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# Algal and riparian plant diversity and ecology of Bakingili Crater Lake in the Mount Cameroon National Park

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**Contribution** | **Awo, M.E** conception, laboratory analyses and writing of manuscript; **M.A Ngoasong** conducted field work and data analyses; **N.G.Fru** conducted data analysis and **B.A Fonge** conception and supervision of the study.

## ABSTRACT

High altitude lakes, typically found in mountainous regions, are unique ecosystems supporting distinct biological communities. There is limited knowledge about the diversity and ecology of riparian plants growing in the Bakingili Crater Lake. The objectives of study were to assess the water quality of Bakingili Crater Lake and to determine the phytoplankton and riparian plant community structure of Bakingili Crater Lake. Three sets of water samples were collected at the top 10 cm of the surface and at 3 m depth of the Lake using a van don water sampler. Phytoplankton and physicochemical parameters were determined in the laboratory using standard procedures and spectrophotometric methods. Inventory of riparian plants was done by delimiting two transects. In each transect, 2 plots of 10 m × 100 m each were demarcated. The Braun-Blanquet method was used for sampling herbaceous species. Tree frequency and diameter at breast height were recorded. Water pH was weakly acidic, 6.2 and 5.65 on the surface and depth respectively, with a low conductivity (0.02 µS/cm), with no significant difference at the bottom. A higher phytoplankton diversity was recorded for surface water (H'=1.58) than bottom water (H'=1.27). Cyanophyta was the most abundant taxon, with a relative dominance of 77% and 83% in surface and depth respectively. A total of 22 herbaceous species were identified. Shannon-Weiner's diversity was 1.27, and species having the highest relative frequency included *Cyperus atrovirdis (16.7%), Melanthera scandens (11.93%), Achyranthes aspera. var. sicula* (7.7%) and *Aframomum flavum*6.84%). A low tree diversity of 0.67 was obtained, with the most abundant species being *Tabernaemontana crassa* Benth (35.42%) and *Syzygium staudtii* (Engl.) Mildbr (29.17%). Lake Bakingili is nutrient-poor and weakly acidic, driving a low phytoplankton abundance and diversity predominantly cyanobacteria which may have health implications on the tourists and wildlife in Mount Cameroon National Park.

**Keywords**: Phytoplankton, Riparian plants, Crater Lake, Water quality, Lake Bakingili, diversity

**INTRODUCTION:** Lakes are inland water bodies that do not have any direct exchange with any other water body (Tita, 2008). Lakes may contain fresh or saltwater, holding about 98% of surface freshwater, and they are characterized by physical, chemical, and biological properties (Nelson and Fussmann, 2002; Awo *et al.*, 2020; Sterner *et al.*, 2020). The biological components of lakes which include but not limited to algae, bacteria, and protozoa are influenced by their physicochemical characteristics such as temperature, pH, dissolved oxygen, conductivity, and clarity. The biodiversity of lakes includes; algae (both benthic and phytoplankton), aquatic macrophytes, zooplankton, mollusks, crustaceans, fishes, and other aquatic organisms, and the maximum phytoplankton abundance is obtained when the physico-chemical factors are at optimum level; even slight disruptions result in disequilibrium of their structure community and sometimes results to local extinction of some species from the system (Nelson Fussmann, 2002). Lakes carry out a range of ecosystem services which can be categorized into provision, regulation, cultural and aesthetic services (Li and Gao, 2016; Sterner *et al.*, 2020).

High altitude lakes, typically found in mountainous regions, are unique ecosystems that support distinct biological communities, including algae and riparian vegetation. These lakes are influenced by factors such as low temperatures, high UV radiation, and limited nutrient availability, all of which shape their ecological dynamics (Kuefner *et al.*, 2020; WWF 2009). Although apparently pristine, lakes in high altitudes are subjected to natural stressors such as climate change (Kuefner *et al.*, 2020) invasive species, volcanic eruptions (for those in mountainous areas), and are usually exposed to mountain tourism activities and long distance transport of atmospheric pollutants.

These lakes have been classified as water bodies having a distinctive water source that provides a habitat for different species and equally possess spiritual and cultural significance in areas where they occur (WWF 2009).

Phytoplanktons are unicellular or multicellular organisms found drifting in the water column (Bellinger and Sigee, 2015; Anyinkeng *et al.*, 2016; Parfait *et al.*, 2020). Planktonic species float in the water column while substrate-associated ones attach themselves to plants (epiphytic), stones (epilithic), or can live in benthic fauna and are referred to as benthic algae (Bellinger and Sigee, 2015). Phytoplankton is the most important biological component of a water body as it is responsible for a large part of the primary production and account for about 50% of the global net primary production (Salmaso and Tolotti, 2021; Gong *et al.*, 2022). Phytoplankton is mainly autotrophic (producer), but some could either be heterotrophic, e.g. green algae and brown algae (consumers) or mixotrophic, capable of both autotrophic and heterotrophic nutrition (Wehr *et al.*, 2015). Information on the diversity of algal species could potentially be useful as early signs of water deterioration (Fonge *et al.*, 2015; Awo *et al.*, 2020; Enawgaw and Wagaw, 2023)

Riparian vegetation plays a vital role in aquatic ecosystems by influencing nutrient dynamics and providing a shade and habitat to some aquatic organisms, it also filters sediments-laden runoff by slowing its movement, promoting its infiltration into the soil, and causing the sediments and the attached nutrients to be deposited on the land before reaching the water (Aguiar *et al.*, 2018). The nutrients entering the water from below the ground can be reduced greatly by the surrounding riparian plant communities (Price and Lovett, 2002).

Heavy metals such as copper, iron, chromium, and nickel are essential metals since they play an important role in biological systems, whereas cadmium and lead are non-essential metals, as they are toxic, even in trace amounts. Their contamination of drinking water poses a serious threat to humans due to their persistence in the environment. The heavy metals contaminate the groundwater and surface water through a natural process (excessive levels of trace metals may occur by geographical phenomena like volcanic eruptions, weathering of rocks, leaching into rivers, lakes, and oceans due to the action of water), and anthropogenic activities (e.g. industrial, agricultural, mining, traffic activities, e.t.c. (Arora *et al.*, 2025).

High altitude lakes are crucial, yet understudied ecosystems characterized by extreme environmental conditions such as low temperatures, high ultra violet radiation, low oxygen and nutrient scarcity and therefore support unique biodiversity (Cho, 2006; Labaj *et al.*, 2018). The two main components which are the algae and riparian zones remain poorly understood. There exist several crater lakes in Cameroon, three of which are found in the Southwest region. In-depth ecological studies have been carried out in lakes Barombi Mbo (Tabot *et al.*, 2016) and Lake Barombi Kotto (Awo *et al.*, 2018; Egbe *et al.*, 2019; Awo *et al.*, 2020) but very little information is documented on the phytoplankton and riparian ecology of Lake Bakingili within the Mount Cameroon National Park (MCNP). Lake Bakingili is exposed to tourists and a wide range of wildlife in the MCNP (Awung and Marchant, 2016; Maurice *et al.*, 2023). It is a valuable recreational pool for birds and other wildlife within the park. Given that this park harbors endemic and threatened wildlife it is therefore very important to assess the water quality using both physicochemical and biological parameters, and also the riparian plant composition of Lake Bakingili in MCNP.

Phytoplankton community structure is an important bio-indicator for water quality; therefore, a proper microscopic analysis of water samples of the Mount Cameroon Crater Lake will provide information on the water quality, and algal diversity useful as early warning signs of deterioration conditions. Algal blooms can greatly cause an oxygen reduction which can lead to fish kill and animal die-back (Anderson *et al.*, 2002; Enawgaw and Wagaw, 2023). The study is necessary to elucidate the water quality given that it already provides tourists, birds, and other animals with drinking water to prevent future occurrences of health problems associated with algal blooms and those related to the toxic effects of some of the physicochemical parameters. A detailed ecological study of this nature shall bridge this knowledge gap.

**OBJECTIVES:** The overall objective of the study was to assess the phytoplankton and riparian plant community structure and some physicochemical parameters related to the water.

The specific objectives were to:

1. determine some physicochemical parameters of the water of Bakingili Crater Lake.
2. establish the phytoplankton and riparian plant community structure of Bakingili Crater Lake.

**MATERIALS AND METHODS: Description of the study site:** The study was carried out in the Bakingili Crater Lake, locally called Lake '*Manjamondoa*' in the Mount Cameroon National Park (MCNP). Bakingili Crater Lake is located between latitude $4^0$, 13'95.0''N and longitude $9^0$, 08'15.8''E, and 040 13' 81.8''N to $009^0$ 08' 14.6''E with an elevation of 1669 m above sea level. This lake covers an area of about 117 $m^2$ with a maximum depth of 10.5m (personal communication). The inner slopes of the Crater Lake are covered with herbaceous vegetation and scattered trees or tree patches. The slopes are interwoven with a network of elephant tracts. This lake is the biggest lake on Mount Cameroon during both the rainy season and the dry season and the samples were collected at four different points (figure 1). It is an important source of water for big animals like Elephants, bushbucks, or monkeys and also serves as a source of drinking water to tourists and researchers or other lake users who visit the Mount Cameroon National Park either for leisure or research purposes. This lake is a priority conservation area and thus restricts users. There is the altitudinal zonation of vegetation in mount Cameroon, and based on this, lake Bakingili is located in the montane forest zone (figure 1).

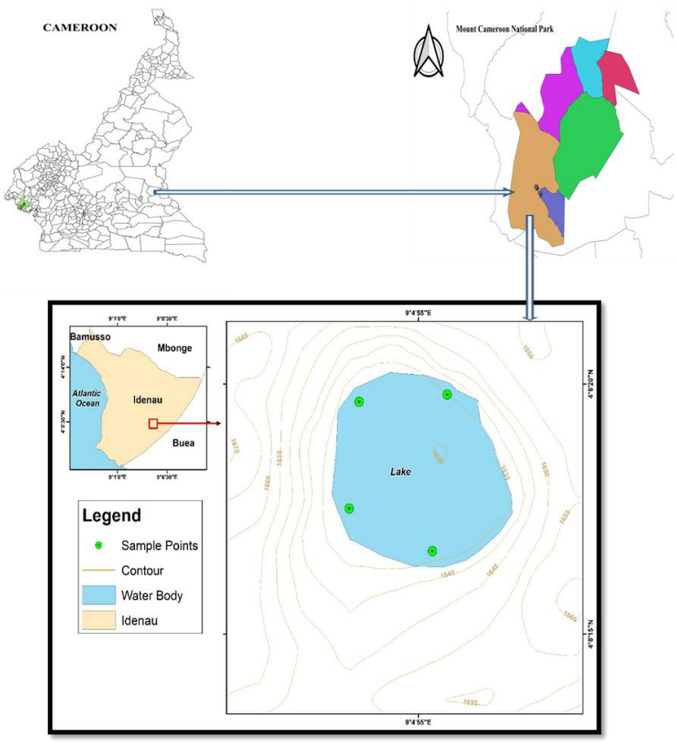


Figure 1: description of study area showing sampling points in Lake Bakingili

**Assessment of the water quality of Lake Bakingili: Sample collection and handling for water analysis:** Water samples were collected in the early hours of the morning (between 7 and 8 am), from 2 depths, top 0.1 m and 3 m down, and all samples were collected in duplicates in order to minimize the error margin. Samples were collected in at the different depths using a Van Dorn water sampler.

Two sets of water samples were collected; these included samples for phytoplankton analysis and physicochemical analysis. Water was collected from four water sampling points at the top 10 cm and at the bottom (table 1). A total number of 48 water samples were collected for both surface and depth water respectively. **Phytoplankton sample collection and handling:** Samples were collected at the top 10 cm, and 3 m down (bottom). Samples were collected in a one litre plastic bottle in duplicates and a total of 16 water samples were collected in the early hours of the day. Samples collected were fixed with 10% Lugol's iodine and kept in ice coolers. All water samples collected were transported in ice coolers to the Life Science Laboratory of the University of Buea for phytoplankton analysis. For physicochemical analyses, the samples were sent to the Soil and Water laboratory of the University of Dschang, Cameroon.

**Laboratory analysis for physicochemical parameters:** Nutrients were analyzed in the Soil and Water laboratory of the University of Dschang, Cameroon using standard methods of American Public Health Association (APHA, 2005). The atomic absorption spectrophotometer was used to determine concentrations of potassium, sodium, phosphorus, calcium, magnesium, iron, copper, boron, lead, and astatine. Turbidity was determined using the Nephelometric meter.

**Phytoplankton sample analysis:** Algal enumeration was done using the drop count technique. Slides of each sample were prepared in triplicates. A drop of the well-mixed sample was placed on a glass slide and covered with a cover slide, mounted, and observed under an Olympus light microscope, at different magnifications following a 24 h sedimentation of a known volume of water sample for 24 h as described by Parfait *et al.* (2020). The identification was done using comparative morphology based on phytoplankton identification keys (Verlecar and Desai, 2004; Van Vuuren *et al.*, 2006; Bellinger and Sigee, 2010; Bellinger and Sigee, 2015; Suthers *et al.*, 2019). Algal abundance was expressed in cells/L. Classification was done using algaebase.org (Guiry, 2010).

**Data collection for riparian vegetation sampling:** Data on riparian plants were collected within a 10 m belt around the lake. Two transects of 10 m by 100 m were demarcated and in each transect, data on the tree species number and frequency were gotten. Trees with a diameter at breast height (DBH) ≥ 10 cm were counted and identified within two plots of 10 m by 100 m. The DBH (1.3 m) of the species was measured using a diameter tape. In the cases where buttresses were present, measurements were made above the buttress following standard forestry procedures. Trees were identified using identification keys in the Flora of West Africa. This was done together with experienced field experts of the Limbe Botanical Garden, Cameroon. Voucher specimens were collected in triplicates for the unidentified species and taken to the Limbe Botanical Garden for identification. The nomenclatural dataset was updated to the APG III classification of angiosperm families (Apg, 2003). For the herbaceous plant species, sub-plots of 5 by 5m were made within the already demarcated plots. At each sub-plot, the plant species were recorded within sub-quadrats of $1m^2$ and the species richness, number of individuals of each plant species, including percentage of plant cover estimated (Solomou *et al.*, 2023).

**Data analyses:** Data on biological parameters such as abundance, diversity, evenness, and richness of species was analysed using the relevant ecological formulae.

For the diversity of species across the different sites, Shannon-Weiner's diversity index was used.

Shannon diversity $H' = -\sum_{i=1}^{s} Pi \ln Pi$ ..... *Equation (1)*

where Pi = ni/N; ni was the number of individuals belonging to a species i and N corresponded to the total number of species.

The species abundance per milliliter was obtained using Equation 2

*Abundance (ml) = $(n_1+n_2+n_3/0.15)$*.....*Equation (2)*

Where $n_1$, $n_2$, $n_3$, are algal counts per drop and 0.15 was the volume of a drop of water.

Pearson's correlation was used to relate physicochemical parameters and phytoplankton parameters using the Statistical Package for Social Science (SPSS) version 20. Means were separated by the use of One-Way-Analysis of Variance (ANOVA).

The relative frequency of each species was calculated in Equation 3;

$R_f=(Fi/Ft)\times100$.....*Equation 3*

Where $R_f$= relative frequency

*Fi* = frequency of species i

*Fi* = total frequency of all species

*Rd= (Di/Dt)×100……Equation 4*

From the density which is the occurrence per unit area, the relative density (Rel d) of each species was calculated using the formula;

Rel d = relative density

Di= Density of species i

Dt= total density of all species

The dominance (D) is the proportion of individuals of one particular species (n) divided by the total number of individuals found

$D = \frac{n}{N}$……*Equation 5*

From the dominance calculated above the relative dominance of each species was calculated by dividing the dominance of each species by the total dominance of all individual species by the formula;

$RD = \left(\frac{Di}{Dt}\right) x100$……*Equation 6*

Where,

RD = relative dominance, Di = dominance of species i, Dt= total dominance of all species

The Importance Value Index (IVI) for the tree species was determined as the sum of the relative frequency, relative density and relative dominance (Armstrong *et al*., 2011).

Basal area ($m^2$) = π (1/2 dbh) $^2$……*Equation 7*

**RESULTS: Water Quality of Lake Bakingili: Physico-chemical parameters of Lake Bakingili:** The water quality of Lake Bakingili is presented on table 2. Generally there was no statistically significant difference between the surface and bottom water in terms of the physicochemical parameters analyzed except for Na and Ca. The lake was weakly acidic with a mean surface water pH of 6.2±0.09 and 5.65±0.28 on the surface and bottom respectively, The mean lake water conductivity was 0.02±0.00 µS/cm. Turbidity ranged from 16.7±2.80 NTU to 64.28±38.80 NTU in the top and bottom respectively. Carbonate ranged from 54.9 ± 2.49 to 56.4 ± 3.84 mg/l in the surface and depth respectively. The average phosphate of the lake ranged from 0.37 ± 0.16 mg/l to 1.36 ± 0.81 mg/l in the surface and depth respectively. The average lake nitrates ranged from 0.37 ± 0.16 mg/l to 1.36 ± 0.81 mg/l in the surface and depth respectively. The average concentration of ammonia ranged from 0.13 ± 0.07 mg/l to 0.17 ± 0.05 mg/l in the surface and depth respectively. The average potassium concentration ranged from 0.16 ± 0.07 mg/l to 0.15 ± 0.05 mg/l in the surface and depth respectively. The average sodium concentration ranged from 0.05 ± 0.01 mg/l to 0.02 ± 0.00 mg/l in the surface and depth respectively. For the heavy metals, the average concentration of Fe ranged from 0.62 ± 0.01 mg/l to 0.63 ± 0.01 mg/l at the surface and depth respectively. The average concentration of copper was 0.44 ± 0.01 mg/l for surface and depth. The average concentration of boron ranged from 0.01 ± 0.01 mg/l to 0.04 ± 0.01 mg/l at the surface and depth respectively. The average concentration of lead ranged from 0.27±0.13mg/l to 0, 74±0.30mg/l for top and bottom respectively. Water turbidity was found to differ across sites with Site 1 having the highest turbidity of 20.4 NTU. On the other hand, Site 4 had the lowest turbidity of 8.5 NTU. There was a significant difference in water turbidity across sites (P = 0.00). Water turbidity was above the WHO (2017) standard for drinking water of 5 NTU. For the nutrients, the average concentration of potassium and sodium in sampling sites showed no significant difference. Potassium and sodium concentrations were within the WHO (2017) standards for drinking water which are 10 mg/l and 50 mg/l respectively. Boron concentration was not significantly different across sites (p = 0.010). The mean Boron concentration was 0.02 mg/l.

**Phytoplankton and riparian plant community structure of the mount Cameroon Crater Lake: Phytoplankton Community Structure of Lake Bakingili:** A total of 12 species were identified from 4 families within the surface water (table 3). The division with the highest abundance was the Cyanophyta (197: 77%) and the least was Bacillariophyta (10: 4%) (table 4). The most abundant species were M*icrocystis flos-aquae* (122: 48%) and *Microcystis aureginosa* (75: 29%) while, *Aulacoseira granulata* (1: 0.5%), *Pleurosigma angulatum* (1: 0.5%) and *Gymnodinium* sp. (1: 0.5%) were the least abundant species (table 5). Bacillariophyta was the most diverse division, with 6 species. This was followed by Chlorophyta, Cyanophyta and Dinophyta which all had 2 species each.

| SN | Latitude | Longitude |
|---|---|---|
| 1 | $04^0$ 13′ 87.4′′N | $009^0$ 08′ 20.3′′E |
| 2 | $04^0$ 13′ 87.0′′N | $009^0$ 08′ 16.0′′E |
| 3 | 040 13′ 87.0′′N | $009^0$ 08′ 20.3′′E |
| 4 | 040 13′ 81.8′′N | $009^0$ 08′ 14.6′′E |

Table 1: Sampling points and coordinates of Lake Bakingili.

| | Surface water | Bottom water | P-value |
|---|---|---|---|
| $HCO_3$ (mg/l) | 54.9 ± 2.49a | 56.43 ± 3.84a | 0.75 |
| pH | 6.2 ± 0.09a | 5.65 ± 0.28a | 0.1 |
| Conductivity (µS/cm) | 0.02 ± 0.00a | 0.02 ± 0.00a | 0.36 |
| Turbidity (NTU) | 16.7 ± 2.80a | 64.28 ± 38.80a | 0.27 |
| NO3 (mg/l) | 0.37 ± 0.16a | 1.36 ± 0.81a | 0.28 |
| NH4 (mg/l) | 0.13 ± 0.07a | 0.17 ± 0.05a | 0.62 |
| K (mg/l) | 0.16 ± 0.07a | 0.15 ± 0.05a | 0.87 |
| Na (mg/l) | 0.05 ± 0.01a | 0.02 ± 0.00a | 0.07 |
| Cl (mg/l) | 32.84 ± 3.94a | 23.96 ± 2.23a | 0.1 |
| Ca (mg/l) | 7.32 ± 1.38a | 3.80 ± 0.46a | 0.05 |
| Mg (mg/l) | 2.55 ± 0.34a | 2.55 ± 0.57a | 1 |
| Fe (mg/l) | 0.62 ± 0.01a | 0.63 ± 0.01a | 0.4 |
| Cu (Mg/l) | 0.44 ± 0.01a | 0.44 ± 0.01a | 0.58 |
| B (mg/l) | 0.01 ± 0.01a | 0.04 ± 0.01a | 0.16 |
| Pb (mg/l) | 0.27 ± 0.13a | 0.74 ± 0.30a | 0.19 |

Table 2: Mean nutrient concentration across surface and bottom water in Lake Bakingili.

Means separated with LSD, and means with the same letter are not statistically significant. P-Values with * are significant at α =0.05 (95% confidence interval.

| S/N | Divisions | Families | Species | 1 | 2 | 3 | 4 | A | RA(%) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Bacillariophyta | Diadesmidaceae | *Diadesmis* sp. | 0 | 0 | 0 | 2 | 2 | 1 |
| 2 | | Aulacoseiraceae | *Aulacoseira granulata* | 1 | 0 | 0 | 0 | 1 | 0.5 |
| 3 | | Fragilaraceae | *Fragilara construens* | 0 | 2 | 0 | 0 | 2 | 1 |
| 4 | | Pleurosigmataceae | *Pleurosigma angulatum* | 0 | 1 | 0 | 0 | 1 | 0.5 |
| 5 | | Cymbellaceae | *Cymbella cystulla* | 0 | 0 | 0 | 2 | 2 | 1 |
| 6 | | Stephanodiscacaceae | *Cyclotella* sp. | 1 | 0 | 0 | 2 | 3 | 1 |
| 7 | Chlorophyta | Desmidiaceae | *Staurastrum crenulata* | 24 | 6 | 0 | 0 | 30 | 12 |
| 8 | | Hydrodictyaceae | *Hydrodicton reticulatum* | 0 | 4 | 0 | 1 | 5 | 2 |
| 9 | Cyanophyta | Microcystaceae | *Microcystis flos-aquae* | 61 | 33 | 17 | 12.5 | 122 | 48 |
| 10 | | | *Microcystis aeruginosa* | 20 | 19 | 8 | 28 | 75 | 29 |
| 11 | Dinophyta | Gymnodiaceae | *Gymnodinium fuscus* | 4 | 10 | 0 | 0 | 13 | 5 |
| 12 | | | *Gymnodinium* sp. | 0 | 0 | 1 | 0 | 1 | 0.5 |
| Total | 4 | 10 | 12 | 109 | 73 | 25 | 48 | 255 | 100 |

Table 3: Occurrence of phytoplankton in surface water of Lake Bakingili.

**Diversity indices across sites for surface water in Lake Bakingili**: Shannon- Weiner index of diversity of the lake's surface was 1.58 bits. The surface water's species richness is presented in table 5, with a total of 12 species identified. The checklist of these species is presented in table 6.

**Algal Community Structure at the bottom of Lake Bakingili: Algal occurrence in the bottom water of Lake Bakingili:** A total of 8 species were identified from 4 families and 4 algal divisions in the bottom water across sampled points. The most abundant species were *Microcystis aureginosa* (67 cells/ml: 51.34%) and M*icrocystis flos-aquae* (42 cells/ml: 31.80%) from the Cyanophyta. On the other hand, *Cymbella cystulla* (1 cell/ml: 0.8%), and *Diadesmis* sp. were the list abundant (1 cell/ml: 0.8%) (table 7). For bottom water, the division with the highest abundance was the Cyanophyta (109: 83%) while Bacillariophyta (4 cells/ml: 3%) and Dinophyta (4 cells/ml: 3%) (table 8).
The species richness at the bottom was 8 species.

| Divisions | Point 1 | Point 2 | Point 3 | Point 4 | Abundance | Relative abundance (%) |
|---|---|---|---|---|---|---|
| Bacillariophyta | 2 | 3 | 0 | 6 | 10 | 4 |
| Chlorophyta | 24 | 10 | 0 | 1 | 35 | 14 |
| Cyanophyta | 80 | 52 | 25 | 41 | 197 | 77 |
| Dinophyta | 4 | 10 | 1 | 0 | 14 | 5 |
| Total | 109 | 73 | 25 | 48 | 255 | 100 |

Table 4: Phytoplankton species abundance per division in Surface water across sites in Lake Bakingili.

| Diversity indices | Surface water |
|---|---|
| Abundance (cells/ml) | 255 |
| Diversity | 1.58 |
| Evenness | 0.64 |
| Richness | 12 |

Table 5: Diversity indices for surface water in Lake Bakingili.

| Species | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| *Diadesmis* sp. | - | - | - | + |
| *Aulacosera granulata* | + | - | - | - |
| *Fragilara construens* | - | + | - | - |
| *Pleurosigma angulatum* | - | + | - | - |
| *Cymbella cystulla* | - | - | - | 2 |
| *Cyclotella* sp. | + | - | - | 2 |
| *Staurastrum crenulata* | + | + | - | - |
| *Hydrodicton reticulatum* | - | + | - | 1 |
| *Microcystis flos-aquae* | + | + | + | + |
| *Microcystis aureginosa* | + | + | + | + |
| *Gymnodinium fuscus* | + | + | - | - |
| *Gymnodinium* sp. | - | - | 1 | - |

Table 6: Check list of phytoplankton for surface water of Lake Bakingili.

| S/N | Divisions | Families | Species | Point1 | Point2 | Point3 | Point4 | A | RA(%) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Bacillariophyta | Cymbellaceae | *Cymbella cystulla* | 0 | 0 | 1 | 0 | 1 | 0.8 |
| 2 | | | *Cyclotella meneghenamia* | 0 | 0 | 2 | 0 | 2 | 1.53 |
| 3 | | Diadesmidaceae | *Diadesmis* sp. | 0 | 0 | 0 | 1 | 1 | 0.8 |
| 4 | Chlorophyta | Desmidiaceae | *Staurastrum crenulata* | 6.5 | 0 | 0 | 0 | 7 | 4.98 |
| 5 | | Hydrodictyaceae | *Hydrodicton reticulatum* | 0 | 2 | 0 | 6 | 8 | 6.13 |
| 6 | Cyanophyta | Microcystaceae | *Microcystis flos-aquae* | 4 | 8 | 15 | 14.5 | 42 | 31.80 |
| 7 | | | *Microcystis aureginosa* | 41 | 14 | 5 | 7 | 67 | 51.34 |
| 8 | Mizozoa | Gymnodiniaceae | *Gymnodinium fuscus* | 2.5 | 0 | 1 | 0 | 4 | 2.68 |
| Total | | | | 54 | 24 | 24 | 28.5 | 131 | 100.00 |

Table 7: Algal occurrence and abundance in Bottom water of Lake Bakingili.

| Division | Point1 | Point2 | Point3 | Point4 | Abundance | Relative abundance (%) |
|---|---|---|---|---|---|---|
| Bacillariophyta | 0 | 0 | 3 | 1 | 4 | 3 |
| Chlorophyta | 7 | 2 | 0 | 6 | 15 | 11 |
| Cyanophyta | 45 | 22 | 20 | 22 | 109 | 83 |
| Mizozoa | 3 | 0 | 1 | 0 | 4 | 3 |
| Total | 54 | 24 | 24 | 29 | 131 | 100 |

Table 8: Phytoplankton abundance per division in bottom water across sites in lake Bakingili.

**Comparison between surface and depth water for phytoplankton community structure:** Phytoplankton abundance was higher in bottom water with 131 cells/ml as opposed to 48 cells/ml for surface water. Moreover, with respect to species diversity, species were more diverse for bottom water (1.27) than surface water (1.58). Species evenness was more for bottom water (0.18) than surface water (0.12) (figure 2).

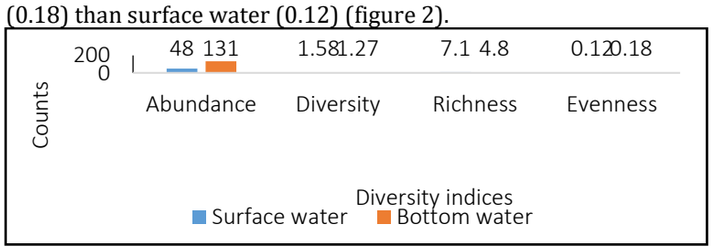


Figure 2: Comparison between surface and bottom water for phytoplankton Community structure.

**Riparian Plant vegetation of Lake Bakingili: Herbaceous community structure:** A total of 22 herbaceous plant species from 7 clades, 17 families, and 21 genera were identified in the study. Asterids and Eudicots were the dominant clades while, Asteraceae (3 species), Lamiaceae (2 species), and Amaranthaceae (2 species) were the most diverse plant families. The remaining plant families were all represented by one species each. Lower plant families were also recorded among the herbaceous plants, these included *Sellaginella myosurus* (Sellaginellaceae), *Pteris ekemae* Benl, and *Asplenium aethiopicum* (Aspleniaceae) (table 10).

**Herbaceous species density:** The species with the highest relative densities included *Cyperus atrovirdis (*Cyperaceae) *Laportea alatipes* (Urticaceae), *Achyranthes aspera* (Amaranthaceae), and *Aframomum flavum* (Zingiberaceae) with a relative density of 10.27%, 9.48%, 9.48%, and 8.42 % respectively. On the other hand, the species with the least relative densities were *Dicranolepis* sp. (Thymelaeaceae) and *Crassocephalum gracile* (Hook.f.) (Asteraceae) with a density of 0.58% and 1.3% respectively (table11).

**Diversity indices of herbaceous species:** The Shannon- Weiner's diversity index of herbaceous plants was 1.25. The top 5 species with the highest abundance were; *Cyperus atrovirdis* C.B. Clarke (427, 16.7%), *Melanthera scandens* Schumach. &Thonn *(305, 11.93%), Achyranthes aspera* L *and Laportea alatipes* Hook*. f (197, 7.7%) and Aframomum flavum* Lock (175, 6.84%). These plants belong to Cyperaceae, Asteraceae, Urticaceae, and Zingiberaceae respectively.

**Family and species of Trees community:** A total of six tree species from six families belonging to the Asterids and Rosids were identified in this study (table 16). The species with the highest density was *Tabernaemontana crassa* with a density of 8.5 (50%).

| Species | Point 1 | Point 2 | Point 3 | Point 4 |
|---|---|---|---|---|
| *Cymbella cystulla* | - | - | + | - |
| *Cyclotella meneghenamia* | - | - | + | - |
| *Diadesmis* sp. | - | - | - | + |
| *Staurastrum crenulata* | + | - | - | - |
| *Hydrodicton reticulatum* | - | + | - | + |
| *Microcystis flos-aquae* | + | + | + | + |
| *Microcystis aureginosa* | + | + | + | 7 |
| *Gymnodinium fuscus* | + | - | + | - |

Table 9: Check list of phytoplankton at the bottom of Lake Bakingili.

| SN | Clades | Families | Genera | Species |
|---|---|---|---|---|
| 1 | Asterids | Asteraceae | *Crassocephalum* | *Crassocephalum gracile* (Hook.f.) |
| 2 | Asterids | Asteraceae | *Melanthera* | *Melanthera scandens* (Schumach.&Thonn |
| 3 | Asterids | Asteraceae | *Vernonia* | *Vernonia myriantha* Hook.f |
| 4 | Asterids | Lamiaceae | *Clerodendrum* | *Clerodendrum capitatum* (Wild.) |
| 5 | Asterids | Lamiaceae | *Plecanthus* | *Plectranthus kamerunensis* Gurke |
| 6 | Eudicot | Amaranthaceae | *Achyranthes* | *Achyranthes aspera L.* var. *sicula* |
| 7 | Eudicot | Amaranthaceae | *Celosia* | *Celosia isertii* C.C. Towns. |
| 8 | Tracheophytes | Aspleniaceae | *Asplenium* | *Asplenium aethiopicum* (Burm.f.) Bech |
| 9 | Eudicot | Cyperaceae | *Cyperus* | *Cyperus atrovirdis* C.B.Clarke |
| 10 | Tracheophytes | Pteridaceae | *Pteris* | *Pteris ekemae* Benl |
| 11 | Eudicot | Zingiberaceae | *Afromomum* | *Aframomum flavum* Lock |
| 12 | Lamids | Acanthaceae | *Brillantaisia* | *Brillantaisia owariensis* P. Beauv |
| 13 | Tracheophytes | Selaginellaceae | *Sellaginella* | *Selaginella myosurus* (Sw) Alston |
| 14 | Magnelids | Piperaceae | *Piper* | *Piper capense* L.f. |
| 15 | Rosids | Begoniaceae | *Begonia* | *Begonia ampla* Hook.f |
| 16 | Rosids | Malvaceae | *Triumfetta* | *Triumfetta rhomboidea* Jacq |
| 17 | Rosids | Vitaceae | *Cissus* | *Cissus dinklagei* Gilg & Brandt |
| 18 | Rosids | Thymelaeaceae | *Dicranolepis* | *Dicranolepis* sp. |
| 19 | Supperasterids | Balsaminaceae | *Impatiens* | *Impatiens niamniamensis* Gilg |
| 20 | Supperasterids | Balsaminaceae | *Impatiens* | *Impatiens sakerana* Hook.f. |
| 21 | Supperosids | Cucurbitaceae | *Momordica* | *Momordica foetida* Schum &Thonn |
| 22 | Supperosids | Urticaceae | *Laportea* | *Laportea alatipes* Hook. f |

Table 10: Species composition of herbaceous plants in the riparian zone of Lake Bakingili.

| | Species | N | Density | Rel. Density | Relative Frequency |
|---|---|---|---|---|---|
| 1 | *Achyranthes aspera* L. var. sicula | 394 | 197 | 9.48 | 5.26 |
| 2 | *Aframomum flavum* Lock | 350 | 175 | 8.42 | 5.26 |
| 3 | *Asplenium aethiopicum*(Burm.f.) Bech | 120 | 60 | 2.89 | 5.26 |
| 4 | *Begonia ampla* Hook.f | 170 | 85 | 4.09 | 5.26 |
| 5 | *Brillantaisia owariensis* P. Beauv | 322 | 161 | 7.75 | 5.26 |
| 6 | *Celosia isertii* C.C. Towns. | 126 | 63 | 3.03 | 5.26 |
| 7 | *Cissusdink lagei* Gilg & Brandt | 105 | 52.5 | 2.53 | 5.26 |
| 8 | *Clerodendrum capitatum* (Wild.) | 132 | 66 | 3.18 | 5.26 |
| 9 | *Crassocephalum gracile* (Hook.f.) | 54 | 27 | 1.3 | 5.26 |
| 10 | *Cyperus atrovirdis* C.B. Clarke | 427 | 213.5 | 10.27 | 2.63 |
| 11 | *Dicranolepis* sp. | 24 | 12 | 0.58 | 2.63 |
| 12 | *Impatiens niamniamensis* Gilg | 208 | 104 | 5 | 5.26 |
| 13 | *Impatiens sakerana* Hook.f. | 93 | 46.5 | 2.24 | 2.63 |
| 14 | *Laportea alatipes* Hook.f | 394 | 197 | 9.48 | 5.26 |
| 15 | *Melanthera scandens* (Schumach &Thonn) | 305 | 152.5 | 7.34 | 2.63 |
| 16 | *Momordica foetida* Schum&Thonn | 47 | 23.5 | 1.13 | 2.63 |
| 17 | *Piper capense* L.f. | 61 | 30.5 | 1.47 | 2.63 |
| 18 | *Plectranthus kamerunensis* Gurke | 257 | 128.5 | 6.18 | 5.26 |
| 19 | *Pteris ekemae* Benl | 115 | 57.5 | 2.77 | 5.26 |
| 20 | *Selaginella myosurus* (Sw) Alston | 201 | 100.5 | 4.84 | 5.26 |
| 21 | *Triumfettarhomboidea* Jacq | 110 | 55 | 2.65 | 5.26 |
| 22 | *Vernonia myriantha* Hook.f | 142 | 71 | 3.42 | 5.26 |
| Total | 22 | 4157 | 2079 | 100 | 100 |

Table 11: Relative density and frequency of herbaceous plants in the riparian zone of Lake Bakingili.

On the other hand, the species with the least density were *Schefflera abyssinica* and *Ficus lutea* with a density of 1 (5.9%). The Shannon-Weiner's diversity index of trees was 0.6 with *Tabernaemontana crassa* and *Syzygium staudtii* being the most abundant tree species (table 13).

**Basal Area, Dominance, and Important Value Index of trees:** The total basal area of trees was 113604.2 $m^2$ with *Tabernaemontana crassa Benth* having the highest Basal area of 42356.8 $m^2$ and *Ficus lutea Vahl* having the lowest basal area of 9022.8 $m^2$ (Table 14). The dominance of species was 56802.1 with *Tabernaemontana crassa* Benth having the highest dominance of 21178.4 and *Oncobaglauca* (P. Beauv.) having the lowest dominance of 1304.2.

**Important value Index (IVI) of trees:** Based on the IVI of trees, *Tabernaemontana crassa* Benth had the highest value index of 112.285, and *Ficus lutea* Vahl had the lowest IVI of 26.325.

**Discussion: Water Quality assessment of Bakingili Crater Lake**: Physicochemical parameters analysed revealed that the lake's pH was weakly acidic and there was no variation between the surface and depth for most of the parameters during the studied period. This could be as a result of the shallow nature of this lake which is

homogenously mixed by winds, thus equally distributing the nutrients. Significantly higher concentrations of calcium and sodium were recorded at the bottom of the lake. This could be associated to gradual weathering of the bedrock and other water-rock interactions and geological factors (Nagaraju *et al.*, 2016).

| | Species | Abundance | Rel. Abundance | H' | Evenness |
|---|---|---|---|---|---|
| 1 | *Achyranthes aspera* L. var. *sicula* | 197 | 7.7 | 0.10 | 0.07 |
| 2 | *Aframomum flavum* Lock | 175 | 6.84 | 0.09 | 0.07 |
| 3 | *Asplenium aethiopicum* (Burm.f.) Bech | 60 | 2.35 | 0.04 | 0.03 |
| 4 | *Begonia ampla* Hook.f. | 85 | 3.32 | 0.06 | 0.04 |
| 5 | *Brillantaisia owariensis* P. Beauv | 161 | 6.3 | 0.09 | 0.06 |
| 6 | *Celosia isertii* C.C. Towns. | 63 | 2.46 | 0.05 | 0.03 |
| 7 | *Cissus dinklagei* Gilg & Brandt | 52.5 | 2.05 | 0.04 | 0.03 |
| 8 | *Clerodendrum capitatum* (Wild.) | 66 | 2.58 | 0.05 | 0.04 |
| 9 | *Crassocephalum gracile* (Hook.f.) | 27 | 1.06 | 0.03 | 0.02 |
| 10 | *Cyperus atrovirdis* C.B.Clarke | 427 | 16.7 | 0.10 | 0.08 |
| 11 | *Dicranolepis* sp. | 24 | 0.94 | 0.01 | 0.01 |
| 12 | *Impatiens niamniamensis* Gilg | 104 | 4.07 | 0.07 | 0.05 |
| 13 | *Impatiens sakerana* Hook.f. | 93 | 3.64 | 0.04 | 0.03 |
| 14 | *Laportea alatipes* Hook.f | 197 | 7.7 | 0.10 | 0.07 |
| 15 | *Melanthera scandens* Schumach & Thonn | 305 | 11.93 | 0.08 | 0.06 |
| 16 | *Momordica foetida* Schum & Thonn | 47 | 1.84 | 0.02 | 0.02 |
| 17 | *Piper capense* L.f. | 61 | 2.39 | 0.03 | 0.02 |
| 18 | *Plectranthus kamerunensis* Gurke | 128.5 | 5.03 | 0.08 | 0.06 |
| 19 | *Pteris ekemae* Benl | 57.5 | 2.25 | 0.04 | 0.03 |
| 20 | *Selaginella myosurus* (Sw) Alston | 100.5 | 3.93 | 0.06 | 0.05 |
| 21 | *Triumfettar homboidea* Jacq | 55 | 2.15 | 0.04 | 0.03 |
| 22 | *Vernonia myriantha* Hook.f | 71 | 2.78 | 0.05 | 0.04 |
| Total | 22 | 2557 | 100 | 1.25 | 0.93 |

Table 12: Diversity of herbaceous plants around Lake Bakingili.

| Species | Diversity | Evenness | Abundance | Rel. Abundance |
|---|---|---|---|---|
| *Sorindeia grandifolia* Engl | 0.093 | 0.120 | 1.5 | 6.25 |
| *Tabernae Montana crassa* Benth | 0.151 | 0.193 | 8.5 | 35.42 |
| *Schefflera abyssinica* (Hochst.ex A.Rich) | 0.072 | 0.093 | 2 | 8.33 |
| *Ficuslutea* Vahl | 0.072 | 0.093 | 2 | 8.33 |
| *Syzygium staudtii* (Engl.) Mildbr | 0.141 | 0.182 | 7 | 29.17 |
| *Oncoba glauca* (P.Beauv.) Planch | 0.093 | 0.120 | 3 | 12.50 |
| Total | 0.623 | 0.800 | 24 | 100.00 |

Table 13: Diversity, Evenness, and abundance of tree species in Lake Bakingili.

| | BA | Relative BA | Dominance | IVI |
|---|---|---|---|---|
| *Sorindeia grandifolia* Engl | 10433.3 | 9.18 | 5216.7 | 43.007 |
| *Tabernae Montana crassa* Benth | 42356.8 | 37.28 | 21178.4 | 112.285 |
| *Schefflera abyssinica* (Hochst. ex A. Rich) | 12340.5 | 10.86 | 6170.3 | 29.245 |
| *Ficus lutea* Vahl | 9022.8 | 7.94 | 4511.4 | 26.325 |
| *Syzygium staudtii* (Engl.) Mildbr | 36842.5 | 32.43 | 18421.3 | 65.519 |
| *Oncoba glauca* (P.Beauv.) *Planch* | 2608.3 | 2.30 | 1304.2 | 23.620 |
| Total | 113604.2 | 100.00 | 56802.1 | 300.000 |

Table 14: Basal Area, Dominance, and Important Value Index of tree species around Lake Bakingili.

This pH was not within the WHO (2017) standard for drinking water (6.5-8.5). This implies wildlife and tourists using this lake for drinking purposes are exposed to weakly acidic waters.

Furthermore, water turbidity was above the WHO (2017) standard for drinking water of 5NTU. The high turbidity observed in this lake can be explained by the presence of particulate matter, finely divided organic matter and other microscopic organisms such as planktonic algae and partially decomposed leaves from the riparian zone. This is in line with the findings of Awo *et al.* (2020), who correlated high turbidity levels in Lake Barombi Kotto with phytoplankton biomass. Very low conductivities were recorded for both the depth and surface waters of Lake Bakingili. This could be as a result of low temperature at that range which reduces the weathering of the bedrock, thus affecting mineral release into the waters. The fact that there was no significant difference between the surface and depth waters in terms of heavy metals and other physicochemical parameters could be due to the shallow nature of the lake. Adequate light penetrated the lake and so there was no thermal stratification, hence nutrients were uniformly distributed within the sampled range of 0-3 m.

**Phytoplankton community structure of the Bakingili Crater Lake:** Of the 12 phytoplankton species recorded for surface water and 8 species recorded for bottom water, the blue-green algae exhibited the highest dominance amongst the other algal taxa, which recorded about 77% for surface water and 83% of bottom water, with the least taxa being Bacillariophyta which recorded 4% for surface water and Mizozoa which recorded 3% for bottom water. This abundance of cyanobacteria in freshwater is in line with the findings of Awo *et al.* (2018), who found cyanobacteria to peak especially during the dry season. The success of these cyanobacteria is attributed to it having the ability to fix atmospheric nitrogen, use internal sources of phosphorus, high affinity of phosphorus and ammonium and resistance to herbivory by zooplankton, a high capacity for dispersal and low tolerance to low brightness and variation in water temperature. Moreover, it can move in the water column due to the presence of vesicles which gives it buoyancy (Reynolds, 2006). The absence of species belonging to the Chrysophyta and the Euglenophyta may be because they cannot tolerate stressful environments. The Bacillariophyta has the ability to strive in a wide range of physico-chemical parameters but it equally had low abundances in this study (Çelekli and Külköylüoğlu, 2007). Eventhough their abundances were low, Bacillariophyta had the highest species richness (4 species). There is generally a high phytoplankton species richness in African waters as supported by the latitudinal diversity gradient (LDG) but the low species richness and low diversity recorded during this study could be attributed to the low temperatures and harsh climatic conditions associated to mountainous habitats and the low connectivity between other water bodies hence limiting the dispersal of life forms. There was generally a low diversity in Lake Bakingili. The overall low phytoplankton abundance suggests an oligotrophic status of this lake. The less adapted species had very low abundance. There was a noticeable vertical variation in phytoplankton abundance across depths, with the bottom of the lake having a higher abundance than surface water (131 cell/ml at the bottom and 48 cells/ml at the surface). The surface water was more diverse (H= 1.58) than bottom

water. These differences could be attributed to the higher concentrations of Ca and Na at the bottom of the lake. These nutrients are very vital in growth and development of photoautotrophs.

**Riparian plant community of the Bakingili Crater Lake:** The western slope of Mt Cameroon is probably the most diverse and richest area of the mountain and appears to be the only area in West and Central Africa where there is an unbroken vegetation gradient from evergreen lowland rainforest at sea-level, through montane forest, to montane grassland and alpine grassland near its summit. This link between ecosystems largely accounts for the biological diversity of the region. Past surveys of plant species had led to the identification of six main vegetation types on the mountain with their key characteristics (Cheek *et al.*, 1996). The lowland rainforest (0-800m), the sub-montane forest (800 – 1,600 m), montane forest (1600-1800m), montane scrub (1,800–2,400m), montane grassland (2,000–3,000m), and the sub-alpine grassland (3,000–4,100m). Lake Bakingili falls within the montane forest Zone, characterized by a low diversity of tree species and species poor sparse vegetation (Cheek *et al.*, 1996; Cable and Cheek, 1998).

A total of 17 trees belonging to 6 plant species under 6 families were identified in this study. The species recorded within the riparian zone of this lake are typical commonly encountered plants within riparian zones of other wetlands. These results are in line with the findings of Egbe *et al.* (2021) who carried out a study on tree species composition and diversity in the riparian forest of Lake Barombi Kotto, Cameroon and recorded Anarcadiaceae as one of the most dominant plant families. The low diversity of tree species (0.6 bits) recorded in this study is typical of the montane forest of Mount Cameroon National Park. There was a higher diversity of the herbaceous plant species (1.25) as opposed to a tree diversity of 0.6 bits. The sparse nature of the trees in the motane forest zone permitted light penetration which facilitated the growth of herbaceous plants at the forest floor. Elevation has been documented as a major factor structuring the composition of plant communities, highlighting a typical vertical zonation of vegetation in mountain environments (Solefack *et al.*, 2018). The low tree diversity recorded in the study could be attributed mainly to the effects of altitude since this forest is within the protected mount Cameroon National Park, thus limiting access by the community. This is in line with findings by Solefack *et al.* (2018) who found that altitude exerts a profound effect on vegetation in mount Oku, Cameroon.

**CONCLUSION:** Lake Bakingili, is a small oligotrophic lake occurring within the montane forest of mount Cameroon, characterized by a weakly acidic pH. There is no variation of nutrients and physicochemical parameters such as conductivity, temperature, pH, TDS and nutrients such as nitrates, ammonium, chlorides, magnesium and boron. Heavy metals such as iron, copper, and lead were recorded in Lake Bakingili but there was no significant difference in their concentration at the bottom and surface water. Traces of heavy metals were recorded in the water, with a characteristically low nutrients level, far below the WHO 2017 permissible standards for drinking water. Significantly higher algal diversity occurred between the surface and bottom water, with a lower diversity of at the bottom than the top. A total of 12 algal species were recorded in the surface, as opposed to only 8 in the depth, with *Microcystis aeruginosa* and *Microcystis flos-aquae* recorded as the most abundant species in both surface and bottom waters. There was a higher herbaceous plant diversity than tree diversity in the riparian zone of lake Bakingili and species having the highest relative abundance included *Cyperus atrovirdis* C.B. Clarke (16.7), *Melanthera scandens* Schumach.&Thonn (11.93), *Achyranthes aspera* L. *var. sicula* (7.7) and *Aframomum flavum* Lock (6.84). Lake Bakingili, is a small, weakly acidic and nutrient-poor lake, driving a low phytoplankton diversity predominantly cyanobacteria species. These species are known for the production of cyanotoxins which may have health implications on the tourists and wildlife in MCNP.

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