotrichia</i> sp.	0	0	0	0	10	0	0	53
				<i>Microcystis aeruginosa</i>	600	407	213	0	0	27	0	0
	Cyanophyta	Cryptophyceae	Chroococcales	<i>Microcystis flos-aquae</i>	0	0	0	0	0	33	0	27
				<i>Oscillatoria rubescens</i>	17	0	0	0	13	0	0	0
		Oscillatoriales	Oscillatoriaceae	<i>Arthrospira</i> sp.	0	0	0	0	0	33	0	0
			Microcoleaceae	<i>Arthrospira</i> sp.	0	0	0	0	0	33	0	0
			Synechococcaceae	<i>Synechococcus</i> sp.	183	473	2133	160	0	93	270	207
		Synechococcales	Merismopediaceae	<i>Merismopedia</i> sp.	0	0	0	0	80	0	0	30
				<i>Aphanocapsa</i> sp.	0	0	0	0	0	47	43	0
				<i>Ceratium hirundinella</i>	3	0	0	0	0	40	0	0
		Gonyaulacales	Ceratiaceae	<i>Ceratium</i> sp.	0	37	20	0	0	0	7	20
				<i>Gymnodinium rotundatum</i>	10	0	0	0	0	0	0	0
	Dinophyta	Dinophyceae	Gymnodiniales	<i>Gymnodinium</i> sp.	0	13	137	0	0	0	0	23
				<i>Peridinium</i> sp.	10	27	40	7	0	0	0	0
			Peridinales	<i>Peridinium umbonatum</i>	0	0	0	23	0	67	17	107

Continued

				<i>Euglena gracilis</i>	63	40	73	0	0	0	0	0
				<i>Euglena viridis</i>	0	0	0	57	70	13	57	43
				<i>Trachelomonas abrupta</i>	0	0	0	0	50	0	0	0
Euglenophyta	Euglenophyceae	Euglenales	Euglenaceae	<i>Trachelomonas africana</i>	0	0	130	20	0	0	0	0
				<i>Trachelomonas volvocina</i>	0	40	0	0	0	0	0	0
				<i>Trachelomonas</i> sp.	0	0	0	0	0	33	20	33
			Phacaceae	<i>Phacus</i> sp.	0	0	0	0	0	27	57	0

Generally, according to the classification by Shekhar et al. (2008), which associated Shannon's diversity values with water quality, it could be inferred that all sites, except Site 3 in the dry season are mildly polluted since ($3 \leq H \leq 4$).

Table 3. Ecological indices of Lake Mboandong across sampling sites and seasons.

Site	<i>A</i>		<i>S</i>		<i>J</i>		<i>H'</i>	
	<i>D</i>	<i>R</i>	<i>D</i>	<i>R</i>	<i>D</i>	<i>R</i>	<i>D</i>	<i>R</i>
1	1720	770	25	19	0.72	0.80	2.31	2.35
2	1706	893	17	23	0.79	0.94	2.23	2.95
3	3577	917	19	22	0.58	0.85	1.69	2.63
4	597	1007	17	22	0.87	0.92	2.48	2.83

D = dry season, *R* = rainy season, *A* = abundance, *S* = species richness, *J* = evenness index, *H'* = Shannon-Weiner diversity index.

3.3. Similarity between Sampling Sites

The similarity between study sites permitted to grouping of them according to the common species (Figure 2). Group 1 brought together sites 1 and 2 during rainy and dry seasons. Group 2 brought together sites 3 and 4 during rainy and dry seasons. This grouping revealed the proximity of sites 1 and 2, and sites 3 and 4, hence similar algal species.

3.4. Physicochemical Parameters of Water Samples during the Study Period in Mboandong Lake

Generally, these parameters did not display remarkable differences between sampling sites, indicating the homogeneity of water quality in most portions of the lake. That notwithstanding, seasonal differences were recorded for most of the parameters measured.

Water temperature showcased fluctuations with higher mean water temperature in the dry season of $19.04^\circ\text{C} \pm 0.44^\circ\text{C}$ than in the rainy season of $18.38^\circ\text{C} \pm 0.52^\circ\text{C}$ ($p = 0.016$). The recorded low temperatures could be attributed to the shielding effect of the large canopies of trees which dominated the study site.

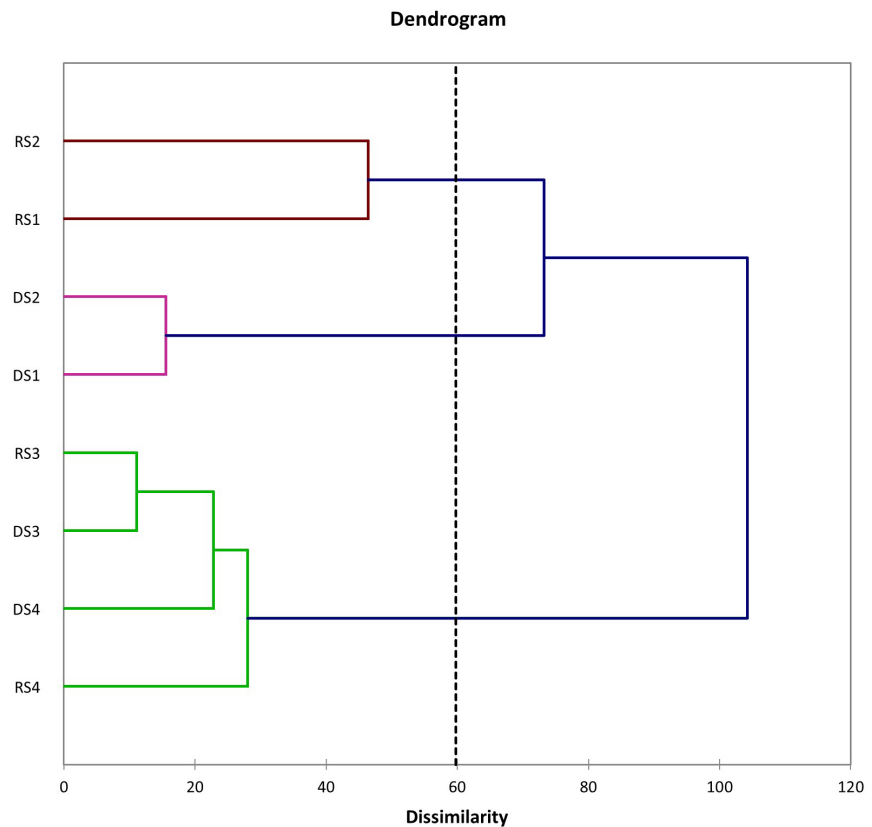


Figure 2. Clustering shows dissimilarity between sampling sites according to species.

Contrary to adjacent Lake Barombi Kotto, a greater portion of this lake was shaded by tree canopies, thus accounting for the lower temperatures. pH was neutral to slightly basic, 7.49 ± 0.28 and 8.66 ± 0.07 in the rainy and dry seasons respectively. Higher pH recorded during the dry season could be because the high phytoplankton biomass carries out photosynthesis, thus reducing inorganic carbon from the water which shifts the pH towards high values by loss of alkaline reserve. This mechanism is thought to drive higher pH values during warmer periods such as the dry season (Staeher & Sand-Jensen, 2006). The pH was within the range of that recorded in Lake Barombi Kotto (Awo et al., 2020; Campbell et al., 2017). The lake's electrical conductivity was in the range of 236-243 but with significant seasonal differences. Higher turbidity occurred during the rainy season at 10.93 ± 3.82 NTU than in the dry season at 6.56 ± 0.44 NTU as a result of the dead organic matter and debris brought into the lake by runoffs during the rainy season (Table 4). Nitrates were significantly higher during the rainy season of 1.92 ± 0.99 mg/l as opposed to 0.52 ± 0.27 mg/l in the dry season ($p = 0.002$). A similar trend was observed for nitrites and ammonium levels. Apart from allochthonous nutrient sources, cyanobacteria are known to increase nitrates in water via processes of nitrogen fixation by the nitrogen-fixing genera. In freshwater lake ecosystems, $\text{NH}_3\text{-N}$, $\text{NO}_3\text{-N}$ and $\text{NO}_2\text{-N}$ are the three main forms of soluble nitrogen which

are very important to phytoplankton and aquatic plants (Liu et al., 2019). $\text{NH}_3\text{-N}$ is generated by heterotrophic bacteria during the decomposition of organic material and remains a very vital source of nitrogen to phytoplankton and this is readily converted via nitrification by bacteria (Datta, 2012). Very low dissolved oxygen levels were recorded in the lake, although significantly higher during the rainy than in the dry season at 3.78 ± 0.43 mg/l and 2.35 ± 0.14 mg/l respectively. Low dissolved oxygen levels suggest high organic pollution possibly from nearby cocoa farms and high inputs of eroded materials from these soils. This is evidenced by the thick mud layer that overlays the lake's bottom. Similar observations were made by Bessa et al. (2025). With the very low dissolved oxygen levels recorded during the study, more ammonium nitrogen could be released from the sediments, leading to an increase in its concentration.

All macronutrients tested were present in Lake Mboandong. Calcium, and Mg, did not show seasonal variations in concentrations but the concentrations of K and Na were higher during the dry season. This could be associated with high rates of evaporation in the dry season. Similarly, orthophosphate concentration was higher during the dry season (3.08 ± 1.87 mg/l) as opposed to 1.53 ± 0.57 mg/l recorded in the rainy season.

Total hardness was higher in the dry season at 32.36 ± 4.84 mg/l than in the rainy season at 14.40 ± 2.49 mg/l.

Table 4. Variation of water physicochemical parameters in Lake Mboandong across seasons.

Parameter	Dry season	Rainy season	<i>p</i> -value ¹
Temp	19.04 ± 0.44	18.38 ± 0.52	0.016*
pH Water	8.66 ± 0.07	7.49 ± 0.28	<0.001***
Cond.	243.38 ± 7.73	236.50 ± 16.70	0.3ns
Turbid	6.56 ± 2.87	10.93 ± 3.82	0.022*
NH ₄	0.61 ± 0.28	1.16 ± 0.66	0.049*
NO ₃	0.52 ± 0.27	1.92 ± 0.99	0.002**
NO ₂	0.34 ± 0.36	1.88 ± 1.43	0.011*
Bicarb	14.90 ± 2.12	15.47 ± 2.85	0.7ns
Ca	1.33 ± 0.22	1.24 ± 0.41	0.6ns
Mg	1.85 ± 0.35	2.04 ± 0.74	0.5ns
K	1.29 ± 0.04	1.00 ± 0.37	0.046*
Na	1.33 ± 0.40	0.88 ± 0.13	0.011*
Orthophosphate	3.08 ± 1.87	1.53 ± 0.57	0.041*
DO	2.35 ± 0.14	3.78 ± 0.43	<0.001***
Total_H	32.36 ± 4.84	14.40 ± 2.49	<0.001***

¹Two samples t-test, ^{ns}Not significant at the 5% level of significance, *Significant at the 5% level of significance, **Significant at the 1% level of significance, ***Significant at the 0.1% level of significance, Temp = temperature, Cond = conductivity, Turbid = turbidity, NH₄ = ammonium, NO₃ = nitrates, NO₂ = nitrites, Bicarb = bicarbonate, Ca = calcium, Mg = magnesium, K = potassium, Na = sodium.

Principal component analyses with Dim1 \times Dim2 axes grouped 16 variables in the dry season (**Figure 3**). Dim1 (51.4%) was positively correlated to Bicarbonate, potassium, H' (Shannon diversity), total H, water pH, magnesium, conductivity, ammonium, and sodium. It was negatively correlated to nitrites, nitrates, DO, calcium, temperature and turbidity. Dim2 (31.9%) was positively correlated to nitrates, calcium, temperature, turbidity, bicarbonate, potassium, H', water pH, and magnesium. It was negatively correlated to DO, nitrites, sodium, total H, ammonium, and conductivity. During dry season, Sites 1 and 2 were similar and constituted a group, and were different from Site 3, likewise Site 4. Site 4, which was closer to the small outflowing stream received more pollutants than other sites.

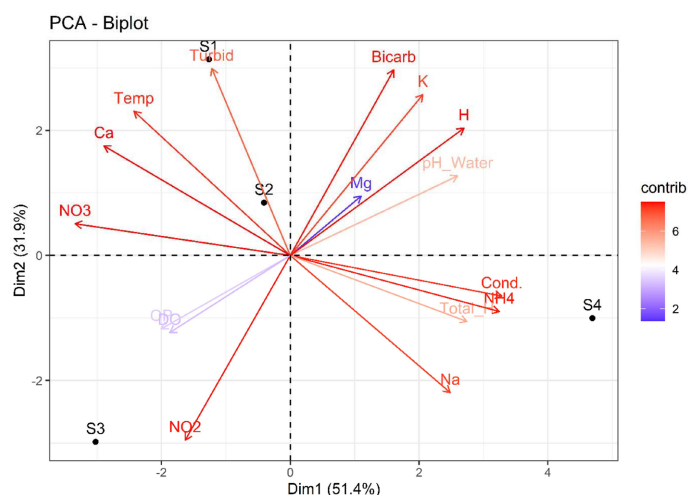


Figure 3. PCA biplot for water physicochemical parameters and phytoplankton diversity in the dry season.

Principal component analyses with Dim1 \times Dim 2 axes grouped 16 variables in the rainy season (**Figure 4**). Dim1 (50.7% of inertia) was positively correlated to H, nitrites, water pH, nitrates, Total H, temperature, and sodium. It was negatively correlated to ammonium, bicarbonate, potassium, conductivity, magnesium, DO, orthophosphates, turbidity and calcium. Dim2 (35.2% of inertia) was positively correlated to magnesium, conductivity, potassium, bicarbonate, ammonium, H, nitrites and water pH. It was negatively correlated to total H, nitrates, temperature, sodium, calcium, orthophosphates, turbidity, and DO. During the rainy season, Sites 1 and 3 were more similar and different to Site 2, and also different to Site 4. Site 4 received more pollutants than other sites (**Figure 4**).

3.5. Seasonal Distribution of Phytoplankton and Some Physicochemical Parameters According to Study Sites

Physicochemical parameters were found higher during the dry season as opposed to the rainy season. NO_3 , NO_2 , DO, NH_4 , Turb, Bicarb and Mg were higher during the rainy season as opposed to the others high during the dry season. Species related to these parameters during rainy season included *Achnanthydium minutissimum*,

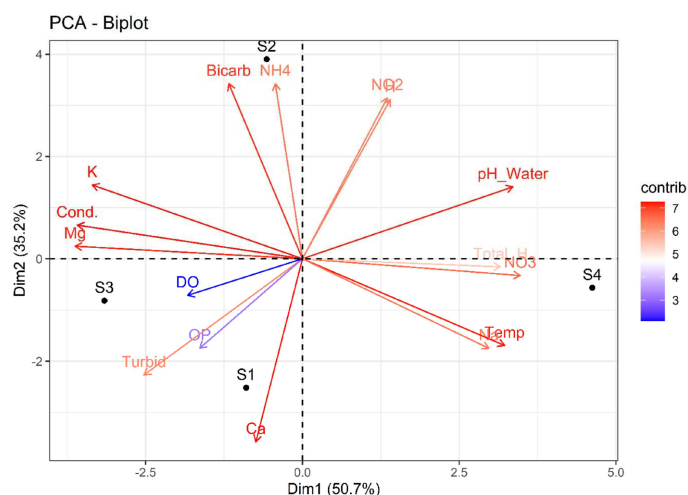


Figure 4. PCA biplot for water physicochemical parameters and phytoplankton diversity in the rainy season.

Cymbella sp., *Pinnularia* sp., *Pinnularia viridis*, *Nitzschia palea*, *Urosolenia eriensis*, *Asterionella formosa*, *Tabellaria flocculosa*, *Closterium* sp.2, *Cosmarium minutum*, *Micrasterias* sp., *Spirogyra* sp., *Mougoetia* sp., *Chlorella* sp., *Oedogonium* sp.2, *Tetraedron caudatum*, *Pediastrum duplex*, *Ankistrodesmus* sp., *Ankyra* sp., *Chlamydomonas* sp., *Haematococcus* sp., *Cladophora fracta*, *Dinobryon divergens*, *Synura* sp., *Rhodomonas* sp., *Anabaena circinalis*, *Gloeotrichia* sp., *Microcystis flos-aquae*, *Arthrospira* sp., *Merismopedia* sp., *Aphanocapsa* sp., *Ceratium hirundinella*, *Peridinium umbonatum*, *Euglena viridis*, *Trachelomonas abrupta*, *Trachelomonas* sp., and *Phacus* sp.

In most phytoplankton studies, nutrients have been implicated as one of the key variables controlling their community structure and biomass. In this study, there were some species highly related to some physicochemical parameters during the dry season. These included *Cocconeis pediculus*, *Aulacoseira granulata*, *Cymbella cistula*, *Navicula amphora*, *Navicula* sp., *Gyrosigma acuminatum*, *Urosolenia gracilis*, *Melosira varians*, *Meridion circulare*, *Synedra ulna*, *Closterium* sp.1, *Cosmarium contractum*, *Cateria* sp., *Oedogonium* sp., *Scenedesmus quadricauda*, *Scenedesmus obliquus*, *Lagerhemia* sp., *Tetraedron caudatum*, *Tetraedron* sp., *Selenastrum* sp., *Chlorogonium* sp., *Haematococcus pluvialis*, *Pandorina* sp., *Dictyosphaerium* sp., *Chorella vulgaris*, *Oocystis lacustris*, *Dinobryon cylindricum*, *Mallomonas* sp., *Aphanizomenon flos-aquae*, *Anabaena* sp., *Microcystis aeruginosa*, *Oscillatoria rubescens*, *Synechococcus* sp., *Ceratium* sp., *Gymnodinium rotundatum*, *Gymnodinium* sp., *Peridinium* sp., *Euglena gracilis*, *Trachelomonas africana*, and *Trachelomonas volvocina* (Figure 5). Nitrogen and phosphorus are two nutrients having dramatic influences on algal composition as demonstrated in bioassay experiments (Mebane et al., 2021). The appearance of more species in the dry season could be explained by the nutrient limitation theory. Most of these species have been identified in mild to heavily polluted waters in different ecosystems (Fai et al., 2023; Tabot et al., 2016). Typical Cyanophyte

genera such as *Microcystis*, *Oscillatoria*, and *Synechococcus* were recorded in adjacent Lake Barombi Kotto (Awo et al., 2020). Higher abundances of these species during the dry season could be attributed to higher temperatures and nutrients associated with this season that favoured the growth and proliferation of these species. These findings aligned with the outcomes of several studies of phytoplankton community structure, underscoring a high level of correlation between key water quality variables. Qu and Zhou (2024) recorded similar observations in Xuanwu Lake, China. The variation of phytoplankton composition between the rainy and dry seasons could be significant for their use as indicators of water quality. The concentration of phosphates in the rainy season is attributed to the fact that the lake is surrounded by agricultural farms which make use of higher doses of agrochemicals during this season to prevent the blackening and rot of cocoa pods. These chemicals are easily leached during the high rains into the lake. Other distinctive properties of the lake, different from surrounding land uses could explain variability noticed in terms of phytoplankton species occurrence in different sites. The lake's pH falls within the 6.5 - 8.5 range, suitable for aquatic biodiversity (WHO, 2017). This study does not address its suitability for drinking since its murky appearance and high organic (muddy benthic layer) deter people from using it for this purpose.

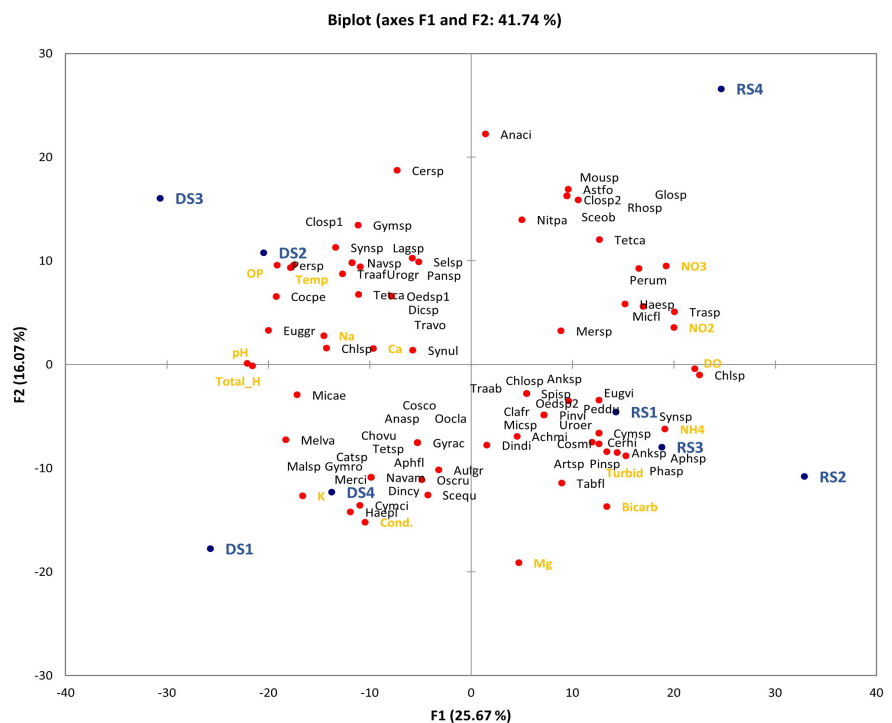


Figure 5. Spatiotemporal variation of physicochemical parameters and species according to the study sites and seasons.

(*Achnantheidium minutissimum* = Achmi, *Cocconeis pediculus* = Cocpe, *Aulacoseira granulata* = Aulgr, *Cymbella cistula* = Cymci, *Cymbella* sp. = Cymsp, *Na-*

vicula amphora = Navam, *Navicula* sp. = Navsp, *Pinnularia* sp. = Pinsp, *Pinnularia viridis* = Pinvi, *Gyrosigma acuminatum* = Gyraac, *Nitzschia palea* = Nitpa, *Urosolenia gracilis* = Urogr, *Urosolenia eriensis* = Uroer, *Melosira varians* = Melva, *Meridion circulare* = Merci, *Synedra ulna* = Synul, *Asterionella Formosa* = Astfo, *Tabellaria flocculosa* = Tabfl, *Closterium* sp.1 = Closp1, *Closterium* sp.2 = Closp2, *Cosmarium contractum* = Cosco, *Cosmarium minutum* = Cosmi, *Micrasterias* sp. = Micsp, *Spirogyra* sp. = Spisp, *Mougoetia* sp. = Mousp, *Cateria* sp. = Catsp, *Chlorella* sp. = Chlsp, *Oedogonium* sp. = Oedsp1, *Oedogonium* sp. = Oedsp2, *Scenedesmus quadricauda* = Scequ, *Scenedesmus obliquus* = Sceob, *Tetraedron caudatum* = Tetca, *Pediastrum duplex* = Peddu, *Lagerhemia* sp = Lagsp, *Tetraedron caudatum* = Tetca, *Tetraedron* sp. = Tetsp, *Ankistrodesmus* sp. = Anksp, *Selenastrum* sp. = Selsp, *Ankyra* sp. = Anksp, *Chlamydomonas* sp. = Chlsp, *Chlorogonium* sp. = Chlosp, *Haematococcus* sp. = Haesp, *Haematococcus pluvialis* = Haep, *Pandorina* sp. = Pansp, *Dictyosphaerium* sp. = Dicsp, *Cladophora fracta* = Clafr, *Chorella vulgaris* = Chovu, *Oocystis lacustris* = Oocla, *Dinobryon cylindricum* = Dincy, *Dinobryon divergens* = Dindi, *Mallomonas* sp. = Malsp, *Synura* sp. = Synsp, *Rhodomonas* sp. = Rhosp, *Aphanizomenon flos-aquae* = Aphfl, *Anabaena circinalis* = Anaci, *Anabaena* sp. = Anasp, *Gloeotrichia* sp. = Glosp, *Microcystis aeruginosa* = Micae, *Microcystis flos-aquae* = Micfl, *Oscillatoria rubescens* = Oscru, *Arthrospira* sp. = Artsp, *Synechococcus* sp. = Synsp, *Merismopedia* sp. = Mersp, *Aphanocapsa* sp. = Aphsp, *Ceratium hirundinella* = Cerhi, *Ceratium* sp. = Cersp, *Gymnodinium rotundatum* = Gymro, *Gymnodinium* sp. = Gymsp, *Peridinium* sp. = Persp, *Peridinium umbonatum* = Perum, *Euglena gracilis* = Euggr, *Euglena viridis* = Eugvi, *Trachelomonas abrupta* = Traab, *Trachelomonas africana* = Traaf, *Trachelomonas volvocina* = Travo, *Trachelomonas* sp. = Trasp, *Phacus* sp. = Phasp, Temp = temperature, pH = hydrogen potential, Cond. = conductivity, Turbid = turbidity, NH₄ = ammonium, NO₃ = nitrates, NO₂ = nitrites, Bicarb = bicarbonate, Ca = calcium, Mg = magnesium, K = potassium, Na = sodium, OP = orthophosphates, DO = dissolved oxygen, Total_H = total hardness).

3.6. Management Recommendations for Mitigating the Effects of Agriculture on Lake Mboandong

Based on findings from this study and previous studies on this lake and adjacent Lake Barombi Kotto, agriculture has profound effects on the lake ecosystem through runoff, sedimentation and chemical pollution. The following recommendations could mitigate the effects of agriculture on Lake Mboandong: The village Council should establish vegetated buffer strips along the Lake's shoreline to filter runoff and reduce the influx of sediments and nutrients from the surrounding agricultural farmlands. This riparian vegetation should comprise native trees already existing in the area, which can effectively absorb nutrients without altering the habitat characteristics. Regional councils should offer training programs to communities on tree selection/planting, silvicultural best practices and riparian

buffer zone establishment and maintenance. Climate-Smart agricultural practices that maintain soil cover could be implemented by the community to reduce soil disturbance and erosion, thus preventing siltation in and around this lake.

4. Conclusion

The present study aimed to determine the floristic composition and temporal variations in environmental factors in Lake Mboandong through the analyses of its phytoplankton community structure and water's physicochemical properties had remarkable variations in physicochemical and phytoplankton composition in Lake Mboandong during the study.

The results demonstrated that:

1) Lake Mboandong exhibited seasonal fluctuations in its nutrient levels, with generally higher water temperature in the dry season of $19.04^{\circ}\text{C} \pm 0.44^{\circ}\text{C}$ than in the rainy season of $18.38^{\circ}\text{C} \pm 0.52^{\circ}\text{C}$. pH was neutral to slightly basic, 7.49 ± 0.28 and 8.66 ± 0.07 in the rainy and dry seasons. Higher turbidity occurred during the rainy season of 10.93 ± 3.82 NTU than in the dry season of 6.56 ± 0.44 NTU. Nitrates were significantly higher during the rainy season of 1.92 ± 0.99 mg/l as opposed to 0.52 ± 0.27 mg/l in the dry season. Very low dissolved oxygen levels were recorded in the lake, although significantly higher during the rainy than in the dry season of 3.78 ± 0.43 mg/l and 2.35 ± 0.14 mg/l. Calcium, Mg, did not show seasonal variations in concentrations but the concentrations K and Na were higher during the dry season.

2) The comprehensive study identified a total of 77 phytoplankton species from seven algal divisions: Bacillariophyta (18 species), Charophyta (7 species), Chlorophyta (23 species), Chrysophyta (5 species), Cyanophyta (11 species), Dinophyta (6 species), and Euglenophyta (7 species). Higher Shannon-Weiner diversity was recorded during the rainy season than the dry season, ranging between 1.69 - 2.48 and 2.35 - 2.95 during the dry and rainy seasons respectively.

Situated amid agricultural farms, specifically cocoa farms owned by the Barombi natives, Lake Mboandong is mildly polluted as it still harbours a high diversity of phytoplankton species, which are well-documented bio-indicators of water quality.

Future research should be geared towards carrying out a thorough molecular identification of the algae of Lake Mboandong using techniques like DNA barcoding to distinguish morphologically-identical species thus overcoming the challenges associated with morphological identification.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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