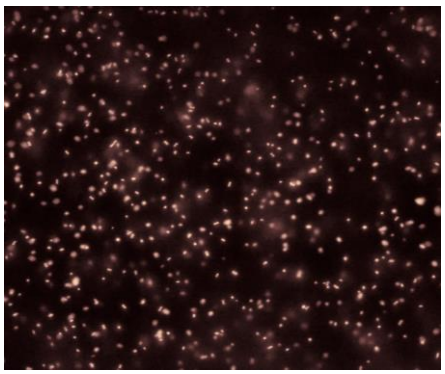
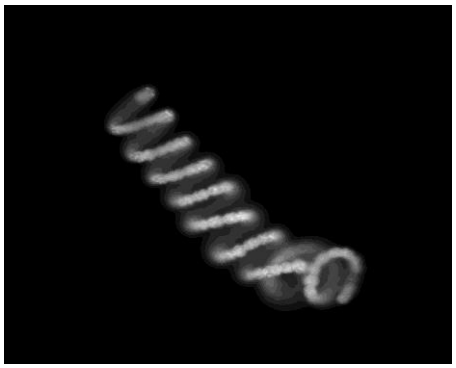
Conesus Lake Monitoring 2023:
Understanding the Determinants of Summer Cyanobacterial Blooms





Report Submitted to
The Livingston County Planning Department

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Summary

- The 2023 Conesus Lake Monitoring Program focused on the summer cyanobacterial phytoplankton community and the physical and chemical characteristics of the water column. Our goals were to document patterns of species composition and abundance and to identify the physical and chemical determinants of any seasonal trends.

- Sampling of the water column for this study was conducted approximately every 2 weeks starting on 5 July 5 and ending on 21 September. More frequent sampling was conducted in July to thoroughly document the bloom of single-celled picocyanobacteria that now occurs every year in July. On each sampling date, we collected integrated water samples (0-3 m) for phytoplankton analysis. These samples were preserved on site, then stored refrigerated until analyzed. On each sampling date we also obtained vertical profiles of temperature and other water column characteristics and collected samples from several depths for analysis of Total Phosphorus, Orthophosphate, Total Nitrogen and Nitrate-Nitrite concentrations by SUNY Brockport.

- This single cell picocyanobacteria bloom began around 16 July and peaked on 20-26 July with cell numbers exceeding 250 thousand per mL. The start of the bloom coincided with surface temperatures of 25°C and very low nutrient P levels that first occurred after onset of water column stratification.

- The bloom was associated with a major $CaCO_3$ precipitation (whiting) event that persisted for more than 7 days. Water column transparency was greatly reduced during that time, producing Secchi depths as shallow as 0.85 m and turbidity as high as 7.63 NTU. We estimate that the loss of transparency could reduce light penetration (and heat distribution) by 2-3 m in depth.

- The community of filamentous and colony-forming cyanobacteria that are often associated with HABs was dominated by species of *Dolichospermum* that are capable of fixing nitrogen from dissolved N_2. During July, cell and filament/colony numbers seemed to be inversely related to the picocyanobacteria cell numbers, remaining low during the bloom possibly due to light and nutrient limitation, and increasing afterward to their usual peak in late August and September.

- There were two major findings from this study. First, the picocyanobacterial bloom in July was associated with a major fallout of calcium carbonate known as a whiting event. The combination of the bloom and the whiting resulted in major reductions in water clarity and light penetration into the water column. Second, there was an apparent decline of filamentous/colonial cyanobacteria cells in surface waters during the bloom period. We suggest this may be the result of light limitation. Other possible ecosystem-level consequences of the picocyanobacterial bloom are discussed.

Background

The phytoplankton community of Conesus Lake has been studied extensively in recent years. The renewed interest in the phytoplankton has been driven by changes taking place in the lake itself (warming surface waters, increasing turbidity), by the persistent risk of harmful algal blooms (HABs), and by the emergence over the past 10 years of single cell cyanobacterial blooms that dominate the lake during most of July.

Detailed taxonomic surveys of the Conesus Lake phytoplankton were carried out in 1996, 1999 and 2004 and most importantly in 2014 by Makarewicz and Lewis. This last study was very important because it documented cell numbers and biomass of cyanobacteria that were unprecedented for Conesus Lake. Makarewicz (2014, 2016) proposed that the lake might have entered a new ecological state of elevated phytoplankton and cyanobacteria biomass. Their observation raised important questions about the state of the phytoplankton and the ecosystem of Conesus Lake that should be a focal point of the monitoring plan for the foreseeable future. Since 2014 there have been limited surveys of the lake cyanobacteria community, but it was not until 2022 that the first comprehensive phytoplankton study since 2014 was conducted by Bosch and Colleagues. The 2022 work reaffirmed the pattern of cyanobacteria dominance observed by Makarewicz (2014,2016) but reported much lower biomass of cyanobacteria. Moreover, Bosch and Collegues (2023) found that the cyanobacteria community was dominated by species of the genus *Dolichospermum*, which are unique in being able to fix biologically usable forms of nitrogen from dissolved N_2. Bosch and Colleagues (2023) also characterized the bloom of single cell cyanobacteria (technically "picocyanoplankton"). This bloom, which has become a regular July phenomenon in the lake phytoplankton, was first reported by Makarewicz and Lewis in 2014, but water quality records show signs of it as early as 2011 (Bosch observations).

The main goal of the 2023 monitoring study was to investigate the environmental determinants associated with the July picocyanobacterial bloom and the subsequent dominance of the lake cyanobacteria in August and September by several species of the genus *Dolichospermum*. Samples of the cyanobacteria were collected regularly from July 13 to September 14 and analyzed for species composition and cell abundance. Additionally, we collected data on water quality characteristics (such as light penetration, conductivity, oxygen, redox potential, etc.) and nutrient levels to assess the potential drivers of the bloom.

Methods

Sampling for this study was conducted approximately on a bi-weekly basis beginning on 5 July and ending on 21 September, 2023. More frequent samples were taken in late July (July 20, 24, 26) to document the intensive bloom of single cell picocyanobacteria that now is typical of the summer phytoplankton dynamics in Conesus Lake. All collections for phytoplankton and all profiles of water column characteristics, nutrient concentrations, turbidity and measurements of Secchi depth were taken in the South Basin of Conesus Lake over 18 m of water at approximately the exact position of the long-term monitoring station first established by the DEC at or near the following coordinates: *42.75473 N and -77.71535 W.*

For consistency with previous studies, the taxonomic study of the phytoplankton community was conducted on integrated (mixed) samples collected at depths of 1, 2 and 3 m. Subsamples of approximately 72.5 mL volume were immediately fixed with 2.5 mL of paraformaldehyde to a 1% final concentration. Samples were stored in plastic bottles in a refrigerator until analysis in late December. These phytoplankton samples meant to be analyzed by PhycoTech Inc. However, on 10/5 we were informed that PhycoTech would not be able to analyze our samples by the scheduled end of the contract in January. Analysis of these samples was therefore carried out at SUNY Geneseo using methodology that is described below.

We used a standard filtration method to concentrate picocyanobacteria and filamentous/colonial cyanobacteria and then analyzed the filter retained material using fluorescence microscopy. Water samples were gently but thoroughly mixed and an aliquot of 4 mL was filtered onto gridded 25 mm Millipore membrane filter with 0.45-micron pore size. Several precautions were taken. To achieve equal distribution of cells on the filter each 4 mL sample was first mixed with 4 mL of nanopure water in the 10 mL filtration tower. To minimize the risk of damaging the membrane filter while on the metallic/glass filtration tower, a 5-micron pore size, 25 mm diameter nucleopore filter was first placed on the filtration grid. Finally, to prevent lysis of cells or tearing of the membrane filter, vacuum pressure was generated by a handheld vacuum pump that maintained pressure at 15 psi or lower.

To count picoplankton cells, three fields were photographed from the filter retained material at 200x magnification on a Zeiss Epifluorescence scope. The scope was fitted with a Texas Red Filter Set that caused Phycocyanin and especially the Phycoerythryn pigment in

cyanobacteria to fluoresce. The resulting .jpeg image files were later loaded onto the image analysis program *ImageJ* (Version 1.54; National Institutes of Health). Cells were counted manually using the "Multi Point" function of *ImageJ*. To extrapolate cells counted to # of cells per mL of sample, the area of the image field at 200x magnification (0.154 mm^2) was measured by using a calibrated ocular micrometer to determine the height and width of the field of view. The filtration area of the filter tower was determined by directly measuring the inner diameter of the filtration tower (16 mm) and using the corresponding radius to calculate the area of the filtration circle (201.2 mm^2). To calculate # of cells per mL we multiplied the # of cells counted per field * 1305.4 (201.2/0.154) and divided that number by the volume of sample that was filtered.

Filamentous and colonial cyanobacteria were counted directly following the grid on the filter to scan the whole sample at 100x magnification. We focused our analysis on known HAB forming species that were more easily identified. Colonies of very few cells such as, *Aphanocaspa*, *Aphanothece, Chroococcoccus*, *Cyanogranis* and *Snowella* were observed but not included in the tally. Counts were made under using fluorescence with a Texas Red filter set that made it very easy to see all the colonies and filaments on the membrane filter.

Water column profiles were obtained with a Hydrolab 5a sonde is equipped with sensors for depth (m) temperature (°C), conductivity (µSiemens/cm^2), dissolved oxygen (mg/L and % saturation), pH, redox potential (mV). All sensors were calibrated before and after sampling, in adherence to the procedures and recommendations of the manufacturer (OTT Hydromet) and guidelines in our quality assurance plan (QAPP). Included in the water column profiles we report on photosynthetically active radiation levels (PAR, 300-700 nm) at different depths. The light data, reported as µEinsteins/m^2/sec, can be used to calculate the attenuation coefficient (μ) that indicates how quickly light is attenuated when passing through the water column. Following is the formula for the attenuation coefficient between any two depths:

$$\mu = (\mathrm{Ln}(I_o) - \mathrm{Ln}(I_d))/(Z_d - Z_o)$$

I_o = light at shallower depth, I_d = light at deeper depth

Z_d = deeper depth (m) and Z_o shallower depth (m)

Two other independent measures of water transparency were recorded in addition PAR. Water turbidity as nephelometer turbidity units (NTU) was measured with a calibrated Hach 2100P turbidity meter- in the field or in the laboratory within two hours of collection. The Secchi depth was measured with a black and white 20-cm disk following standard operating procedures. Water samples were collected from 0-3, 7 and 9m and delivered to SUNY Brockport for analysis in their ELAP certified water quality laboratory. The data and QC information for these analyses have been submitted to Livingston County directly by SUNY Brockport. Here we report only a brief analysis of the trends in the data.

Results and Discussion

Filamentous and Colonial Cyanobacteria

Table 1 shows results of the analysis of cell counts for dominant filamentous/colonial cyanobacteria. For this analysis we counted only known HABs forming species. The dominant taxonomic group were several species of the genus *Dolichospermum* that we tentatively assigned to species previously seen in Conesus Lake (**Figures 1, 2,3**). Notable among these was *D. planctonicum*, which was especially abundant from mid-August and into September. The species forms long trichomes that have many heterocyst cells interspersed in a regular pattern between vegetative cells; *D. planctonicum* produced more heterocysts than other species of *Dolichospermun* and may be very active in N_2 fixation. *D. circinale* was also abundant in most of the samples. In addition to *Dolichospermum* species, we found *Oscillatoria* in some samples, as well as *Waronichinea. Microcystis* colonies were rare through most of the study. We provide a more detailed analysis of trichome and colony abundance below. *Dolichospermum* dominance in Conesus Lake is not unexpected. In a comprehensive study of Conesus Lake phytoplankton, Bosch and Colleagues (2023) reported finding 8 species of *Dolichospermum* over the growing season, which at their peak in late August comprised nearly 55% of the phytoplankton biomass. One difference between our study and the 2022 study was that *Dolichospermum* was still abundant in the September 15 2023, sample whereas in 2022 the phytoplankton community by 15 September had shifted to dominance by diatoms, specifically *Fragillaria crotonensis*, and there were no *Dolichospermum* in surface waters.

The Bloom of Single Cell Cyanobacteria

The abundance patterns of picocyanoplankton are shown in **Table 2**. The numbers can be seen to first increase from 0.062 million cells/mL on 5 July to 0.127 cells/million on 16 July, then peak with counts over 0.225 million cells/mL on July 20- 26 at the height of the picoplankton bloom. The coefficient of variation (Mean/Standard Deviation x 100) among three replicate measurements for each date was as low as 2.4 % and as high as 18.3% and averaged 9.1%, which is acceptable variation and indicates that the filter method combined with fluorescence microscopy is a reliable method for quantifying picocyanobacteria. The seasonal trend for 2023 is shown in **Figure 4** along with a graph showing a very similar pattern of abundance and seasonal distribution for 2022, based on counts conducted by PhycoTech Inc.

The seasonal changes in cell number for picoplankton and for filamentous/colonial cyanobacteria at the 0-3 m depth range are compared in **Figure 5.** This comparison shows a very interesting pattern in which the HAB forming species declined from 674 cells/mL on 16 July to 129 and 102 cells/mL on 20 and 26 July during the peak of the picoplankton bloom. We consider possible explanations for this inverse relationship below in the next section. After the picoplankton bloom, the abundance of filamentous/colonial cyanobacteria increased, peaking on 16 August at 840 cells/mL and remaining high during the remainder of the our sampling dates (See Table 1, Appendix IA). The number of trichomes and colonies per mL were also high, (8.3-11 per mL) after August 2. In Conesus Lake, cyanobacterial numbers are normally high in during late summer season (Makarewicz and Lewis 2014, Bosch et al. 2023) and 2023 followed that pattern (**Figure 5**).

Environmental Conditions and Cyanobacteria Abundance

The temperature profiles shown on **Figure 6** reveal a very typical seasonal pattern for Conesus Lake. By 5-July , warming of surface waters had begun to establish a thermocline at a depth of about 7 m, with a mixed layer (‘epilimnion”) in which temperature was nearly equal from the lake’s surface to the thermocline. Once stratification had set in, the heat entering the lake was not readily mixed below the thermocline and surface waters begin to warm very quickly. In 2023, there was rapid warming by 13-July (**Figure 7)** and between 7/13 and 7/24, surface waters were hovering around a very balmy 25 °C. These warm July temperatures were

associated with two important events that happened simultaneously: the bloom of cyanobacteria picoplankton and a "whiting event" caused by precipitation of $CaCO_3$ from the alkaline waters of the lake ($CaCO_3$ is less soluble at warmer temperatures). During the height of the bloom, we found that many of the freshly collected picocyanobacterial cells could be found in small cell clusters surrounding what we believe to be newly precipitated $CaCO_3$ aggregates. Whiting events have been observed in marine and lake waters. In Green Lake, Fayette New York, whiting events occur annually (Thompson et al., 1990). Research has shown that they are associated with blooms of the single-cell cyanobacterium *Synechococcus.* According to Thompson and colleagues (1977), as the *Synechococcus* photosynthesize each cell consumes Carbon Dioxide around a very narrow cell boundary layer narrow boundary. This raises the pH around the cell and causes precipitation of $CaCO_3$. The action of millions of these cells in the water column is responsible for the lake-wide whiting event. It is worth noting that the dominant picocyanobacterium in Conesus Lake is also a species in the *Synechococcus* group. Whether the Conesus Lake picocyanoplankton facilitate the whiting or the whiting provides a surface that promotes cell growth remains to be seen.

The aggregate effect of the bloom and the whiting event in Conesus Lake has significant consequences in terms of decreasing water transparency (see **Table 3** and **Table 4)**. Between 16-26 Jully, the Secchi depth became very shallow (as shallow as 0.85 m) and the corresponding turbidity increased from 1.7 NTU on July 5 to as high as 7.63 NTU on 20 July. The loss of transparency was evident throughout the mixed layer to a depth of 7 m, but it was more prominent in the upper 5 m (**Table 3**). Under the turbid conditions caused by the bloom/whiting, light is rapidly absorbed in the water column. The light profiles shown on **Figure 8** show how light levels changed with depth on two different days, one during the bloom and one in September. These two profiles were selected because both have the same incident light levels (~ 1230 μEinsteins/m^2/sec) at a depth of 1 m. With depth, however, light on July 24 is absorbed more rapidly as shown by the lower slope of the line and the higher calculated attenuation coefficient (μ) of 0.69, compared to 14-Sept., which shows a lower μ of 0.52. The two profiles also allow for a comparison of how deep light penetrates the lake. We used the 1% light level as our indicator. This is the compensation depth, which is defined as the depth (and corresponding light level) at which on average the amount of energy created by a cell's

photosynthesis equals the amount of energy consumed by its respiration. As shown in **Figure 8**, the compensation depth was more than 2 m shallower on July 24, indicating that plant growth would be constrained by as much as 2 m as compared to September, even though the light levels at a depth of 1 m were the same. The data in **Table 4** allow for a more comprehensive comparison; they show that the compensation depth during the picocyanobacteria bloom/whiting event was on average at 8.2 m compared to 11.1 m outside of the bloom period, a difference of nearly 3 m.

We found a strong correlation between all the metrics for water transparency (Secchi depth, turbidity, and attenuation coefficient (**Figure 5**) that we used to study the bloom. While Secchi depth and turbidity are valuable in shown trends, the light penetration data allows us to frame the discussion in terms that can be related to ecological interactions. For example, we mentioned earlier that the abundance of filamentous/colonial cyanobacteria declined during the single cell bloom/whiting event. This could have been the result of less light being available for growth. The reduced light levels could also account for the decreased biomass of macrophytes that has been observed in recent years. It might also affect the maximum depth at which macrophytes can survive in Conesus Lake. Lastly, increased light/heat absorption near the surface could be responsible for differential warming of the lake, which could increase the stability of the water column stratification, perhaps even cause shallowing of the thermocline. Any change in the physical structure of the water column over time could affect the exchange of nutrients between the hypolimnion and the epilimnion, the time of the fall turnover and other interactions.

All the relevant metrics (turbidity, Secchi Depth) indicate that by 2-August the picoplankton bloom and whiting event had abated. Picocyanobacterial numbers had dropped to about half of the bloom peak number (**Table 2, Figure 4**). By 2-August at the 0-3 m depth the filamentous/colonial cyanobacterial community had more than tripled in cell numbers since the previous collection on 26-July (**Table 1, Figure 5**). From that date until our last sampling date on 14 Sept., the number of cells and trichomes/colonies, remain high. What causes the collapse of the picoplankton bloom and the subsequent rise of *Dolichospermum* species and other HABs forming cyanobacteria? We looked closely at nutrients for a possible clue. Orthophosphate levels were generally very low (< 1.6 μg/L or less) and NO_x was typically below

detection (data not shown). Total Phosphorus and Total Nitrogen concentrations were moderate throughout the sampling period (**Table 5**, **Figures 10** and **11**) but there were no obvious trends in the data that could explain the patterns of cyanobacteria abundance. When plotted against one another there was a consistent direct relationship between TP and TN with two outliers (**Figure 12**) on 20 July and 2 August. Those two dates stand out, with the former being near the peak of the bloom and the latter marking the re-establishment of the filamentous/colonial cyanobacteria community dominated by *Dolichospermum*. However, we cannot to draw any major conclusions from such a limited sample.

Conclusions

The cyanobacterial community of Conesus Lake followed a pattern of dominance over the summer season that was consistent with that of previous studies, most recently 2022. Significantly in 2023, we reaffirmed previous observations that the July picocyanobacterial bloom was somehow linked to a major whiting event caused by lake-wide precipitation of $CaCO_3$. The timing of this event in July seems to follow the establishment of water column stratification that leads to rapid warming of surface waters and reduced nutrient availability.

We show that the picocyanobacterial bloom and accompanying whiting event greatly reduce water clarity and light penetration for about two weeks. This phenomenon could have significant ecosystem consequences by changing patterns of light penetration with depth and the distribution of heat. We suggest that the growth of filamentous/colonial cyanobacteria may be slowed by the reduced light availability. By end of July the bloom has abated and species of *Dolichospermum* as well as other HAB forming cyanobacteria once again dominate the biomass of the phytoplankton. More frequent sampling of nutrient availability in late July and August will be needed to gain a better understanding of the factors that promote the rise of filamentous/colonial cyanobacteria during the late summer.

Acknowledgements

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Tables

Table 1. Summary data of surface (0-3m) sample analysis for dominant HABs forming cyanobacteria species.

2023 Sample Date	# of Cells per mL	Heterocysts % of all cells	Dominant Cyanobacteria Species (Trichomes and Colonies)
16-Jul	674	0.8	*D. lemmermannii, D. circinalis, Oscillatoria sp.*
20-Jul	247	1.6	*D. circinalis, D. spiroides, D. planctonicum*
24-Jul	129	2.6	*D. circinalis, D. planctonicum, D. crassum*
26-Jul	102	3.3	*D. planctonicum, D. crassum, D. circinalis*
2-Aug	384	-	*Dolichospermum sp., Oscillatoria, Waronichinia*
9-Aug	385	1.5	*D. circinalis, D. spiroides, D. lemmermani*
16-Aug	840	3.4	*D. circinalis, D. planctonicum, D. crassum*
23-Aug	555	2.9	*D. circinalis, D. planctonicum, Oscillatoria sp.*
1-Sep	453	3.4	*D. macrosporum, D. crassum, D. circinalis, Oscillatoria sp.*
14-Sep	809	4.7	*D. planctonicum, D. crassum, D.circinalis, Microcystis sp,*

Table 2. Summary of surface (0-3m) picocyanoplankton abundance. The average coefficient of variation was 9.1%. Three replicate counts were made for each sample.

Sample Date	Avg # cells per mL x 10^6	Standard Deviation	Coeff. of Variation (%)
7/5/23	0.062	0.005	8.1
7/16/23	0.127	0.003	2.4
7/20/23	0.228	0.022	9.7
7/26/23	0.254	0.018	6.9
8/2/23	0.118	0.011	9.0
8/9/23	0.082	0.014	17.2
8/16/23	0.060	0.003	4.4
8/23/23	0.094	0.005	4.8
9/1/23	0.053	0.006	10.7
9/14/23	0.153	0.028	18.3

Table 3. Secchi Depth and Turbidity data from July 5 to September 21 showing the effects of the picocyanobacterial bloom (highlighted) and accompanying whiting event on water transparency in the epilimnion (0-7 m).

2023	Secchi Depth (m)	Turbidity (NTU)			
		0-3 m	5 m	7 m	9 m
5-Jul	2.43	1.71	1.61	1.60	1.67
13-Jul	2.05	2.11	2.40	2.09	1.65
16-Jul	1.50	4.31	4.56	3.57	2.06
20-Jul	0.85	7.63	7.18	2.76	2.53
24-Jul	0.85	5.57	5.03	3.06	-
26-Jul	1.75	3.28	3.61	2.22	1.67
2-Aug	2.25	1.65	1.61	2.51	1.51
9-Aug	2.90	1.23	1.23	1.36	1.15
16-Aug	3.07	1.27	1.27	1.17	1.48
23-Aug	2.97	1.51	1.51	1.58	2.56
1-Sep	3.77	-	-	-	-
14-Sep	2.40	1.32	1.59	1.75	1.54
21-Sep	3.00	1.27	1.71	1.73	1.74

Table 4. Secchi Depth, Turbidity and PAR light attenuation data showing the effects of the picocyanobacterial bloom and whiting event on transparency. The 1% of surface light level was determined for each light profile. This is generally considered the light level where photosynthesis equals respiration and is known as the "compensation point".

Date	Secchi Depth (m)	0-3 m Turbidity (NTU)	Mean Attn. Coeff.	Surface PAR [µE/s/m²]	Depth (m) 1% Light Level
7/5/23	2.43	1.71	-	-	-
7/13/23	2.05	2.11	0.429	490	11.66
7/16/23	1.50	4.31	-	-	-
7/20/23	0.85	7.63	0.761	911	8.11
7/24/23	0.85	5.54	0.692	1,326	7.5
7/26/23	1.75	3.23	0.549	1,335	9.07
8/2/23	2.25	1.65	0.477	1,256	11.02
8/9/23	2.90	1.23	0.508	1,781	9.98
8/16/23	3.07	1.27	-	-	-
8/23/23	2.97	1.51	0.454	511	12.17
9/1/23	3.77	-	0.466	958	11.37
9/14/23	2.40	1.72	0.530	1,469	10.23
9/21/23	3.00	1.27	-	-	-

Table 5. Total Phosphorus and Total Nitrogen concentrations at 0-3, 7 and 9 m. This is a summary of analyses conducted by SUNY Brockport. Raw data and QC results were submitted separately to Livingston County.

Date	TP-P 0-3m	TP-P 7m	TP-P 9m
7/13	15.6	16.6	11.5
7/16	17.1	14.4	10.6
7/20	14.1	13.4	10.3
7/26	18.4	14.2	15.2
8/2	18.1	17	19.9
8/9	18.8	22.2	15.2
8/16	16.7	17.6	23.7
8/23	16.2	16.6	22
9/14	14.3	15.4	14.8

Date	TN-N 0-3 m	TN-N 7 m	TN-N 9 m
7/13	0.402	0.430	0.340
7/16	0.417	0.388	0.340
7/20	0.412	0.397	0.331
7/26	0.427	0.329	0.316
8/2	0.395	0.385	0.334
8/9	0.430	0.397	0.311
8/16	0.409	0.378	0.367
8/23	0.405	0.390	0.401
9/14	0.379	0.395	0.352

Figures

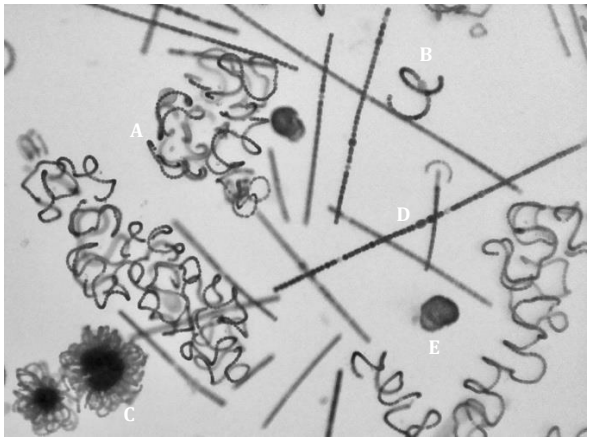

Figure 1. Species of Cyanobacteria from Conesus Lake identified tentatively as *Dolichospermum flos-aquae (A), D. spiroides (B), D. lemmermannii (C), D. planctonicum (D) and Woronichinia* (E).

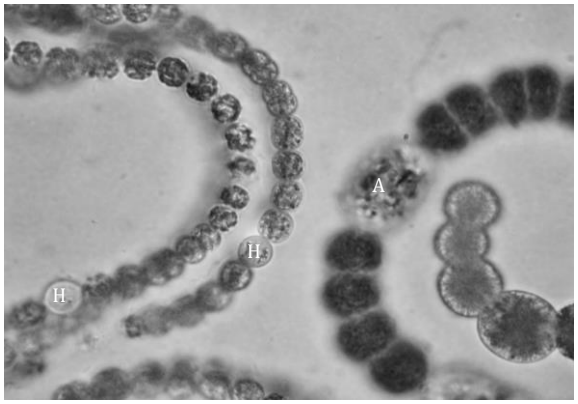

Figure 2. Two species of *Dolichospermum* (*D.circinalis* and *D. crassum*) with nitrogen-fixing heterocysts (H) and dormant cysts called akinetes (A).

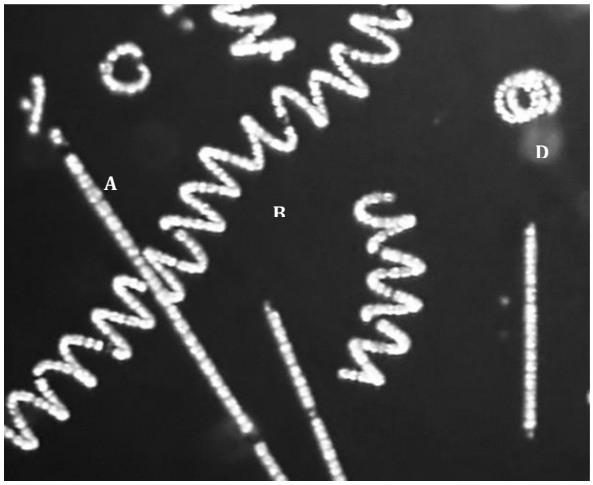

Figure 3. More *Dolichospermum, tentatively identified as : D. planctonicum* (A), *D. crassum* (B) and *D. spiroides* (C).

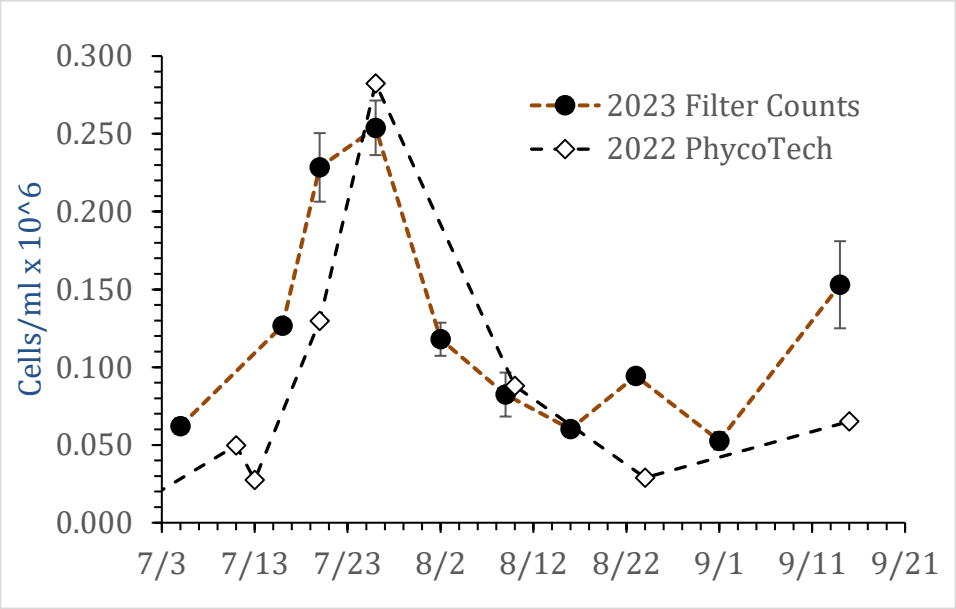

Figure 4. Temporal trends in single-cell picocyanobacteria showing peak abundance during blooms in mid-late July 2022 (data from PhycoTech Inc.) and 2023 (this study). The timing and abundance for the two years are very similar.

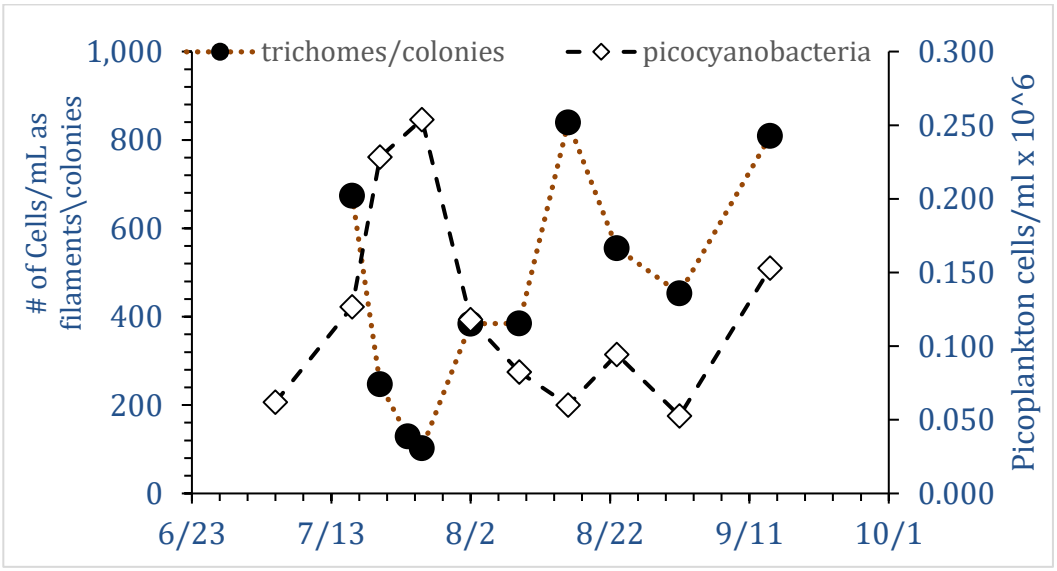

Figure 5. Tends in cell numbers at 0-3 m for single-cell picocyanobacteria and trichome/colonial cyanobacteria, which were dominated by species of *Dolichospermum*. Note the very abrupt decrease in trichomes/colonies during the picocyanobacterial bloom.

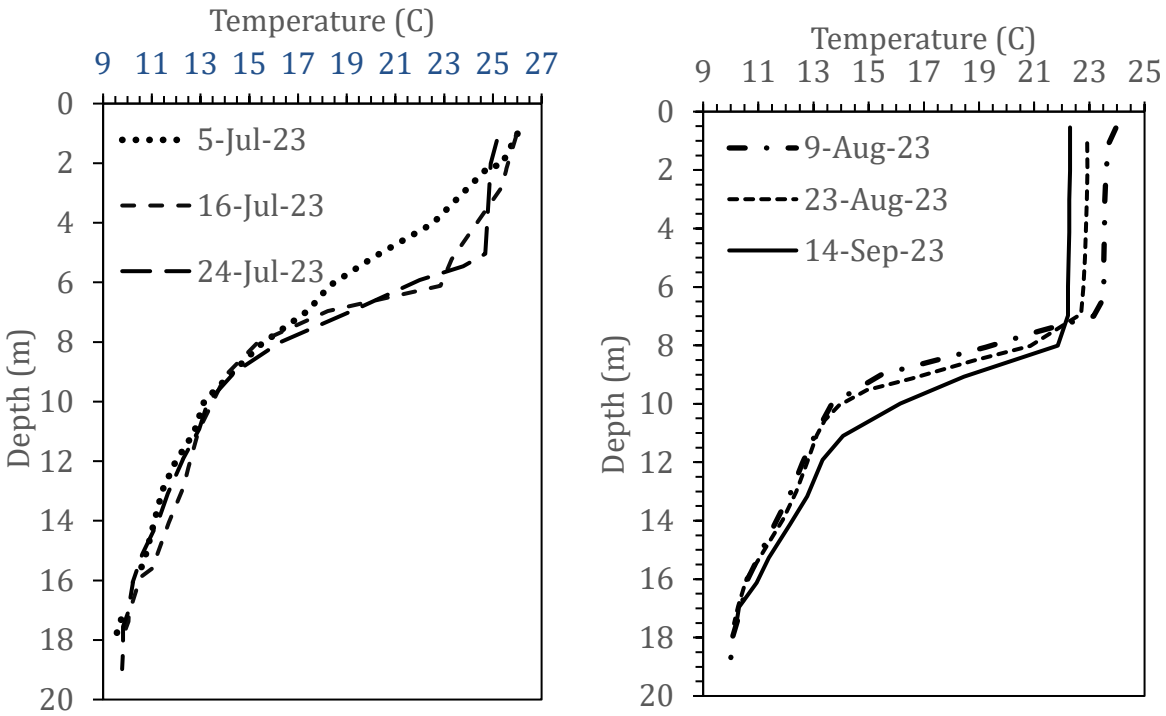

Figure 6. Temperature profiles showing the establishment of full water column stratification in mid-July (Left) and the beginning of the cooling phase in the epilimnion in late August (Right).

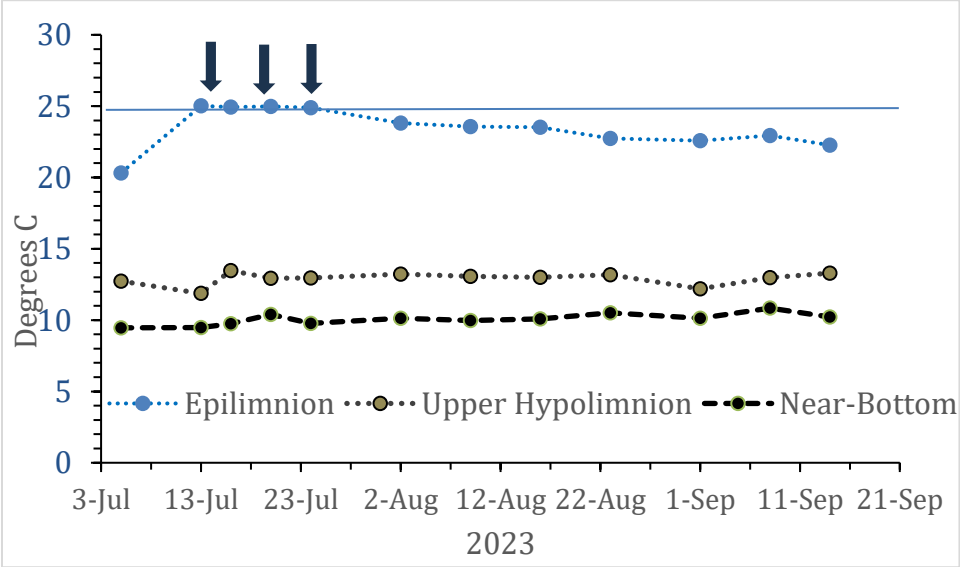

Figure 7. Average temperatures in the epilimnion, the upper hypolimnion and near the bottom. The transition to a stratified water column in July causes a rapid warming of surface waters to temperatures near 25 °C. The arrows show the approximate time frame of the whiting event/picoplankton bloom.

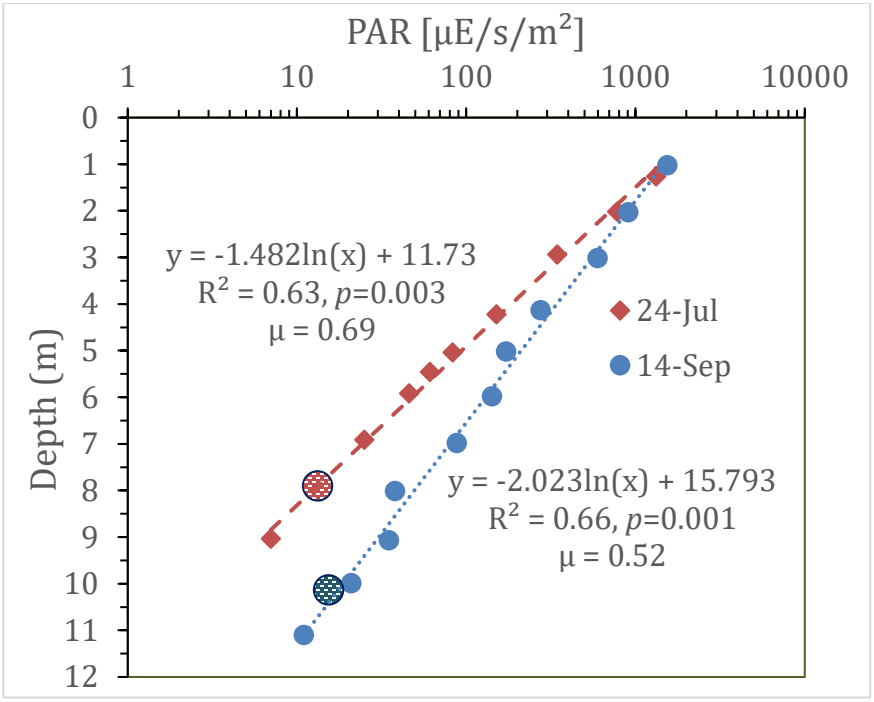

Figure 8. PAR profiles from 24 July and 14 Sep. in which the light at the surface was very similar. The attenuation of light was higher in July during the picocyanobacterial bloom than in September, as by the lines and the calculated attenuation coefficients (µ). Consequently, the 1% light level (large circles) was more than 2 m shallower in July than in September.

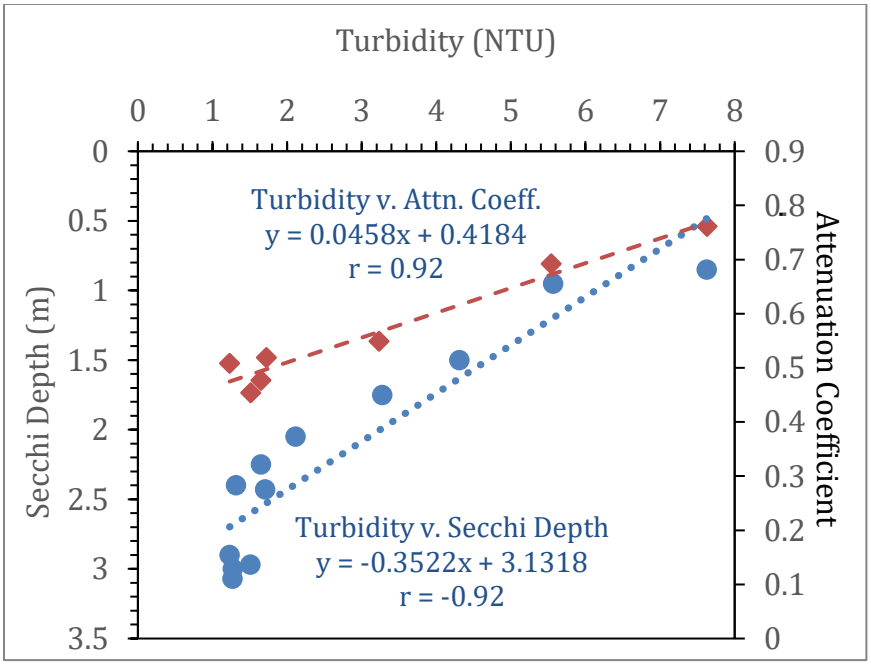

Figure 9. The correlations between Turbidity and Secchi Depth and Turbidity and the Light Attenuation Coefficient were very strong, showing that these metrics all serve as good indicators or light absorption in the water column.

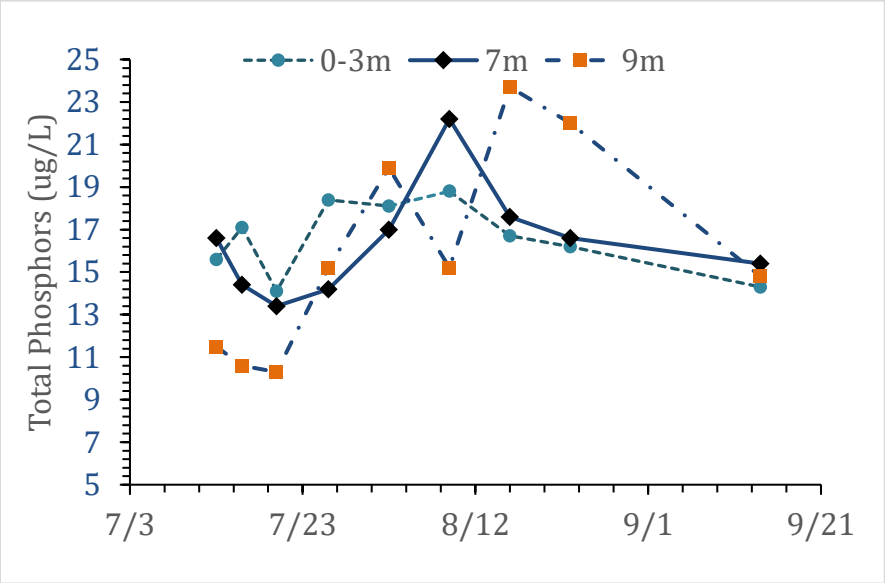

Figure 10. Seasonality of Total Phosphorus concentrations at the surface, at the top of the thermocline and at the bottom of the thermocline where the hypolimnion begins. TP levels were low at all depths during the bloom of picocyanobacterial.

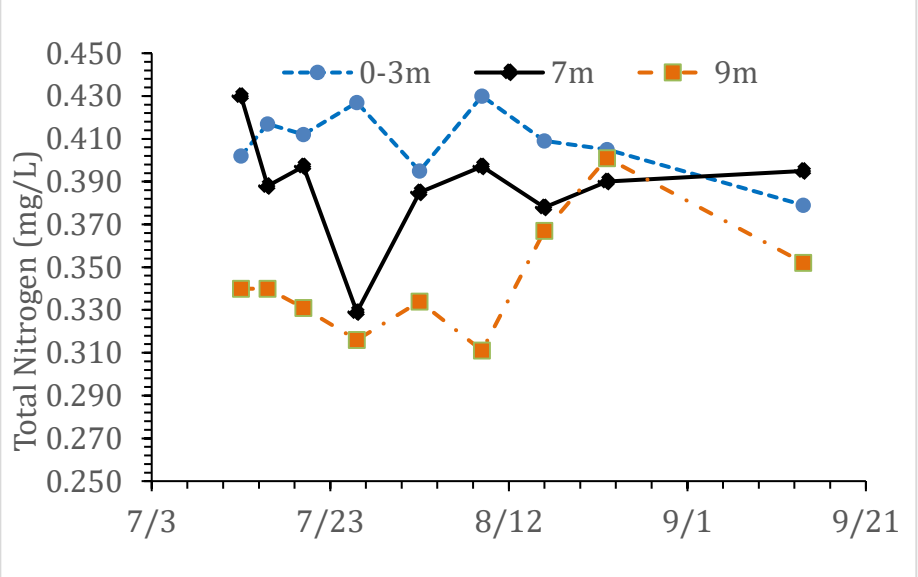

Figure 11. Seasonality of TN concentrations at the surface, the top of the hypolimnion and near the bottom of the lake. TN concentrations remain about the same at the surface for most of the summer.

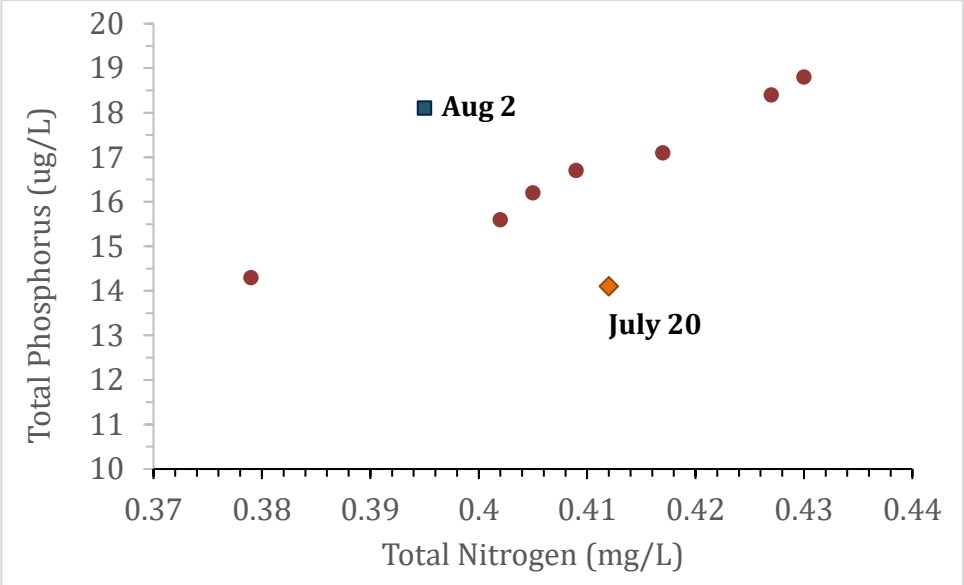

Figure 12. The relationship between Total Nitrogen and Total Phosphorus was generally consistent from July 13 to Sept. 14. TP was proportionately low on July 20 during the picocyanobacterial bloom, and proportionately high on Aug 2, when trichome/colony cell numbers began to increase.

Appendix I:

A. Results of surface (0-3m) sample analysis showing the #cells/mL (far right) for filamentous and colonial cyanobacteria. The analysis included only well-known HABs forming species. (*corrected for fixative volume)

Date of Collection	Sample Volume (ml)	Fixative Volume (mL)	mL filtered	Total # cells in 4 mL	Total # Heterocysts	Heterocysts % of cells	# trichomes & colonies	# Trichomes & colonies per mL*	# Cells per mL*
7/16/23	72.5	2.5	4	2,605	20	0.8	24	6.2	673.7
D. lemmermannii				1340	15		6		
D. circinalis				215	5		15		
Oscillatoria sp.				1050	0		3		
7/20/23	72.5	2.5	4	956	15	1.6	23	5.9	247.2
D. spiroides				196	0		4		
D circinalis				712	14		17		
D. planctonicum				48	1		2		
7/24/24	72.5	2.5	4	500	13	2.6	11	2.8	129.3
D. circinalis				335	10		8		
D. planctonicum				136	2		2		
D. crassum				29	1		1		
7/26/24	72.5	2.5	4	395	13	3.3	9	2.3	102.2
Dolichospermum sp.				38	2		2		
D. circinalis				28	0		1		
D. planctonicum				293	10		3		
D. crassum				74	1		3		
8/2/24	72.5	2.5	6	2,229	ND	ND	23	4.0	384.3
Dolichospermum spp				804			20		
Oscillatoria				1,350			2		
Waronichina				75			1		
8/9/24	72.5	2.5	4	1488	23	1.5	32	8.3	384.8
Dolichospermum sp.				177	7		6		
D. spiroides				268	1		2		
D. circinalis				801	15		21		
D. lemmermannii				242	0		3		
8/16/24	72.5	2.5	4	3,360	115	3.4	44	11.0	839.9
D. circinale				650	39		14		
D. planctonicum				1,684	63		21		
D. crassum				91	5		2		
D. flos-aquae				311	7		2		
Oscillatoria				624	0		5		
8/23/23	72.5	2.5	4	2,219	65	2.9	35	8.8	554.8
D circinalis				1,059	29		16		
D. planctonicum				555	25		13		
D lemmermannii				335	8		2		
D. crassum				120	3		1		
Oscillatoria sp.				150	0		3		
9/1/24	72.5	2.5	4	1813	61	3.4	39	9.75	453.25
D. circinalis				290	9		11		
D. planctonicum				203	18		2		
D. macrosporum				768	23		15		
D. crassum				291	11		8		
Oscillatoria				261	0		3		
9/14/24	72.5	2.5	4	3238	151	4.7	71	17.75	809.5
D. spiroides				203	7		4		
D. circinalis				258	10		8		
D. planctonicum				1735	77		35		
D. macrosporum				141	6		4		
D. crassum				821	51		19		
Microcystis aeruginosa				80			1		

Appendix I:

B. Tables of raw Hydrolab profiles from 15 sampling trips spanning 12 weeks starting on July 5 and ending on September 14, 2023.

Date / Time	Dep25 meters	Temp [°C]	pH	ORP [mV]	LDO% [Sat]	LDO [mg/l]
7/5/23	0.56	26.02	8.86	391	126.6	10.05
15:00 hr	1.01	26.01	8.82	388	127.8	10.14
	2.09	25.33	8.85	386	127.9	10.28
	2.09	24.87	8.87	383	126.9	10.29
	4.02	22.53	8.82	386	118	9.99
	5.15	20.12	8.62	393	101.1	8.98
	6.11	18.29	8.31	404	72.9	6.71
	6.94	17.42	8.12	408	60.4	5.66
	8.1	15.45	8.04	412	45.8	4.48
	8.98	14.36	7.94	415	36.2	3.62
	9.98	13.16	7.84	417	24.5	2.51
	11.03	12.73	7.78	417	26.1	2.71
	12.04	11.96	7.74	418	14.1	1.49
	12.98	11.43	7.73	418	15.3	1.64
	14.27	11.02	7.73	419	7.1	0.77
	15.07	10.78	7.63	419	5.8	0.63
	15.8	10.48	7.62	422	4.4	0.48
	16.97	9.86	7.62	235	4.2	0.47
	17.32	9.74	7.62	120	4.2	0.46
	18.03	9.46	7.62	12	4.2	0.47

Appendix I:
B. Tables of raw Hydrolab profiles.

Date/ Time	Dep25 meters	Temp [°C]	PAR [µE/s/m²]	pH	ORP [mV]	LDO% [Sat]	LDO [mg/l]
7/13/23	0.81	25.09	344	8.77	402	119.8	9.67
10:11 hr	1.41	25.07	262	8.78	398	120.2	9.7
	2.48	25.05	232	8.76	398	120	9.69
	3	25.07	216	8.76	397	120	9.69
	3.94	25.08	166	8.74	396	119.9	9.68
	5.87	24.88	54	8.68	396	118.6	9.61
	6.08	24.36	42	8.73	397	117.3	9.6
	7.19	19.34	40	8.59	405	90.5	8.16
	8.57	15.05	12	8.33	418	38.9	3.81
	8.45	14.78	15	8.15	420	25.7	2.55
	10.89	12.45	11	8.07	424	15.4	1.61
	12.08	11.87	6	7.98	426	9.1	0.97
	12.28	11.84		7.95	426	7.8	0.82
	13.41	11.46		7.9	427	7.7	0.82
	14.43	11.21		7.86	428	7.2	0.77
	15.18	11		7.83	428	6	0.65
	16.3	10.16		7.81	275	5.2	0.57
	18.08	9.47		7.81	68	4.7	0.52

Appendix I:
B. Tables of raw Hydrolab profiles.

Date/ Time	Dep25 meters	Temp [°C]	pH	ORP [mV]	LDO% [Sat]	LDO [mg/l]
7/16/23	0.34	25.99	8.89	357	133.3	10.6
15:02 hr	1.08	25.93	8.87	358	133.3	10.6
	1.11	25.95	8.88	358	132.9	10.56
	2.18	25.55	8.85	358	132.7	10.62
	2.25	25.54	8.86	358	133.2	10.66
	2.83	25.35	8.84	359	130.6	10.5
	5.22	23.31	8.69	365	103.4	8.63
	6.11	22.85	8.62	368	95.4	8.03
	6.96	18.23	8.36	381	49.5	4.57
	8.04	15.32	8.15	388	31	3.04
	9.11	14.03	8.04	391	24.7	2.49
	10.07	13.47	7.93	393	21.9	2.23
	10.98	12.92	7.9	394	17.2	1.77
	12.23	12.5	7.87	397	10.5	1.1
	12.87	12.3	7.81	398	8.7	0.91
	14.06	11.69	7.8	397	8.3	0.88
	15.43	11.09	7.77	397	6.1	0.65
	15.59	11.04	7.76	397	5.9	0.63
	15.9	10.53	7.71	347	5.1	0.56
	17.38	10.04	7.75	73	4.5	0.49
	18.02	9.75	7.75	30	4.4	0.49

Appendix I:
B. Tables of raw Hydrolab profiles.

Date/ Time	Dep25 meters	Temp [°C]	PAR [µE/s/m²]	pH	ORP [mV]	LDO% [Sat]	LDO [mg/l]
7/20/23	1.56	25.15	911	8.68	368	125.4	10.21
11:50 hr	2	24.98	848	8.68	367	125.2	10.20
	2.96	24.96	406	8.65	368	125.6	10.16
	2.94	24.96	397	8.66	368	126.1	10.21
	2.97	24.96	360	8.66	367	126.7	10.26
	3.91	24.95	176	8.67	368	124.9	10.11
	4.96	24.93	90	8.65	368	126.1	10.21
	6.04	23.71	41	8.52	375	102.1	8.46
	6.04	23.71	41	8.52	375	100.8	8.35
	6.93	19.2	23	8.25	390	45.2	4.09
	8.01	17.06	14	8.12	395	30.6	2.89
	9.02	15.02		8	398	16	1.57
	9.98	13.39		7.95	402	8.4	0.86
	10.94	12.94		7.9	404	6.1	0.63
	11.02	12.95		7.89	404	5.7	0.59
	12.01	12.33		7.84	407	5.1	0.53
	13.08	11.64		7.83	342	4.8	0.51
	14	11.31		7.79	162	4.6	0.49
	15.15	10.66		7.77	69	4.5	0.49
	15.75	10.37		7.74	39	4.5	0.49

Appendix I:
B. Tables of raw Hydrolab profiles.

Date/	Dep25	Temp	PAR		ORP	LDO%	LDO
Time	meters	[°C]	[µE/s/m²]	pH	[mV]	[Sat]	[mg/l]
7/24/23	1.26	25.18	1326	9	385	115.1	9.34
11:30 hr	2.02	24.92	778	8.9	384	115.1	9.34
	2.94	24.85	345	8.85	385	115.8	9.39
	4.22	24.7	151	8.77	385	114.4	9.31
	5.04	24.69	83	8.73	385	111.4	9.07
	5.46	23.78	61	8.42	395	81.1	6.71
	5.92	22	46	8.26	402	52.7	4.51
	6.91	19.36	25	8.14	407	33.5	3.02
	8.02	16.26	14	8.05	410	18.9	1.81
	9.03	14.39	10	7.95	412	8	0.8
	10.07	13.5		7.9	415	4.6	0.47
	10.93	12.95		7.86	414	6.8	0.7
	11.95	12.27		7.79	414	9.4	0.99
	13.08	11.66		7.73	415	5.9	0.62
	13.96	11.29		7.67	416	4.5	0.48
	15.12	10.6		7.68	139	4.2	0.46
	16.07	10.23		7.74	71	4.2	0.46
	17.1	10.01		7.82	51	4.1	0.45
	17.55	9.82		7.77	23	4.1	0.45
	18.05	9.82		7.77	14	4.1	0.46
	18.57	9.8		7.74	10	4.1	0.46
	18.98	9.78		7.71	7	4.2	0.46

Appendix I:

B. Tables of raw Hydrolab profiles.

Date/	Dep25	Temp	PAR		ORP	LDO%	LDO
Time	meters	[°C]	[µE/s/m²]	pH	[mV]	[Sat]	[mg/l]

7/26/23	1.19	24.81	1335	8.51	423	114.7	9.56
12:17 hr	2.12	24.8	714	8.45	423	115	9.57
	3.12	24.7	391	8.45	422	114.5	9.56
	3.11	24.68	429	8.45	421	113.8	9.51
	3.47	24.67	299	8.46	420	113.5	9.48
	4.02	24.61	224	8.43	420	111.7	9.34
	5	24.29	149	8.4	421	105.8	8.9
	6.01	21.73	80	8.02	438	40.4	3.56
	6.1	21.83	70	7.91	440	38.5	3.39
	7.09	17.37	44	7.84	444	18.5	1.78
	7.17	17.5	40	7.74	444	18.4	1.77
	8.12	15.28	25	7.6	446	9.1	0.91
	9.07	13.96	17	7.61	447	5.2	0.54
	10.01	13.06	12	7.58	448	4.4	0.46
	11.02	12.53	9	7.52	448	4.7	0.5
	10.99	12.53	9	7.4	448	4.7	0.5
	12.05	12.13		7.57	422	4.5	0.49
	13.06	11.69		7.45	407	4.2	0.46
	14.17	11.34		7.46	405	4	0.44
	15.15	10.76		7.39	185	4	0.44
	15.13	10.76		7.42	174	4	0.45
	16.27	10.04		7.49	63	4	0.46
	16.31	10.04		7.46	36	4.1	0.47
	16.97	9.93		7.63	24	4	0.46
	17.51	9.9		7.47	19	4	0.46
	17.93	9.8		7.54	5	4	0.46

Appendix I:
B. Tables of raw Hydrolab profiles.

Date/ Time	Dep25 meters	Temp [°C]	PAR [µE/s/m²]	pH	ORP [mV]	LDO% [Sat]	LDO [mg/l]
8/2/23	0.96	23.96	1256	8.71	412	--	--
11:34 hr	1.99	23.93	779	8.67	410	--	--
	2	23.93	830	8.67	410	--	--
	3.08	23.9	543	8.68	407	--	--
	3.44	23.9	420	8.64	407	108.8	9.23
	4.15	23.8	318	8.61	407	107.5	9.13
	5.07	23.72	206	8.6	407	106	9.02
	5.96	23.62	130	8.58	407	105.5	8.99
	6.61	23.54	91	8.55	407	101.7	8.68
	7.13	22.01	73	8.25	423	40.2	3.53
	7.99	17.09	47	8.14	430	7	0.68
	9.07	14.71	26	7.98	383	4.6	0.47
	9.99	13.23	19	7.97	306	4.5	0.47
	11	12.53	13	7.93	225	4.3	0.47
	12.06	12.27		7.91	102	4.3	0.46
	13.04	12.06		7.86	97	4.3	0.46
	13.96	11.73		7.83	85	4.2	0.46
	14.02	11.73		7.85	84	4.2	0.46
	14.97	11.29		7.83	59	4.2	0.46
	16.01	10.64		7.79	31	4.2	0.47
	16.92	10.39		7.76	20	4.2	0.47
	17.43	10.31		7.77	14	4.1	0.46
	17.91	10.14		7.76	7	4.2	0.47

Appendix I:

B. Tables of raw Hydrolab profiles.

Date/ Time	Dep25 meters	Temp [°C]	PAR [µE/s/m²]	pH	ORP [mV]	LDO% [Sat]	LDO [mg/l]
8/9/23	0.56	23.96	1,781	8.19	384	95.9	8.08
11:12 hr	1.08	23.71	1,332	8.17	385	94.8	8.02
	2.02	23.61	709	8.14	385	94.1	7.98
	3.05	23.56	483	8.11	386	93.5	7.93
	4.02	23.55	274	8.1	386	92	7.81
	5.05	23.53	170	8.09	387	91.7	7.78
	5.5	23.53	137	8.09	386	91.5	7.77
	5.99	23.52	108	8.09	387	91.1	7.74
	6.49	23.46	88	8.06	387	89.3	7.59
	7	23.15	72	7.91	392	64.2	5.49
	7.52	21.17	58	7.73	399	26.1	2.32
	8.06	19.25	46	7.63	404	4	0.37
	8.99	15.47		7.54	407	2.6	0.26
	10	13.66		7.46	228	2.5	0.26
	11.03	13.07		7.38	178	2.6	0.27
	12.03	12.6		7.33	146	2.6	0.27
	13.02	12.18		7.31	133	2.6	0.28
	14.04	11.64		7.27	103	2.6	0.28
	15	11.14		7.28	82	2.6	0.29
	15.98	10.63		7.21	31	2.7	0.3
	17.05	10.36		7.21	19	2.7	0.3
	17.98	10.07		7.22	7	2.9	0.32
	19.08	9.97		7.22	4	2.7	0.31

Appendix I:
B. Tables of raw Hydrolab profiles.

Date/ Time	Dep25 meters	Temp [°C]	PAR [µE/s/m²]	pH	ORP [mV]	LDO% [Sat]	LDO [mg/l]
8/16/23	1.04	23.67		8.5	398	97.2	8.25
11:08 hr	2.02	23.59	No data	8.48	399	98.5	8.38
	2.99	23.56		8.44	400	98.7	8.4
	4.63	23.52		8.42	401	97.7	8.32
	5.01	23.47		8.38	402	97.3	8.3
	5.99	23.45		8.38	402	96.9	8.26
	6.49	23.44		8.36	402	96.5	8.23
	7.01	23.4		8.34	403	95.1	8.12
	7.51	22.24		8.09	410	41.8	3.65
	8	18.8		7.93	416	6.1	0.57
	8.98	15.75		7.77	351	2.5	0.25
	10.02	13.43		7.72	308	2.5	0.27
	10.99	13		7.68	183	2.6	0.27
	11.95	12.63		7.64	156	2.6	0.28
	13.01	12.28		7.59	153	2.6	0.28
	13.97	12		7.63	153	2.6	0.28
	14.15	12.01		7.58	152	2.6	0.28
	15.01	11.58		7.65	97	2.6	0.29
	15.99	11		7.5	67	2.7	0.3
	15.96	11.01		7.54	66	2.7	0.3
	17.01	10.5		7.51	53	2.7	0.31
	17.54	10.23		7.51	43	2.7	0.31
	17.98	10.08		7.49	34	2.7	0.3

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Date/ Time	Dep25 meters	Temp [°C]	PAR [µE/s/m²]	pH	ORP [mV]	LDO% [Sat]	LDO [mg/l]
8/23/23	1.08	22.92	511	8.32	290	105.3	9.07
11:15 hr	2.02	22.93	366	8.34	294	105.3	9.06
	2.97	22.91	245	8.34	297	104.9	9.04
	4.03	22.87	153	8.34	300	104.1	8.97
	5.01	22.84	90	8.35	304	103.7	8.95
	6.03	22.78	73	8.35	306	103.2	8.91
	6.92	22.7	36	8.33	309	100.1	8.66
	8.02	20.86	25	8.04	319	32.1	2.88
	8.52	18.79	19	7.89	322	10.8	1.01
	9.14	16.55		7.82	328	3	0.29
	9.53	14.93		7.71	308	2.6	0.26
	10.06	13.92		7.63	233	2.6	0.27
	10.56	13.41		7.62	210	2.6	0.27
	11.07	13.12		7.59	186	2.6	0.27
	12.03	12.76		7.56	172	2.6	0.28
	13	12.38		7.56	171	2.6	0.27
	13.97	11.89		7.57	164	2.7	0.29
	14.98	11.23		7.52	140	2.7	0.3
	15.98	10.59		7.5	113	2.8	0.31
	15.97	10.58		7.48	85	2.7	0.31
	16.93	10.27		7.45	53	2.7	0.3
	17.52	10.12		7.44	47	2.7	0.3

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Date/ Time	Dep25 meters	Temp [°C]	PAR [µE/s/m²]	pH	ORP [mV]	LDO% [Sat]	LDO [mg/l]
9/1/23	1.09	23.09	958	8.53	396	103.8	8.92
15:44 hr	1.04	23.16	762	8.51	396	104.1	8.92
	2.02	22.56	635	8.49	397	104	9.02
	2.91	22.38	429	8.46	397	104.9	9.13
	2.89	22.38	514	8.47	397	105	9.14
	3.97	22.26	258	8.43	397	103.4	9.02
	5	22.16	163	8.41	399	101.4	8.86
	5.76	22.15	115	8.38	399	100	8.74
	6.99	22.14	66	8.36	400	98.6	8.62
	8	20.21	42	8.01	417	21.8	1.98
	8.05	20.22	41	8.02	417	21.7	1.97
	8.64	18.55	30	7.91	420	11.1	1.04
	9.03	17.3	24	7.79	424	3.4	0.33
	10.05	14.45		7.67	425	2.6	0.27
	11	13.48		7.66	344	2.5	0.26
	12.03	12.77		7.6	235	2.6	0.27
	12.03	12.77		7.61	231	2.6	0.27
	13.05	12.2		7.58	159	2.5	0.27
	14.05	11.91		7.55	95	2.5	0.27
	15.03	11.57		7.48	73	2.6	0.28
	16.02	10.94		7.42	49	2.6	0.29
	17.04	10.54		7.37	37	2.7	0.3
	17.05	10.54		7.37	37	2.7	0.3
	18.02	10.13		7.37	26	2.7	0.31

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B. Tables of raw Hydrolab profiles.

Date/ Time	Dep25 meters	Temp [°C]	PAR [µE/s/m²]	pH	ORP [mV]	LDO% [Sat]	LDO [mg/l]
9/14/23	0.54	22.3	1,469	8.51	424		
14:45 hr	1.02	22.3	1,542	8.47	423		
	2.03	22.3	908	8.45	424	102.9	9.01
	3.01	22.27	597	8.42	424	103.2	9.03
	4.13	22.27	275	8.4	425	103	9.02
	5.02	22.25	102	8.4	425	103	9.03
	5.98	22.23	142	8.4	425	102.5	8.99
	6.98	22.22	88	8.4	425	100.8	8.83
	8.01	21.85	28	8.18	432	59.8	5.28
	9.07	18.45	35	7.86	446	3.5	0.33
	9.99	16.15	21	7.79	451	2.7	0.27
	11.1	14.07	11	7.76	448	2.8	0.29
	11.92	13.33		7.72	428	2.7	0.28
	13.17	12.77		7.67	378	2.6	0.28
	14.13	12.15		7.64	139	2.6	0.28
	15.27	11.38		7.57	112	2.7	0.29
	16.12	10.94		7.54	70	2.7	0.3
	16.96	10.3		7.46	46	2.8	0.31
	17.49	10.21		7.45	36	2.7	0.31