AQUATIC ECOSYSTEM RESEARCH
A Freshwater Conservation Company

Ball Pond

2022 Water Quality Monitoring

Prepared for the
Ball Pond Advisory Commission
New Fairfield, CT
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EXECUTIVE SUMMARY

Aquatic Ecosystem Research (AER) was engaged by the Ball Pond Advisory Committee (BPAC) to assess water quality during the 2022 season. Data and water sample collections occurred on April 20th, May 18th, June 15th, July 20th, August 17th, September 14th, and October 12th. A summary of data collected and our assessment are provided below. AER was also requested to compile and report on data collected in a cyanotoxin monitoring program. Dates of those sampling events and our assessment are provided within. Recommendations are provided at the end of the report.

- Ball Pond was stratified on each sampling date.
    - Relative resistance to mixing was strong (RTRM>80) on each sampling date after April 20th.
    - Hypolimnetic oxygen concentrations were already notably lower than epilimnetic concentrations on April 20th.
        - Oxygen concentrations of <1 mg/L were first observed on May 18th from 8 meters of depth to the bottom.
        - Oxygen concentrations of <1 mg/L were observed from 6 meters of depth to the bottom from June 15th through September 14th, and from 9 meters of depth to the bottom on October 12th.

- Ball Pond's epilimnetic trophic characteristics were largely characteristics of a mesotrophic to late mesotrophic lake.
    - Average summer Secchi transparency were characteristic of late mesotrophic conditions
        - Secchi disk transparency increased (improved) over the course of the season.
    - Average chlorophyll-a concentrations were characteristic of mesotrophic conditions.
        - Chlorophyll-a concentrations decreased from the early part of the season to the late season.
    - Epilimnetic total phosphorus concentrations varied from levels characteristic of oligotrophic lakes to that characteristic of eutrophic lakes.
        - The epilimnetic and metalimnetic season averages were relatively low and within the range characteristic of oligotrophic lakes.
        - The average hypolimnetic total phosphorus concentration was significantly higher and increased with each passing sampling date.
    - Total nitrogen levels in the epilimnion and metalimnion were within ranges characteristic of early mesotrophic to mesotrophic lakes.
        - Concentrations in the hypolimnion were greater.
            - Total nitrogen concentrations also increased with time.
            - Much of the hypolimnetic total nitrogen was in the form of ammonia.

- Specific conductance levels varied with time and depth.
    - In the epilimnion and hypolimnion, levels increased with time.
        - The season epilimnetic maxima occurred on August 17th.

        - The season hypolimnetic maxima occurred on October 12th.
    - The metalimnetic specific conductance was less variable and appeared not to be influenced by changes in the strata above and below.

- Base cations, chloride, and the alkalinity ions were measured in epilimnetic samples.
    - On a milliequivalent basis, sodium and chloride were the most prevalent.

- The algae and cyanobacteria community varied based on habitat.
    - The concentrations near the surface at the deep-water site were generally low.
        - Cyanobacteria was the dominant taxon in the first part of the season, became less dominant in the latter half of the season.
        - Highest cyanobacteria biomass levels based on relative phycocyanin concentrations were between the thermocline and lower metalimnetic boundary and were dominated by the cyanobacteria *Planktothrix spp*.
    - Shoreline blooms were common and dominated by the cyanobacteria *Woronichinia spp*.
    - A robust benthic cyanobacteria mat was found throughout the littoral zone and dominated by the cyanobacteria *Lyngbya spp*.
    - Several types of cyanotoxins were measured during the season.
        - Microcystins were measured weekly for much of the summer at Hahlawah Beach and were always within acceptable levels based on Connecticut State standards.
        - Saxitoxin was measured in a sample collected on August 14th from the benthic mat and found to exceed the acceptable level based on the State of Ohio standards (Connecticut does not have a standard).

- Key findings from the 2022 monitoring and comparison with historical data included:
    - Sodium and chloride concentrations in epilimnetic samples have increased by approximately 80% since 1993.
        - Average specific conductance and averaged, combined ion concentrations have increased by 46% and 49%, respectively since 1993.
    - Ball Pond was stratified by the April sampling date in the last two seasons.
        - Phosphorus concentrations in the hypolimnion were elevated by May 18th and increased with time
        - Other hypolimnetic loading indicators, e.g., increasing alkalinity and ammonia, reinforced the idea of internal nutrient loading being an important factor in the lake's ecology.
    - Elevated hypolimnetic phosphorus and stratification characteristics are likely important variables with regards to the high cyanobacteria biomass below the thermocline.
    - The trophic indicators of Secchi disk transparency and chlorophyll-*a* concentration indicated that algal productivity decrease during the season,

despite higher epilimnetic phosphorus concentrations measured in the latter part of the season.

Recommendations are provided at the end of the report.

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INTRODUCTION

Ball Pond is an 89-acre natural kettle lake located in New Fairfield, CT (Canavan and Siver 1995, Frink and Norvell 1984). The lake's origins are glacial in nature and a result of the retreat of the Laurentide Ice Sheet some *ca* 10,000 to 12,000 years before present. Ball Pond is now an important ecological, economic, and recreational asset to the Town of New Fairfield. Stewardship of the lake is largely led by the Town's Ball Pond Advisory Committee (BPAC) and by the Friends of Ball Pond, a not-for-profit advocacy organization. The Connecticut Department of Energy and Environmental Protection maintains a public boat ramp on the lake, annually stocks the lake with trout (Jacobs and O'Donnell 2004), and performs other environmental services (e.g., fish surveys).

Ball Pond is largely spring or groundwater fed, but also receives some stormwater runoff from its watershed (Fig. 1). Based on Connecticut's Water Quality Standards, Ball Pond is classified as AA. This designation allows for existing or proposed drinking water supplies, habitat for fish and other aquatic life and wildlife, recreation, and water supply for industry/agriculture (NFPC 2014). The lake has a maximum depth of 51 feet (15.4 meters) and a mean depth of 24 ft (7.3 meters).

The 245-acre watershed is relatively small and has been reported to be within the Connecticut Marble Valley geological formation, which is largely metamorphosed calcium carbonate (Canavan and Siver 1995, Jacobs and O'Donnell 2002). Local experts have also described the bedrock as metamorphic but of a granitic composition, over a billion years old, and with possible influences of glacial erratics that may potentially provide the carbonate influences to the system (J. Mellett, personal communication, December 4, 2021).

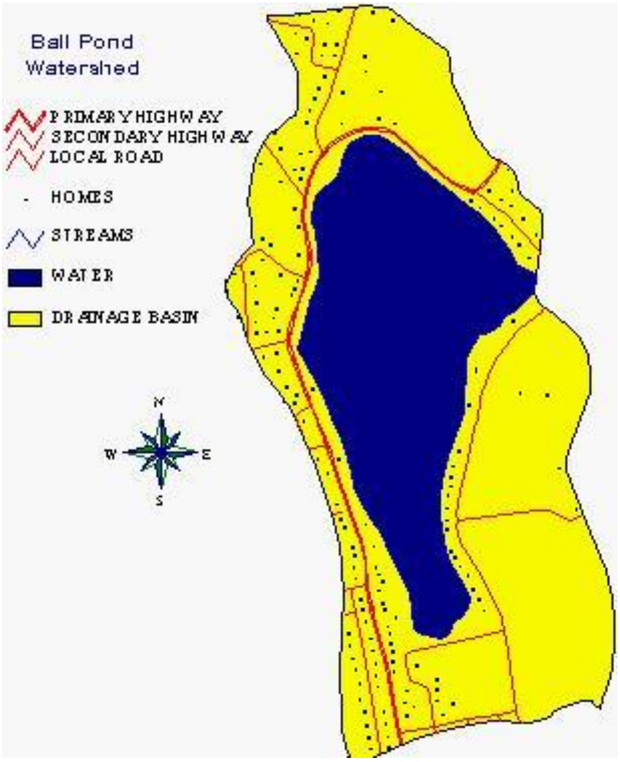

Figure 1. Map of Ball Pond and its watershed (drainage basin). Homes are based on a 1984 map. Image is from the Connecticut College Silica Secchi Disk database (http://fmp.conncoll.edu/Silicasecchidisk/Connecticut_Lakes_Frameset_New.html).

An analyses of historical land cover in the Ball Pond watershed (Field et.al. 1996) is presented in Table 1. In summary, changes in the watershed between 1934 to 1990 included an overall increase in wooded/forested and residential cover at the expense of the agricultural cover that – in 1934 – accounted for over half of the watershed area. Field et. al. also applied empirical models developed for lakes in Connecticut to estimate total phosphorus (Norvell et. al. 1979) and total nitrogen (Frink 1991) concentrations in the lake based on land cover. Those estimated levels for 1934, 1970, and 1990 are also included in Table 1. Jacobs and O'Donnell (2004) more recently described the watershed as mostly residential.

Table 1. Percent of residential, agricultural, wooded (aka forested), and water (including the lake) coverages of the Ball Pond watershed. Also provided are estimated total phosphorus (*e*TP) and estimated total nitrogen (*e*TN) levels predicted from land cover.

Year	Residential (%)	Agriculture (%)	Wooded (%)	Water (%)	*e*TP (µg/L)	*e*TN (µg/L)
1934	4	52	9	35	15	417
1970	25	18	24	33	25	506
1990	37	15	15	33	32	600

In addition to the Field et.al. study, Ball Pond has been included in several state-wide surveys of Connecticut lakes (Deevey 1940, Frink & Norvell 1984, Canavan and Siver 1994, 1995). Siver et.al. (1996) summarized historical changes in 42 lakes, including Ball Pond, using data from those surveys. That study revealed that the average Ball Pond Secchi disk transparency in the lake decreased by 0.1 meter (m) between the 1930s and the early 1990's. Total phosphorus levels increased by 28µg/L between 1934 and the early 1990s, with 19µg/L of that increase occurring since the early 1970s. Canavan and Siver (1995) described Ball Pond as late mesotrophic to eutrophic with total phosphorus levels similar to those of Bantam Lake and Lake Waramaug.

METHODS

A water quality monitoring plan was supported by the Town of New Fairfield and the BPAC, which included having Aquatic Ecosystems Research, LLC (AER) collect field data and water samples at Ball Pond between the months of April and October. The sampling dates were April 20th, May 18th, June 15th, July 20th, August 17th, September 14th, and October 12th. Monthly sampling consisted of visiting one deep water site (41.46286071, -73.52371949; Fig. 2) where the following field data were collected:

- Site maximum depth measured in meters with a weighted field tape
- Secchi disk transparency measured in meters (m) with a standard 20cm Secchi disk

- Temperature (°C), dissolved oxygen (mg/L), percent oxygen saturation (%), specific conductance (µS/cm), pH (SU), oxidation-reduction potential (mV), and relative phycocyanin concentration (µg/L) were measured at 0.5m below the surface, and at each meter from 1m to 15m of depth with a Eureka Manta Multiprobe II.

Water samples were collected with a horizontal Van Dorn water sampler at 1m below the surface (epilimnion), and at approximately 0.5m above the sediment-water interface (hypolimnion). Additional intermediate depth (metalimnion) samples were collected at the approximate depth of the thermocline (see below). Samples were kept at approximately 3°C in an ice-filled cooler and – later the same day – delivered to York Analytical Laboratories, a Connecticut State-certified laboratory located in Newtown, CT. Concentrations of total phosphorus, total Kjeldahl nitrogen, nitrite, nitrate, ammonia, and alkalinity were analytically determined. Epilimnetic samples were also tested for base cations and anions. Those were sodium, potassium, calcium, magnesium, and chloride.

Samples were also collected to evaluate chlorophyll-*a* concentrations and phytoplankton community structure and cell concentrations. For those samples, a weighted tube sampler was used to collect an integrated sample of the top three meters of the water column; those samples were also stored at 3°C. Chlorophyll-*a* analyses were performed by York Analytical Laboratories.

Lugol's solution was added to samples collected for algae cell counts for preservation; those were treated with hydrostatic pressure to the collapse the gas vesicles within the cyanobacteria cells (Lawton et al. 1999). Known volumes of the preserved samples were concentrated into smaller volumes with centrifugation and a vacuum pump/filtration flask system. Portions of those concentrates were transferred to a counting chamber. Genus-level algal cell enumerations were then performed by counting cells in a subset of the chamber's fields using an inverted Nikon Diaphot research microscope; those counts were then corrected to be reflective of the whole water samples.

For a qualitative assessment of the entire pelagic zone's phytoplankton community, a 10µm mesh plankton net was used to collect a concentrated algae sample in the field from the top three meters of the water column. Portions of that concentrated sample were analyzed microscopically to establish qualitative genus lists before preservation with Lugol's solution.

Water temperature data were utilized to determine thermal resistance to mixing scores, which were used to determine the position of the metalimnion and characterize the strength of the thermocline. Resistance to mixing, which is an assessment of the ability of two different water volumes – that differ in temperature and density – to mix, was calculated using the Relative Thermal Resistance to Mixing (RTRM) formula: $(D_1 – D_2)/(D' – D^o)$, where D_1 is the density of upper water volume, D_2 is the density of the lower water volume, D' is the density of water at 5°C, and D^o is the density of water at 4°C. RTRM scores of <30 mean that layers are mixed; scores of ≥ 30 between strata are characteristic of the transitional metalimnion layer. RTRM scores of ≥80 between strata characterizes strong resistance to mixing (Siver et.al. 2018).

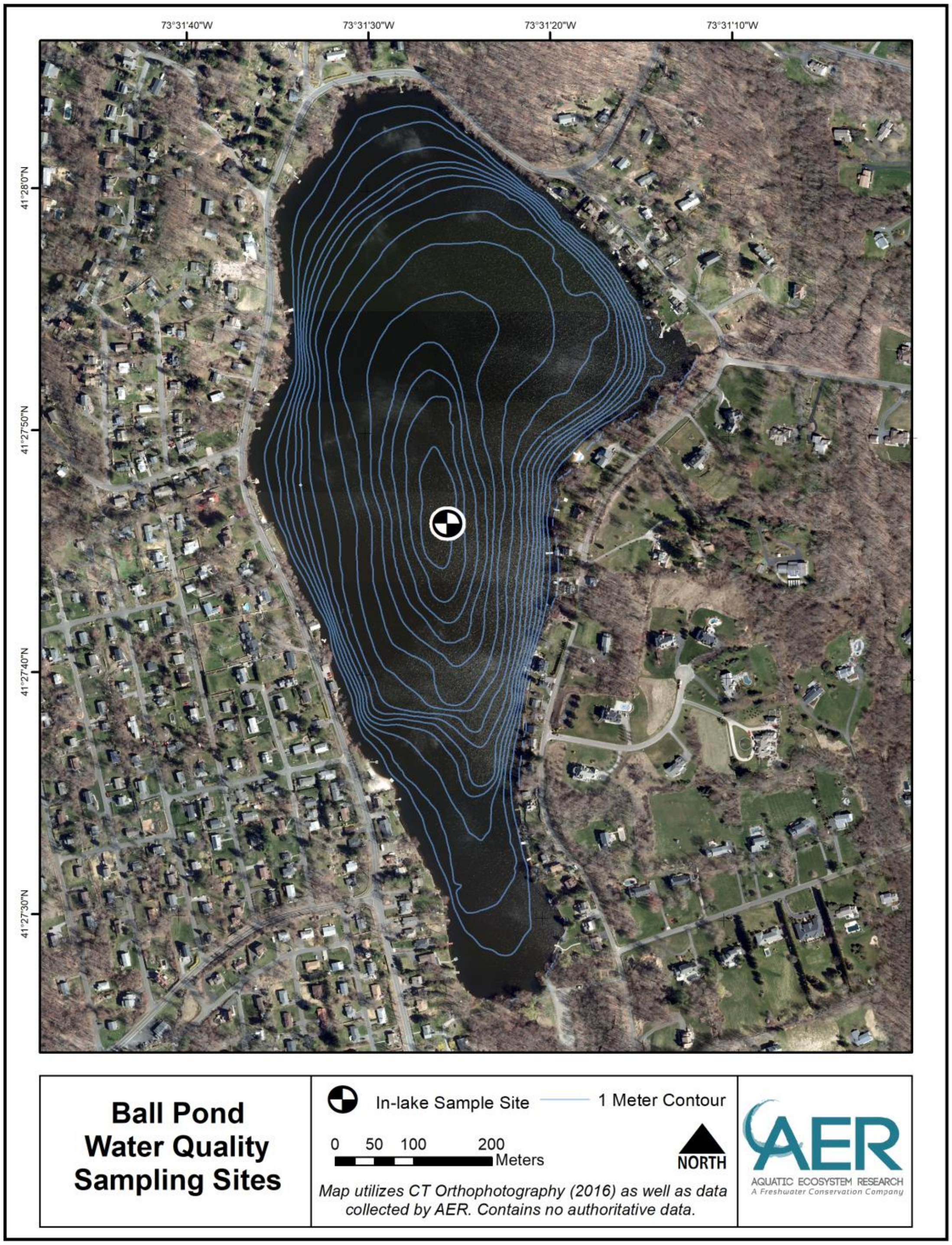

Figure 2. Location of the deep-water sampling site on Ball Pond during the 2022 season.

PROFILE DATA

Water quality variables measured throughout the water column are provided in Appendix A. We have displayed many of those data below in isopleth charts where a variable (e.g., temperature) was displayed as shades of colors throughout the water column at each depth and for all dates when data were collected. Values were then interpolated between depths and dates. Variables of the same value (and color) were connected between dates irrespective of depth to create a theoretical representation of dynamic changes throughout the water column over time.

Temperature and Oxygen

Water temperature data provided a view into the thermal characteristics of the lake and stratification patterns resulting from temperature/density differences between depths/strata. In shallow New England lakes or shallow sites in a deep lake, stratification can occur but it may be short in duration because wind energy has the potential to mix the water column. In deeper lakes or sites, stratification is not as easily broken down by wind energy.

When a lake is stratified, a middle transitional layer (aka metalimnion) separates the upper warmer layer (aka epilimnion) from lower colder waters below (aka hypolimnion). Within the boundaries of the metalimnion resides the thermocline, which is the stratum where the temperature/density change and resistance to mixing are the greatest with increasing depth. Stratified conditions will usually persist in deeper lakes or sites for the entire summer and into the fall until turnover mixes the water column.

An oxygen concentration of 5mg/L is generally considered the threshold that defines favorable conditions for most oxygen-requiring organisms in freshwater systems. As concentrations decrease below that threshold, conditions become stressful for many aquatic forms of life. Minimum oxygen requirements for fisheries in Connecticut's lakes range from 4 to 5mg/L for cold-water fish (e.g., trout), 2mg/L for cool-water fish (e.g., walleye), and 1 to 2mg/L for warm-water fish (e.g., bass and panfish; Jacobs and O'Donnell 2002).

The loss or absence of oxygen at the bottom of the water column modifies the chemical environment as compared to conditions when oxygen is present. These modifications result in the dissolution of compounds (e.g., iron phosphate) in the sediments to the interstitial waters and – then, by diffusion – to the waters above the sediments.

Water temperatures throughout the water column on April 20th were low. However, the water column was stratified with temperatures in the top 7 meters decreasing with depth from 9.5°C to 8.6°C (49°F to 47.5°F), and theoretically separated from the lower half of the water column by a thermocline situated between 7 and 8 meters of depth (Fig.3). Temperatures below the thermocline decreased from 7.2°C to 6.6°C (approximately 45°F to 44°F) at the bottom.

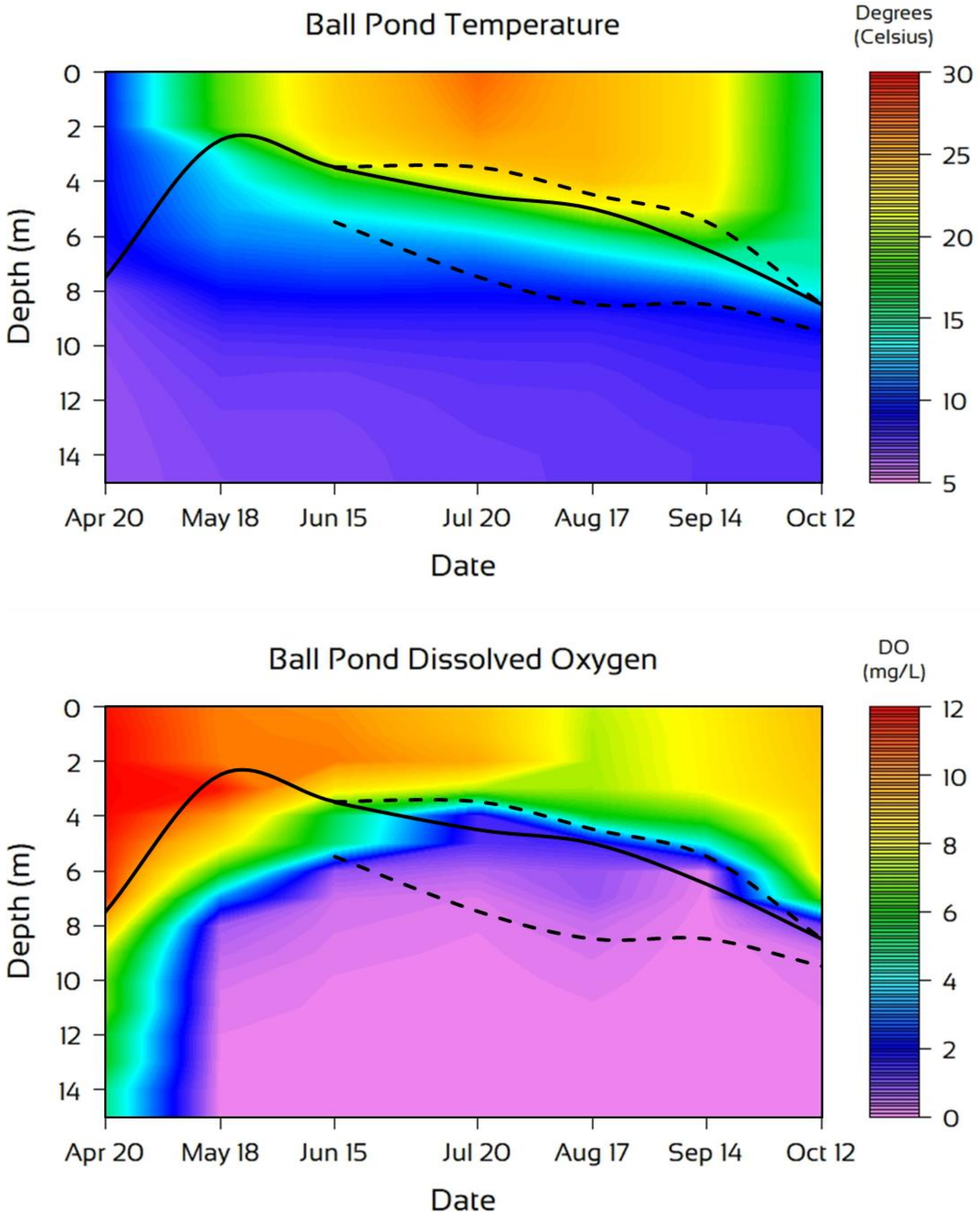

Figure 3. Isopleth plots of water column temperature (top panel) and dissolved oxygen (bottom panel) for Ball Pond in 2022. The dashed black line represents the upper and lower boundaries of the metalimnion; the solid black line represents the thermocline.

A distinct oxygen gradient was already observable in the April 20th water column (Fig 3). Oxygen concentrations above the thermocline were between 11 and 12 mg/L. Below the thermocline, concentrations decreased with depth from 9.4 to 5.0 mg/L.

Surface water temperatures were considerably warmer on May 18th, and modestly decreased from 18.8 to 18.6 in the top two meters of the water column. Between 2 and 3 meters of depth, where a thermocline with strong resistance to mixing (RTRM = 128) was detected, temperatures decreased by over 5°C. From 4 meters of depth to the bottom, temperatures decreased with depth from 13.5°C to 7°C.

Oxygen concentrations of 10 mg/L were recorded in the top four meters of the May 18th water column. From the five to seven-meter stratum, oxygen concentrations decreased with depth from 8.5 to 3.1 mg/L. Most notably, oxygen concentrations of <1 mg/L were recorded from 8m of depth to the bottom (Fig. 3).

Surface waters continued to warm over the next several months, with the recorded season maximum between 26.4°C and 27.4°C (79.5°F and 81.3°F) in the top two meters of the water column on July 20th. After July 20th, surface water temperatures gradually decreased. The volume and size of the epilimnion gradually increased as the thermocline was observed at deeper depths on successive sampling dates (Fig. 3).

On October 12th, the water column was still stratified and a thermocline with strong resistance to mixing (RTRM = 96) was observed between 8 and 9 meters of depth. Temperatures from the surface to 8m of depth decreased with depth from 15.5°C to 13.7°C. From the 9-meter stratum to the bottom, temperatures decreased from 9.9°C to 7.4°C.

Oxygen concentrations in waters above the thermocline or the upper metalimnetic boundary were always above 5mg/L and usually above 7mg/L with one exception. That occurred on October 12th when the concentration just above the thermocline, located between the 8- and 9-meter strata, was 1.1mg/L (Fig. 3). Oxygen concentrations of <1mg/L had extended upward from the bottom to 6 meters of depth by June 15th and persisted throughout those depths until October 12th when anoxic conditions were observed from 9m of depth to the bottom.

TROPHIC LEVEL

Much of the data collected in 2022 were used to assess the trophic state of Ball Pond. A lake's trophic state is a determination of the level of productivity the lake can support. It is assessed by examining the variables that limit or are related to algal productivity (e.g., phosphorus concentrations, Secchi transparencies, chlorophyll-*a* concentrations, etc.). Lakes supporting very little productivity are typically very clear; they are called oligotrophic lakes. Lakes supporting high levels of productivity are more turbid and termed eutrophic or highly eutrophic. It is common that eutrophic or highly eutrophic lakes experience algal blooms. Table 1 lists the criteria used to categorize the trophic state of a lake.

Table 1. Trophic classification criteria used by the Connecticut Experimental Agricultural Station (Frink and Norvell, 1984) and the CT DEP (1991) to assess the trophic status of Connecticut lakes. The categories range from oligotrophic or least productive to highly eutrophic or most productive.

Trophic Category	Total Phosphorus (µg / L)	Total Nitrogen (µg / L)	Summer Chlorophyll-*a* (µg / L)	Summer Secchi Disk Transparency (m)
Oligotrophic	0 - 10	0 - 200	0 - 2	>6
Early Mesotrophic	10 - 15	200 - 300	2 - 5	4 - 6
Mesotrophic	15 - 25	300 - 500	5 - 10	3 - 4
Late Mesotrophic	25 - 30	500 - 600	10 - 15	2 - 3
Eutrophic	30 - 50	600 - 1000	15 - 30	1 - 2
Highly Eutrophic	> 50	> 1000	> 30	0 - 1

Secchi Transparency

Secchi disk transparency is a measure of how much light is transmitted through the water column. That transmission is influenced by a number of factors including the quantity or volume of inorganic and organic particulate material in the water column that absorbs or reflects light. Secchi disk transparency is inversely related to algal productivity, i.e., the more algal growth, the less Secchi transparency will be, and vice versa.

Light in lakes is important for several reasons including its impact on open water photosynthesis and algal productivity. As light diminishes with depth, so too does maximum photosynthetic potential. As photosynthetic potential decreases, a depth is reached where oxygen produced in algal photosynthesis is equaled to the oxygen consumed via algal cellular respiration. That depth is referred to as the *Compensation Depth*; it is commonly estimated by multiplying the Secchi disk transparency by two. The *Compensation Depth* has been associated with the depth of maximum concentration and growth stimulation of cyanobacteria (aka, blue-green algae).

In 2022, Secchi transparencies were lower from April 20th through July 20th, and higher from August 17th to October 12th (Fig. 4).

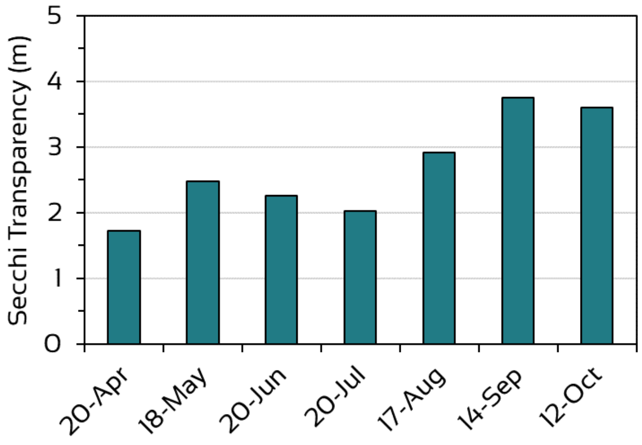

Figure 4. Secchi disk transparency at the deep-water site on Ball Pond during the 2022 season.

The season low occurred on April 20th and was 1.72 meter. Season highs of 3.75 and 3.60 meters occurred on September 14th and October 12th, respectively. The average for the season was 2.68 meters which is characteristic of late-mesotrophic algal productivity. A June – September average (summer months) average was 2.74 meters and was also reflective of late-mesotrophic conditions.

Chlorophyll-a Concentration

Chlorophyll-*a* is the photosynthetic pigment common to all freshwater algae, including cyanobacteria and is used as a surrogate measurement for algal biovolume in the water. Samples analyzed were integrations of the top three meters of the water column where photosynthetic potential was greatest.

Chlorophyll-*a* concentrations were seasonably variable, with a high of 13.5 µg/L on June 20th, and a season lows of 1.6 and 3.1 µg/L on August 17th and September 14th, respectfully (Fig. 5).

The season average was 6.75 µg/L, while the summer month average was 6.55 µg/L. Both were indicative of mesotrophic algal productivity (Table 1). It is worth noting that the season lows on August 17th and September 14th were characteristic of oligotrophic and early-mesotrophic algal biovolumes, respectively.

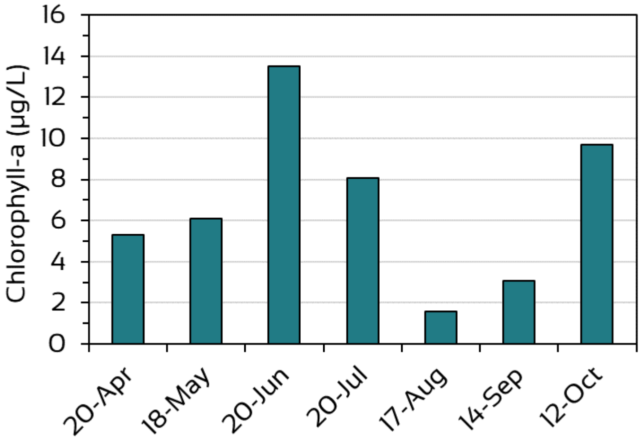

Figure 5. Chlorophyll-*a* concentrations measured in Ball Pond in 2022.

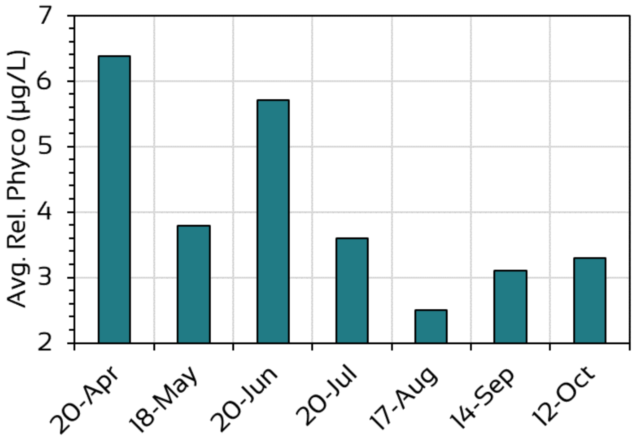

Figure 6. Top 3-meter averaged relative phycocyanin concentrations measure in Ball Pond in 2022.

Relative Phycocyanin Concentrations

Phycocyanin is an auxiliary photosynthetic pigment unique to the cyanobacteria (aka Cyanophyta or blue-green algae). Relative concentrations were measured throughout the water column with a fluorimeter incorporated into the sensor array of the Eureka Manta II multiprobe. Fluorimeters work on the principal that a particular substance fluoresces at a specific wavelength when light of another wavelength is directed on that substance. The fluorimeter in AER's instrumentation emits a wavelength that interacts with phycocyanin. This sensor is not calibrated with known concentrations of phycocyanin so measurements are not quantitative; instead the measurements are relative to other measurements in the water column and to measurements on other dates. AER averaged the relative phycocyanin concentrations in the top three meters of the water column on each date to use as an indicator of cyanobacteria biovolume and productivity (Fig. 6).

Highest average relative concentrations were measured on April 20th and June 20th at 6.4 and 5.7 µg/L, respectively. The lowest average concentration occurred on August 17th and was 2.5 µg/L. All other average relative concentrations were between 3 and 4 µg/L.

Nutrient Level

Nutrient data, including total phosphorus and those nutrients associated with total nitrogen (e.g., total Kjeldahl nitrogen, nitrate, nitrite) are important for understanding the trophic status of a lake. For many years, AER received high quality data from the State-certified laboratory HydroTechnologies, LLC located in New Milford, CT. Most of the historical Ball Pond data in samples collected by other Limnologists before AER were from analyses conducted by the same lab.

HydroTechnologies applied minimum detection limits (MDLs) and reporting limits (RLs) for lake monitoring projects that were consistent and appropriate for Limnological assessments. For other clients, HydroTechnologies appropriately applied MDLs that were not as low, e.g., and instead used for wastewater treatment facility clients, because levels are much higher in those types of samples. In late 2021, HydroTechnologies was purchased by Pace Analytical Laboratory, a New York-based company. By May of 2022, Pace Analytical stopped receiving walk-in samples at the New Milford facility. Additionally, Pace Analytical utilized MDLs and RLs that were not consistent with lake-related studies.

Prior to May sampling events, AER switched its commercial laboratory to Aqua Environmental Laboratory in Newtown, CT, a subsidiary of York Analytical Laboratory. This occurred following discussions between AER and Aqua Environmental on MDLs and RLs. Despite those discussions, consistent and appropriate MDLs and RLs were not always used. We communicated with Aqua Environmental throughout the season the need to retest or recalculate nutrient levels when possible, using appropriate MDLs and RLs.

Aqua Environmental was able to lower its MDL and RL for total phosphorus for this study to 10 µg/L, which is the level delineating oligotrophic phosphorus levels from early-mesotrophic phosphorus levels (Table 1). For total Kjeldahl nitrogen, which is an important constituent of total nitrogen, the MDL was 600 µg/L which is the lower limit of eutrophic levels. MDLs of 50 and 100 µg/L have been used for ammonia, and 50 µg/L was used for nitrate and nitrite.

Total Phosphorus

Algae and cyanobacteria require a variety of macro and micronutrients for growth. The nutrient that is least available in proportion to algal requirements is termed the *limiting nutrient*; in freshwater systems, that nutrient is usually phosphorus. It is the *limiting nutrient* because the amount of available phosphorus will limit the productivity of the algal community. In most Limnological studies, total phosphorus is measured, which is the sum of particulate and dissolved forms of phosphorus.

Total phosphorus was measured in samples collected at 1 of depth, near the thermocline, and approximately 0.5 to 1 meter from the bottom (epilimnion, metalimnion, and hypolimnion, respectively). In cases where phosphorus was reported as <10 µg/L (the equivalent of 0.01 mg/L), 10 µg/L was used for graphic representation, and assessments.

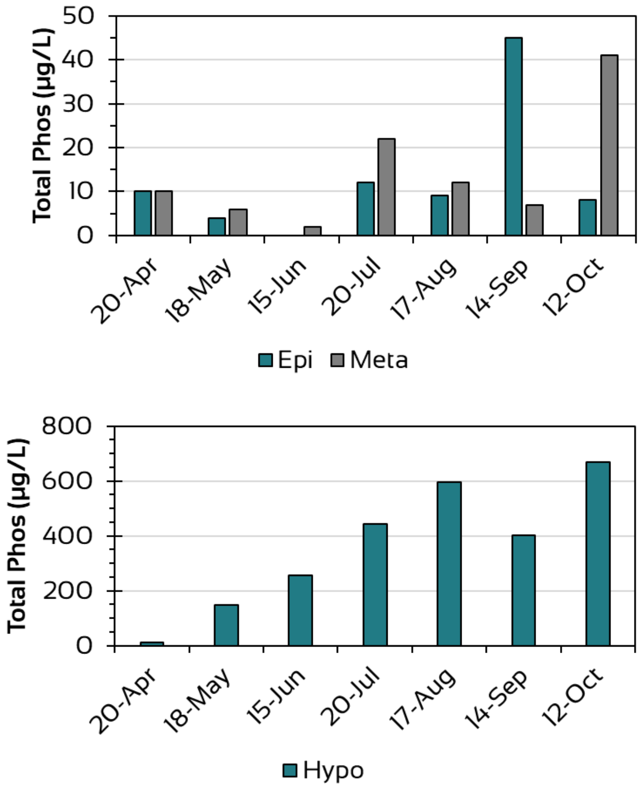

Figure 7. Total phosphorus (Phos.) concentrations in the epilimnion (Epi; top panel) and metalimnion (Meta; top panel) and hypolimnion (Hypo; bottom panel) measured in Ball Pond in the 2021 season.

The MDL used by Pace Analytical Laboratory for April 20th total phosphorus was 100 µg/L which is unsuitable for Limnological studies. As noted earlier, the MDL used by Aqua Environmental was 10 µg/L. May 18th and June 15th levels in the epilimnion and metalimnion were all <10 µg/L. However, concentrations near the bottom were elevated at 148 to 257 µg/L, on the respective dates (Fig. 7).

Concentrations in the hypolimnion continued to increase reaching 596 µg/L by August 17th. After decreasing some by September 14th, concentration reached their maximum level of 668 µg/L by October 12th. Concentrations in the epilimnion and metalimnion were much less variable and mostly ≤10 µg/L with some exceptions, e.g., 22 µg/L in the metalimnetic sample collected on July 20th, and 45 µg/L in the epilimnetic sample collected on September 14th.

The season averages for the epilimnetic, metalimnetic, and hypolimnetic samples were calculated by using 10 µg/L for any concentration reported as <10 µg/L. The respective season averages were 15, 12, and 360 µg/L, respectively. The epilimnetic and metalimnetic averages could support early mesotrophic to mesotrophic algal productivity, while the hypolimnetic average would support highly eutrophic productivity.

Nitrogen

Nitrogen is typically the second most limiting nutrient for algae growth in freshwater systems. It can be present in several forms in lake water. Ammonia – a reduced form of nitrogen – is important because it can affect the productivity, diversity, and dynamics of the algal and plant communities. Ammonia can be indicative of internal nutrient loading since bacteria will utilize other forms of nitrogen (e.g., nitrite and nitrate) in lieu of oxygen for cellular respiration under anoxic conditions, resulting in ammonia enrichment of the hypolimnion.

Total Kjeldahl nitrogen (TKN) is a measure of the reduced forms of nitrogen (including ammonia) and total organic proteins in the water column. Since TKN accounts for

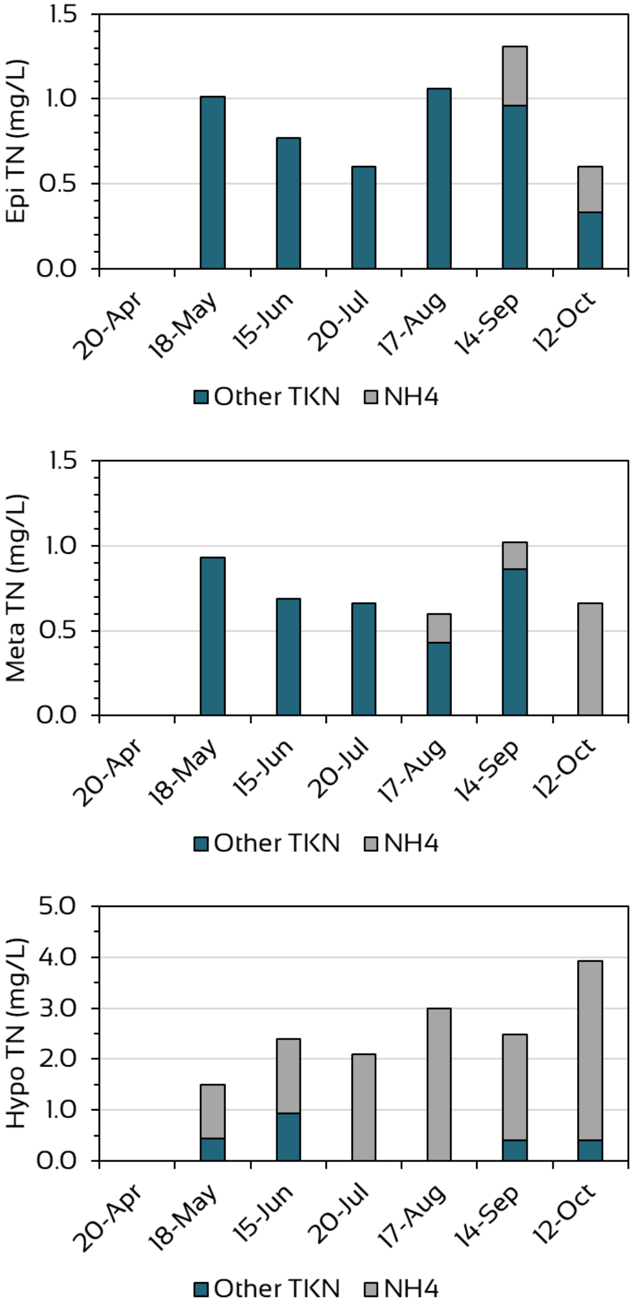

Figure 8. Total nitrogen (TN) concentrations in the epilimnion (top panel), metalimnion (middle panel) and hypolimnion (bottom panel) of Ball Pond in 2022. Total nitrogen is separated into ammonia (NH4), and other TKN. TKN data was not used for April 20th data due to the high minimum detection limit used for those samples. Note that the scale for hypolimnetic concentrations is over three times greater than the epilimnetic and metalimnetic scales.

biologically derived nitrogen-rich proteins in the water column, it is useful in assessing the productivity of the open water system. Nitrate and nitrite are often below detectable levels in natural systems because they are quickly cycled by bacteria and aquatic plants. Total nitrogen is the sum of TKN, nitrate, and nitrite; since the latter two are often below detectable limits, TKN levels are often similar or equal to total nitrogen levels.

Pace Analytical reported the April 20th epilimnetic, metalimnetic, and hypolimnetic TKN as <1,000 µg/L (<1.00 mg/L). That minimum detection limit was very high and not useful for surface water studies; therefore, the data were not utilized in this study. The Aqua Environmental Laboratory MDL for TKN was 0.6 mg/L (600 µg/L), which is also high. However, much of the reported Ball Pond levels exceeded 600 µg/L. Where levels were reported as ND (not detected), AER used the MDL and indicated where that occurred below. We also note here that nitrate and nitrites were not detected. As noted above, this is common because of how quickly those nutrients are cycled.

Epilimnetic total nitrogen levels were generally high. The season average was 890 µg/L, and characteristic of eutrophic conditions (Table 1). The season low was 600 µg/L which was measured in the July 20th sample. It was also applied for the October 12th concentration since the lab reported levels below detectable levels. The highest epilimnetic concentration of 1,310 µg/L was measured in the September 14th sample. That concentration included 350 µg/L of ammonia, which was of two dates ammonia was detected in the epilimnion (Fig. 8). The other date was October 12th.

Metalimnetic total nitrogen concentrations were, on average, lower than epilimnetic concentrations (Fig. 8). The season average was 760 µg/L, and the season maximum, measured in the September 14th sample, was 1,020 µg/L. Detectable levels of ammonia were measured in metalimnetic samples collected on August 17th and September 14th, before all of the total nitrogen was in the form of ammonia on October 12th (Fig. 8).

For the entire season, hypolimnetic total nitrogen was mostly comprised of ammonia. Levels steadily increased from May 18th to October 12th (Fig. 8). The total nitrogen season average was 2,290 µg/L, and the season maximum, measured on October 12th, was 3,930 µg/L.

CHEMICAL CHARACTERISTICS

Specific Conductance and Ions

Conductivity is a surrogate measurement of the sum of the ionized minerals, metals, and salts in the water. As such, it is also a measure of water's ability to transmit an electrical current. Data collections included measures of both conductivity and specific conductance and are measured in microsiemens per cm (µS/cm). Specific conductance is conductivity standardized to a set water temperature (25°C) since temperature influences conductivity and – in the field – temperature varies with depth and/or date.

Specific conductance is an important metric in Limnological studies due to its ability to detect pollutants and/or nutrient loadings. Specific conductance can also have an influence on organisms that inhabit a lake or pond; particularly, algae. The composition of algal communities has been shown to be related, in part, to conductivity levels in lakes (e.g., Siver 1993, McMaster & Schindler 2005). As was done with temperature and oxygen profile data, specific conductance data have been displayed as an isopleth chart (Fig. 9).

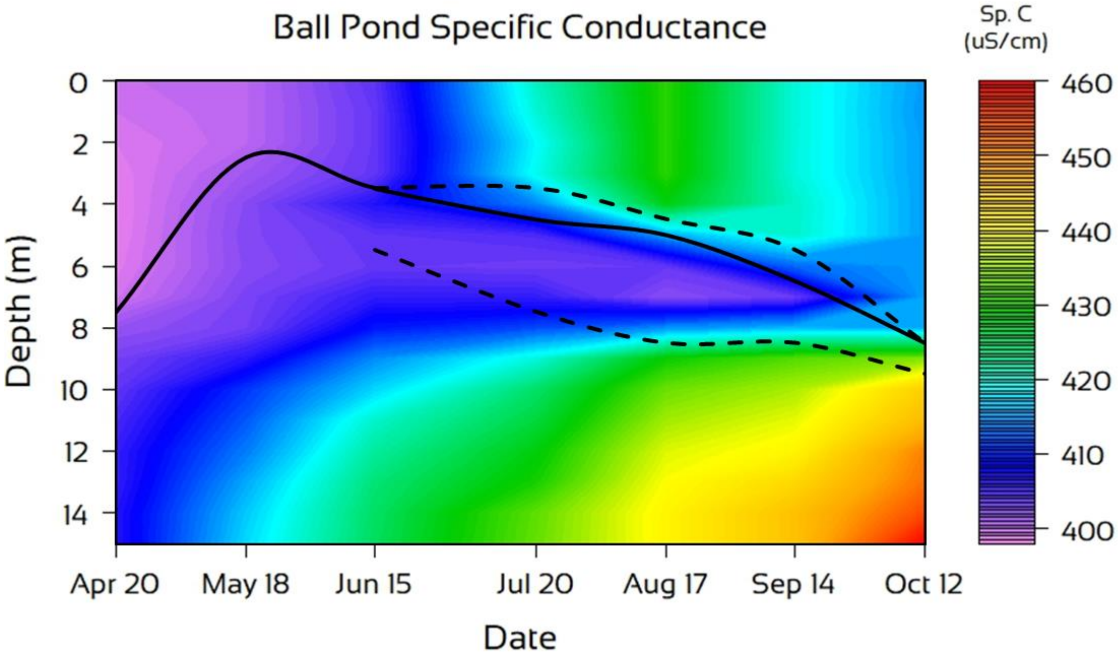

Figure 9. Isopleth plots of water column specific conductance for Ball Pond in 2022. The dashed black line represents the upper and lower boundaries of the metalimnion; the solid black line represents the thermocline.

Specific conductance was variable both spatially and temporally. Lowest levels of just under 400 µS/cm were recorded in the top 7 m of the water column on April 20th. Below that, level slowly increased to 407 µS/cm by 14 m of depth.

Epilimnetic specific conductance steadily increased through August 17th, when levels of 431 µS/cm were measured in the top 3 m of the water column. Epilimnetic levels decreased afterwards (Fig. 9). By October 12th, levels of 415 µS/cm were measured in the top 8 m of the water column.

Metalimnetic levels were the least variable (Fig. 9). Most metalimnetic reading between June 15th and October 12th were between 404 and 416 µS/cm. The exceptions were generally along the upper and lower border of the metalimnion where higher levels were measured. This was particularly evident on October 12th when levels of 434 and 445 μS/cm were measured between at 9 and 10 m of depth, respectively.

The greatest variability occurred in the hypolimnetic strata (Fig. 9). Specific conductance levels at the very bottom increased more rapidly during the season, e.g., levels at 14 m and 15 m of depth increased from 417 to 460 μS/cm between May 18th and October 12th. Increases were also observed moving in an upward direction from the bottom with time. For example, levels ≥425 μS/cm were only measured at 14 and 15 m of depth on June 15th; but, by October 12th levels of ≥425 μS/cm were measured from 9 m of depth to the bottom.

Base Cations and Anions

Base cation and anion concentrations are closely related to specific conductance in that they are what create the "salt bridge" by which the flow of electrical current is measured. Base cations and anions are important in understanding natural influences (e.g., dissolved salts from bedrock geology) as well as anthropogenic influences in the watershed (e.g., road salts). In most lakes, the dominant base cations in lake waters are calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{+}) and potassium (K^{+}). Dominant anions include chloride (Cl^{-}), sulfate (SO_4^{2-}), and the alkalinity ions, i.e., carbonate (CO_3^{2}), and bicarbonate (HCO_3^{-}). Those cations and anions are what collectively contribute to conductivity levels in lake water. The ratios of those ions and combinations of those ions can be diagnostic when compared to other lakes, and when compared to levels in the same lake over time.

Base cations, chloride, and the alkalinity anion levels were measured monthly and reported as mass concentrations (mg/L) by the commercial laboratory. We converted those and reported them based on their electrochemical equivalent concentrations (meq/L). The latter was calculated by dividing the measured mass of an ion by its equivalent weight. This provides a means of accounting for the ionic charge (positive or negative). Accounting for electric charge is useful when comparing ion levels to other electrochemical characteristics of lake water, e.g., specific conductance. Ion data from Ball Pond are reported in Appendix A in both mg/L (mass) and electrochemical milliequivalents (meq/L).

Most of the ion data was generally constant over the season (Fig. 10). The one exception was the alkalinity concentration of 5.6 meq/L reported for the May 18th sample. All other epilimnetic alkalinity data were between 1.5 and 1.8 meq/L. Slight decreases in concentrations were detected between May 18th and June 15th, particularly for sodium and chloride. Those decreases were followed by slight increases (Fig. 10).

Based on electrochemical equivalents, potassium and magnesium were the least abundant of the ions measured (Fig. 10). The most abundant were chloride, followed closely by sodium.

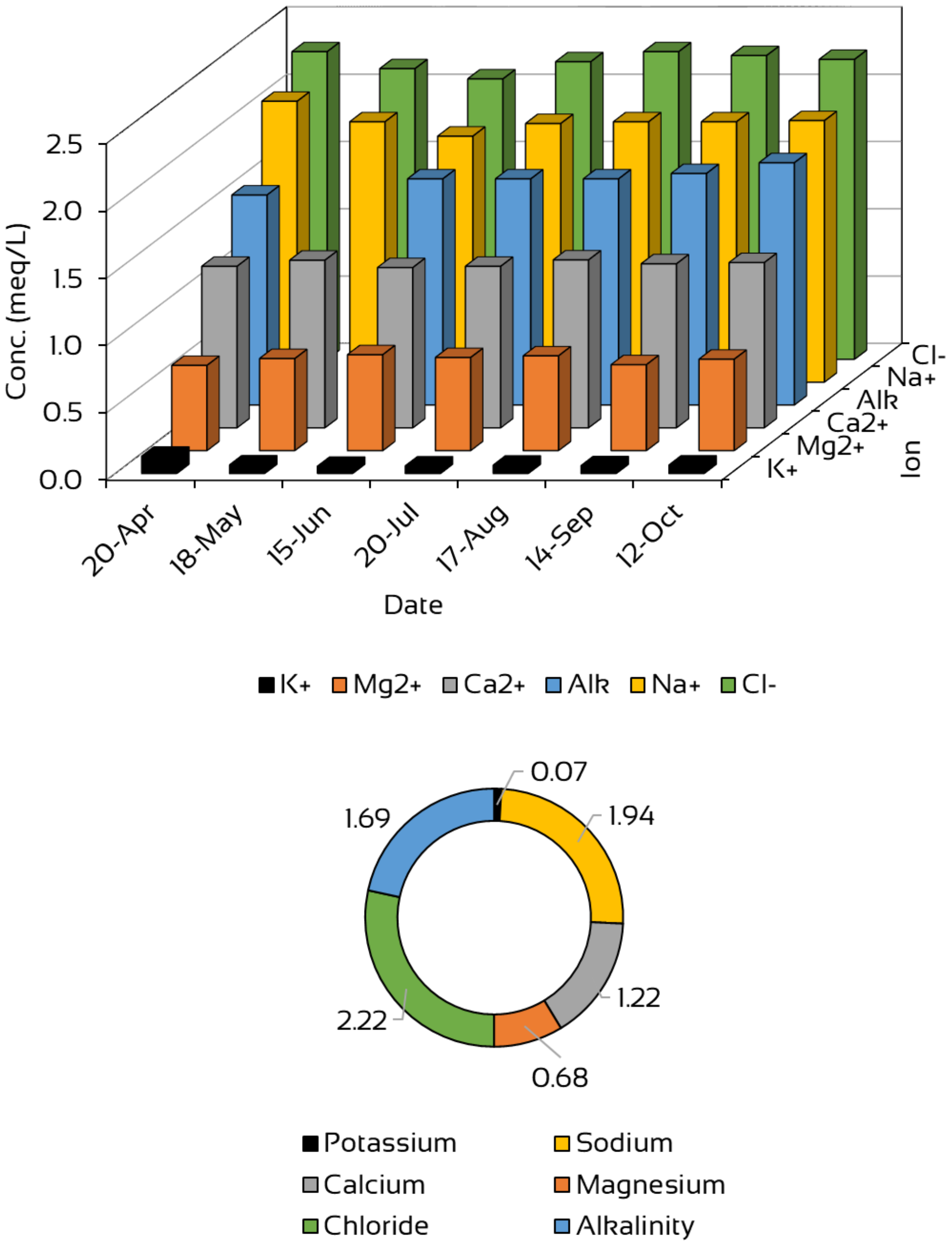

Figure 10. Concentrations of base cations and anions (top) and averages for the season (bottom) at Ball Pond in 2022. Levels are reported in milliequivalents per liter (meq/L). The May 18, 2022 alkalinity measurement of 5.6 meq/L was removed from these analyses since it appeared anomalous. K+ = potassium; Mg2+ = magnesium; Ca2+ = calcium; Alk = alkalinity anions Na+ = sodium; Cl- = chloride; and Conc. = concentration.

Alkalinity and pH

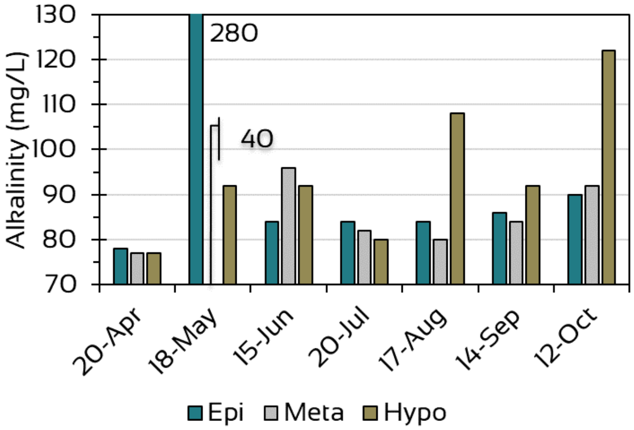

Figure 11. Epilimnetic (Epi), metalimnetic (Meta), and hypolimnetic (Hypo) alkalinity concentrations in Ball Pond during the 2022 season.

Alkalinity is a measure of the water's calcium carbonate content and provides lake water its ability to neutralize acid (i.e., buffering capacity). Alkalinity of surface waters is largely influenced by local geology and other watershed characteristics. Alkalinity at the bottom of the water column can also be generated internally from the biologically mediated reduction of iron, manganese, and sulfate via cellular respiration in the anoxic lake sediments, and denitrification of nitrate to elemental nitrogen (Wetzel 2001). For purposes of assessing alkalinity and comparing it between strata and sites, we used the unit of measure reported by the laboratory, i.e., mg/L.

With the exception of the anomalous 280 mg/L reported for the May 18th sample, all other epilimnetic alkalinity levels were between 78 and 90 mg/L, with concentrations slightly increasing over time. With the exception of May 18th, metalimnetic concentrations were similar (Fig. 11). The season metalimnetic average of 79 mg/L was lower than the epilimnetic average of 84 mg/L (May 18th data not included), but not significantly different (p>0.05).

The hypolimnetic average of 95 mg/L, was also not significantly greater than either the epilimnetic or metalimnetic averages (p>0.05). However, on August 17th and October 12th, hypolimnetic concentrations were notably higher than corresponding epilimnetic or metalimnetic concentrations (Fig. 11).

The normal pH of surface waters of lakes in the Northeast can range from approximately 6 to 9 SU (standard units). Very low or very high pH levels will not support diverse fauna and flora in freshwater ecosystems. Algal community composition is influenced by pH. For example, the pH of the water will influence algae community characteristics by determining the type of dissolved carbon in the water column. At pH levels greater than 8.3, bicarbonate is the dominant form of carbon available to the pelagic algal community; the blue-green algae have adaptive advantages over other algal groups in those conditions in that they can efficiently utilize that form of carbon. Other algal groups are dependent upon carbon dioxide, which is more readily available in water below a pH of 8.3.

Epilimnetic pH in lakes is often higher than hypolimnetic pH, particularly as productivity increases. Carbon dioxide diffuses into the water from the atmosphere and is also a metabolic product of cellular respiration. Photosynthesis by algae and plants in the water utilize carbon dioxide in the water that might otherwise form carbonic acid, which is a weak acid. In the hypolimnion, the photosynthesis is light-limited, therefore carbonic acid levels are higher.

The epilimnetic pH minimum 8.4 occurred on August 17th and September 14th. Epilimnetic maximums of 9.5 and 9.6 were recorded on April 20th and October 12th, respectively, and the epilimnetic season average was high at 8.9. The hypolimnetic season average was similar at 8.7. However, hypolimnetic levels were slightly higher than epilimnetic levels for much of the season (Fig. 12).

The average metalimnetic pH level of 7.6 was significantly ($p<0.05$) lower than averages at the other two strata.

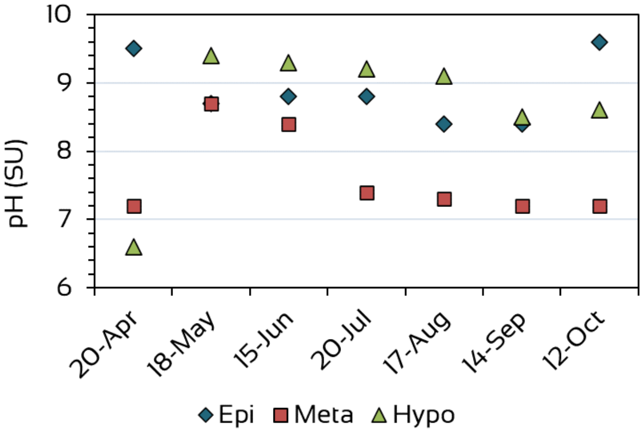

Figure 12. Epilimnetic (Epi), metalimnetic (Meta), and hypolimnetic (Hypo) pH levels in Ball Pond during the 2022 season.

Oxidation-Reduction Potential

The oxidation-reduction potential (aka redox potential or ORP) in lakes refers to the oxidative or reductive state in a particular stratum of the water column; it can provide some insight as to whether phosphorus compounds are changing from an insoluble particulate state in lake sediments to a soluble state that readily diffuses to overlying waters and available to open water algae if mixed into the photic zone (i.e., where algae can harvest it for growth). When OPR is ≥200 millivolts (mV) phosphate remains bound to available iron; at ORP values of <200 mV, iron is reduced and the phosphate that is chemically bound to the iron becomes soluble (Søndergaard 2009). In some cases, a sudden mixing of phosphate-laden bottom waters to the upper reaches of the water column during a storm or wind event can trigger an algae bloom. ORP data collected at the deep-water site was presented as an isopleth plot (Fig. 13).

While most of the water column had ORP levels >200 mV throughout the season, it was notable that levels of <200 mV were observed near the bottom from April 20th through September 14th (Fig. 13). The ORP season low of 0 mV was recorded at 14 m of depth on September 14th. However, by October 12th the entire water column had levels of >200 mV.

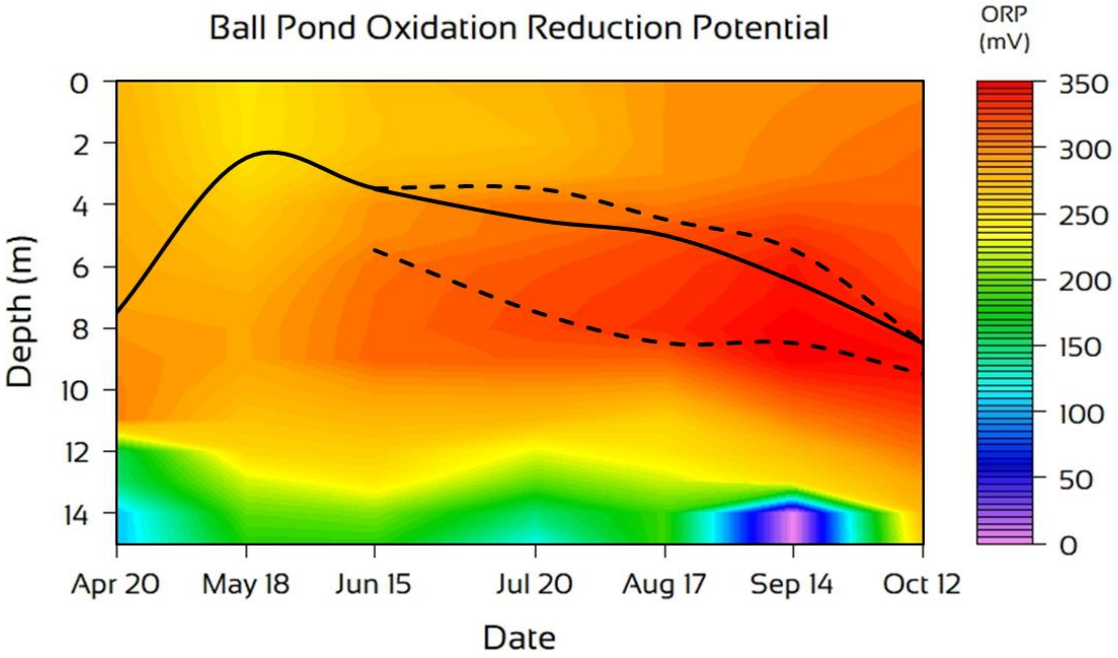

Figure 13. Isopleth plots of oxidation-reduction potential at the Ball Pond during the 2022 season. The black dashed lines and black dots represent the upper and/or lower metalimnetic boundaries. The solid black line represents the location of the thermocline.

ALGAE AND CYANOBACTERIA DYNAMICS

Algae have been used in the assessments of inland water resources for many years. The composition and concentrations of algae living in a lake water column (i.e., phytoplankton) are responsive to environmental conditions. For example, lakes that are high in nutrients are often dominated by Cyanophyta (aka cyanobacteria or blue-green algae) and cell concentrations will likely be high. High concentrations of cyanobacteria can form harmful algal blooms, which can also be toxic (CT DPH & CT DEEP 2021). Algae communities that are more diverse, and include species from the Bacillariophyta (aka diatoms), Chrysophyta (aka golden algae), and Chlorophyta (aka green algae) typically have lower cell concentrations, can reflect lower nutrient conditions, and are not considered toxigenic.

Forty-one algal genera were identified in samples collected at the deep-water site at Ball Pond. Of those, 19 were from the Chlorophyta. The taxonomic group with the next highest number of identified genera was the Cyanophyta at 8 genera. The Bacillariophyta (aka diatoms) was represented by six genera. Four taxonomic groups were represented by three or fewer genera (Table 2).

Table 2. Algal genera observed in samples from Ball Pond in 2022 by taxonomic group.

Chlorophyta

Anikistrodesmus sp.
Carteria sp.
Chlamydomonas sp.
Closterium sp.
Coelastrum sp.
Cosmarium sp.
Elakatothrix sp.
Gloeocystis sp.
Kirchneriella sp.
Mougeotia sp.
Oocystis sp.
Pediastrum sp.
Quadrigula sp.
Scenedesmus sp.
Selenastrum sp.
Sphaerocystis sp.
Staurastrum sp.
Tetraedron sp.
Volvox sp.

Cyanophyta

Aphanizomenon sp.
Aphanocapsa sp.
Chroococcus sp.
Dolichospermum sp.
Lyngbya sp.
Microcystis sp.
Planktothrix sp.
Woronichinia sp.

Bacillariophyta

Asterionella sp.
Aulocoseria sp.
Cyclotella sp.
Fragilaria sp.
Synedra sp.
Tabellaria sp.

Chrysophyta

Dinobryon sp.
Mallomonas sp.
Uroglenopsis sp.

Pyrrhophyta

Ceratium sp.
Glenodinium sp.
Peridinium sp.

Cryptophyta

Cryptomonas sp.

Euglenophyta

Trachelomonas sp.

Highest total cell concentrations occurred on April 13th and June 20th at 15,594 cells/mL and 14,548 cells/mL, respectively (Fig. 14). Cyanobacteria cells concentrations constituted 59% (9,203 cells/mL) and 92% (13,436 cells/mL) of the total cell concentrations on those respective dates. For comparative purposes, the CT DPH and CT DEEP (2020) equates cyanobacteria cell concentration of <20,000 cyanobacteria cells/mL with Visual Rank Category 1 conditions, which present the least amount of risk from cyanobacteria to recreational users of freshwaters. Cyanobacteria cell concentrations of >100,000 cells/mL are characteristic of Visual Rank Category 3 conditions, which present the greatest risk to those in contact with the water, and when the State advises municipalities to post beach closure signage.

By July 20th and through August 17th, the percent of the total cell concentrations that was cyanobacteria were at lowest their levels (Fig. 14). On July 20th, genera from the green algae including *Gloeocystis spp*., *Closterium spp*., and *Scenedesmus spp*., comprised 73% of the algal cell concentrations. On August 17th, green algae and diatoms comprised 44% and 38%, respectively of the total cell concentration. *Coelastrum spp*.

was another colonial green algal genus that became important on August 17th. The centric diatom *Cyclotella spp*. was also important on that date.

Cyanobacteria reemerged as the dominant taxon by September 17th, comprising 70% of the total. However, the cell concentrations of the cyanobacteria and other taxa were low (Fig. 14).

Important cyanobacteria genera observed during season were often from the group that have the ability to regulate buoyancy, and/or are capable of nitrogen fixation. These included *Aphanizomenon spp*., *Dolichospermum spp*., *Lyngbya spp*., *Microcystis spp*., *Planktothrix spp*., and *Woronichinia spp*. (Fig. 15).

Deep-water Cyanobacteria

The reporting above on the algae and cyanobacteria community was based on samples collected by integrating the top three meters of the water column. This was where general photosynthetic potential was greatest.

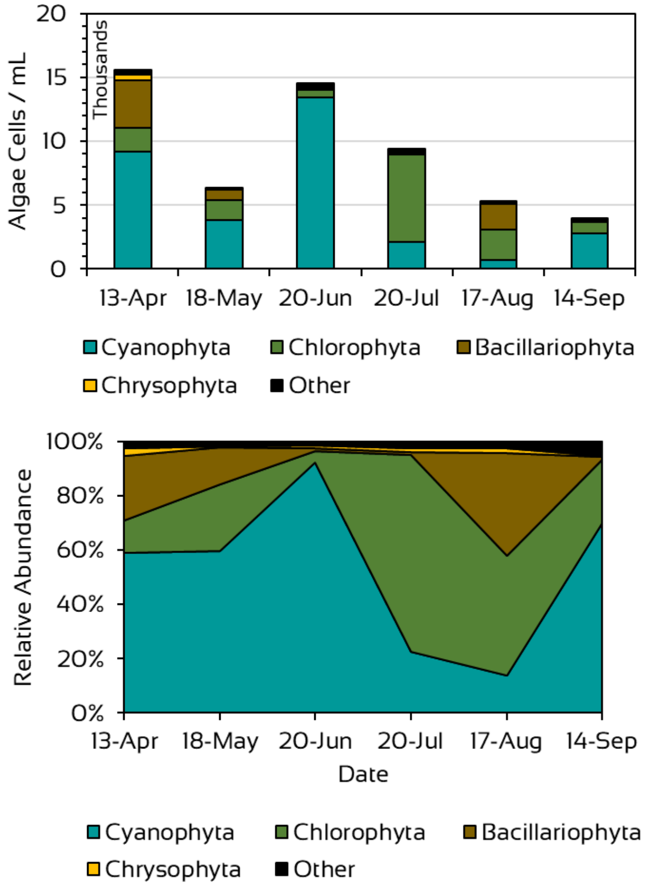

Figure 14. Algae cell concentrations (top) and relative abundance for the major taxonomic groups observed in Ball Pond in 2022.

Cyanobacteria can also be observed irregularly distributed throughout the water column. To assess vertical and temporal distribution, the photosynthetic pigment unique to the cyanobacteria – *phycocyanin* – was measured throughout the water column with a fluorimeter incorporated into the sensor array of the Eureka Manta II multiprobe. Fluorimeters work on the principal that a particular substance fluoresces at a specific wavelength when light of another wavelength is directed on that substance. The fluorimeter in AER's instrumentation emits a wavelength that interacts with phycocyanin. This sensor is not calibrated with known concentrations of phycocyanin so measurements are not quantitative; instead the measurements are relative to other measurements in the water column or to other sites. Those data were also graphically represented in an isopleth chart (Fig. 16).

Beginning in June, highest relative phycocyanin concentrations were observed between the upper and lower boundaries of the metalimnion (Fig. 16). Highest concentrations continued to be observed within the metalimnion through September 14th. The season maximum occurred on August 17th at 7 meters of depth when relative concentrations were ten time higher at 7 m of depth than they were at any depth above that. A water sample was collected at 7 meters on August 17th and nearly all of the cyanobacteria observed from that sample was from the cyanobacteria genus *Planktothrix* (formerly *Oscillatoria*; Fig. 15-E, F).

There are some species of *Planktothrix*, e.g., *Planktothrix rubescens*, that are renowned for forming high concentrations at lower depth, near or below the thermocline. Their ability to regulate buoyancy provides the means to maintain a position at depth in the water column. Their unique photosynthetic pigments provide the means to photosynthesize at these depths – whereas other algae cannot – and at those depths they can take advantage of higher phosphorus concentrations building up in the hypolimnion of the lake.

Shoreline Cyanobacteria Blooms

Although the cyanobacteria concentrations in the surface waters of the deep-water site were never found to be high, shoreline cyanobacteria blooms were commonly observed. Blooms were observed in the cove just west of the State Boat Launch in the south end of the lake, and east of the outlet at the north end of the lake (Figs. 17a, b, c). Samples from these blooms were collected and examined by AER and volunteers. Cell concentrations were not determined but would have clearly exceeded the 100,000 cyanobacteria cells/mL which is indicative of high public health risk (CT DPH & CT DEEP 2021).

Common to all shoreline blooms on Ball Pond examined with microscopy in 2022 was the dominance by the genus *Woronichinia spp*. (Fig. 17d, e, f). Other cyanobacteria genera observed in the blooms included *Aphanizomenon spp*., *Dolichospermum spp*., *Lyngbya spp*., and *Microcystis spp*. All of these genera are capable of regulating buoyancy through the internal formation of gas vesicles. All have been associated with the synthesis of one or more cyanotoxins (see below).

Benthic Cyanobacteria

Assessments of the algae and cyanobacteria growing on the lake sediment are very rare in lake monitoring initiatives. However, a preliminary assessment was conducted due to extensive growth of filamentous algae growing attached to the lake bottom in the littoral zone observed during the quantitative aquatic plant survey conducted on August 14th.

Samples of the filamentous algae observed across much of the bottom of Ball Pond on August 14, 2022 were collected and examined with microscopy. Most of the sample was comprised of the cyanobacteria *Lyngbya spp*. (Fig 18 a, b). Most forms of *Lyngbya* are periphytic (grow attached to substrates) and form benthic mats in freshwater systems (Komárek, & Johansen 2015). Some species are considered toxigenic (Baker et.al. 2012).

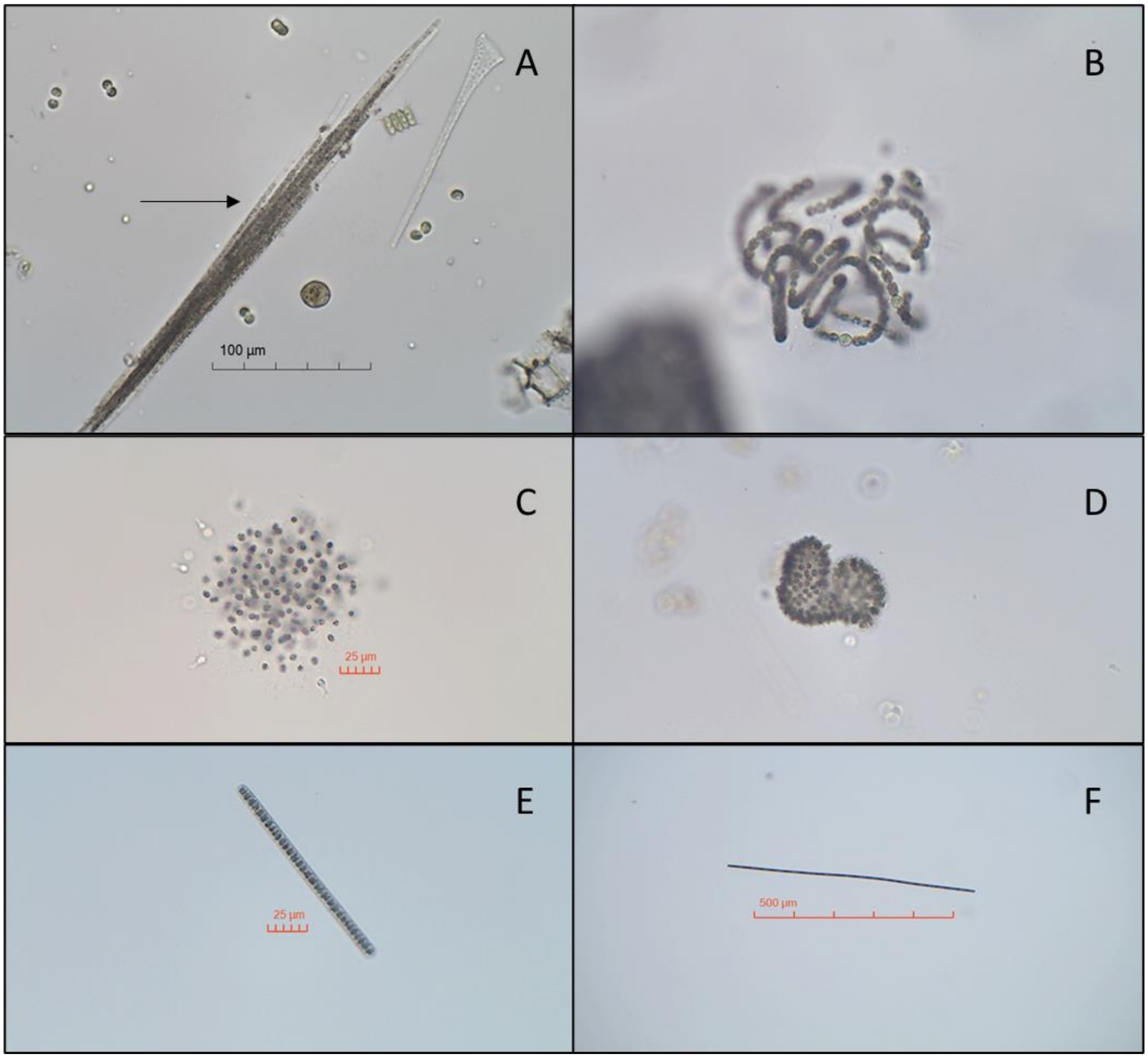

Figure 15. Micrographs of cyanobacteria specimens collected in Ball Pond throughout the 2022 season. Specimens A – D were collected with a plankton net and in the top three meters of the water column. Specimens E and F were collected from 7 meters of depth with a Van Dorn sampling bottle on August 17, 2022. A) *Aphanizomenon spp*. (total mag. 400X); B) *Dolichospermum spp*. (total mag. 400X); C) *Microcystis spp*. (total mag. 400X); D) *Woronichinia spp*. (total mag. 400X); E) *Planktothrix spp*. (total mag. 400X); and F) *Planktothrix spp*. (total mag. 100X).

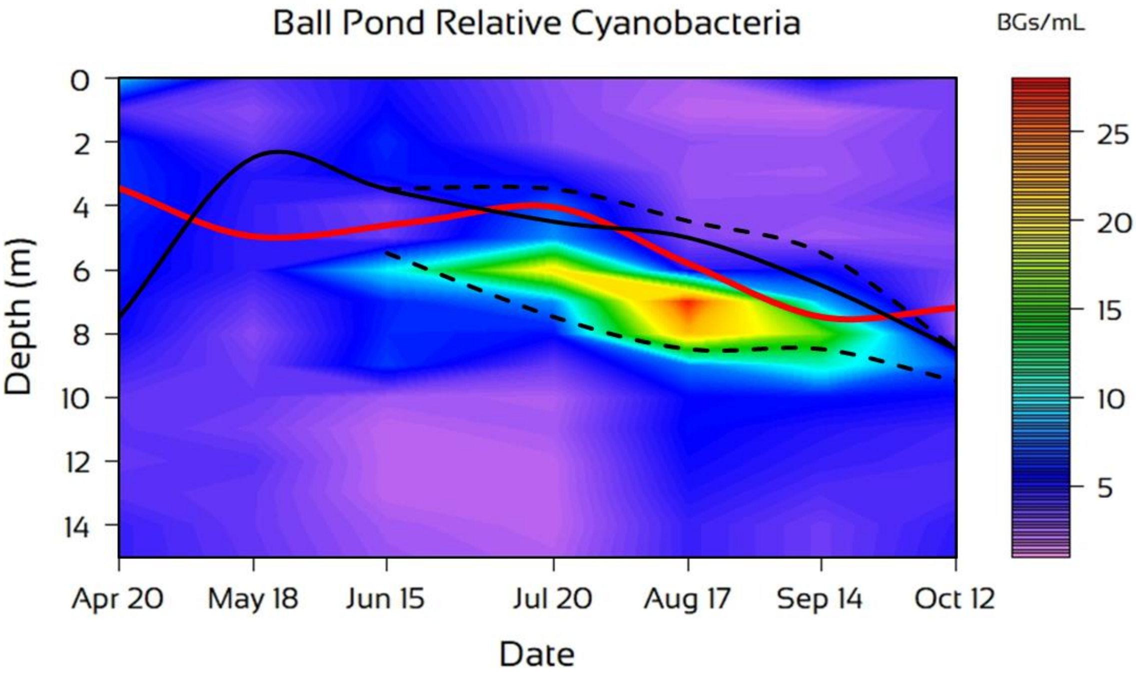

Figure 16. Isopleth chart of relative phycocyanin concentrations at the Ball Pond during the 2022 season. The black dashed lines and black dots represent the upper and/or lower metalimnetic boundaries. The solid black line represents the location of the thermocline. The solid red line represents the approximate location of the *Compensation Depth* throughout the season.

A smaller number of filaments were *Spirogyra spp*., a filamentous genus from the Chlorophyta (aka green algae). The distinctive characteristic of this genus is the spiraling chloroplasts within the cell (Fig. 18c, d). Chlorophyta are not considered toxigenic.

A small mass of cells within a gelatinous matrix was also collected within the sample of algal filaments and examined with microscopy. This was the colonial cyanobacteria *Aphanothece spp*., another periphytic organism (Fig. 18 f).

Cyanotoxins Levels at Ball Pond

Almost all of the cyanobacteria genera discussed above are considered toxigenic, i.e., there are populations of those genera that have synthesize toxic compounds within their cells. It is important to recognize that not all populations of a genus considered toxigenic possess the genes for toxin production, and those that have them are not always expressing those genes, i.e., synthesizing toxins.

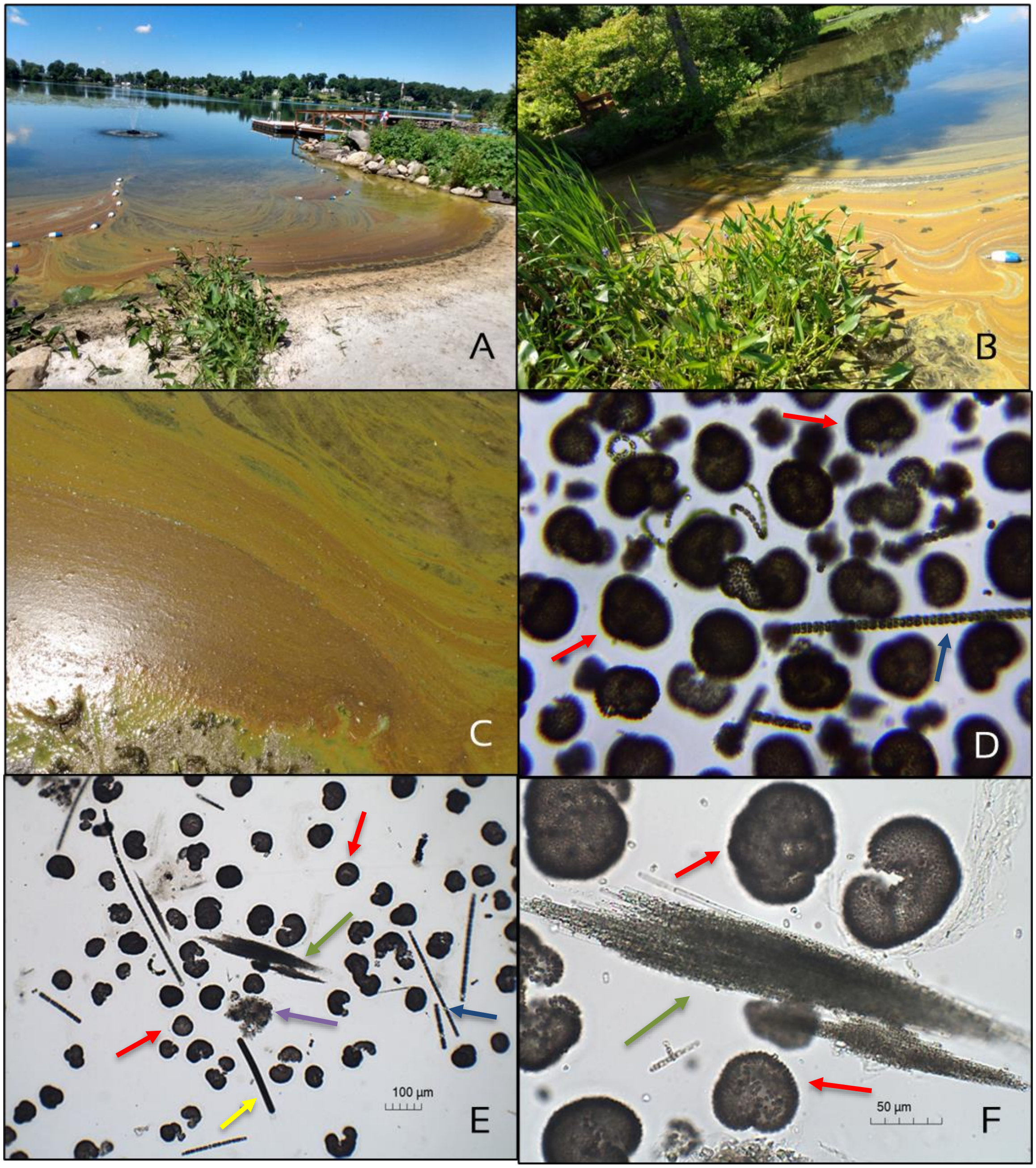

Figure 17. Shoreline cyanobacteria blooms observed at east of the outlet at the north end of Ball Pond on June 25, 2022 (A, B, and C), and micrographs of cyanobacteria specimens collected from blooms. D) Cyanobacteria from the June 25, 2022 bloom east of the outlet, dominated by *Woronichinia spp*. (red arrow) with *Dolichospermum spp*. (blue arrow) also present. E) Cyanobacteria from the June 15, 2022 bloom in the cove west of the State Boat Launch with the dominant genus of *Woronichinia spp*. (red arrow). Other genera included *Aphanizomenon spp*. (green arrow), *Dolichospermum spp*. (blue arrow) *Lyngbya spp*. (yellow arrow), and *Microcystis spp*. (purple arrow). Total magnification was 100X on E; 400X on F. Photo credits: Elissa Johnson for A – D; and AER for E and F.

The State advises municipalities to test for the hepatotoxin *microcystin* to assess health risks and sets a level of 8 µg/L, below which is considered acceptable for recreational contact. Microcystins comprise one of several cyanotoxin groups and one of the most prevalent toxins associated with harmful cyanobacteria blooms.

Water samples were collected weekly from Hahlawah Beach off of Ball Pond Road East from June 26th through August 28th and tested for microcystin levels by faculty and student researchers at Western Connecticut State University. Results are presented in Table 3. No results exceeded the 8 µg/L threshold for microcystins.

Table 3. Microcystin concentrations in samples collected at Hahlawah Beach on Ball Pond in 2022 and analyzed at Western Connecticut State University.

Date	µg/L	Date	µg/L
June 26	0.000	July 3	0.423
July 10	0.405	July 17	0.366
July 24	0.135	July 31	0.100
August 7	0.176	August 14	0.057
August 21	0.097	August 28	0.127

The benthic cyanobacteria *Lyngbya spp*., found attached to much of littoral zone sediments, is considered toxigenic, but does not synthesize microcystins. Instead, it has been found to synthesize other cyanotoxins including two neurotoxins – anatoxin and saxitoxin. In 2022, the faculty and student researchers at WCSU developed methods to test for saxitoxin (also known as paralytic shellfish poison in the marine environment). Connecticut has not set a threshold for acceptable/safe levels of saxitoxin. However, Ohio uses 0.8 µg/L for its threshold.

A sample of *Lyngbya spp*. collected by AER during the plant survey of August 14th was analyzed and found to be >1.6 µg/L or greater than twice the acceptable level used in Ohio. The actual concentration has not been determined at the time of this reporting, but a serial dilution and analyses are planned that may provide greater resolution on the actual concentration. Another sample was collected on August 28th, analyzed, and found to have 0.03 µg/L.

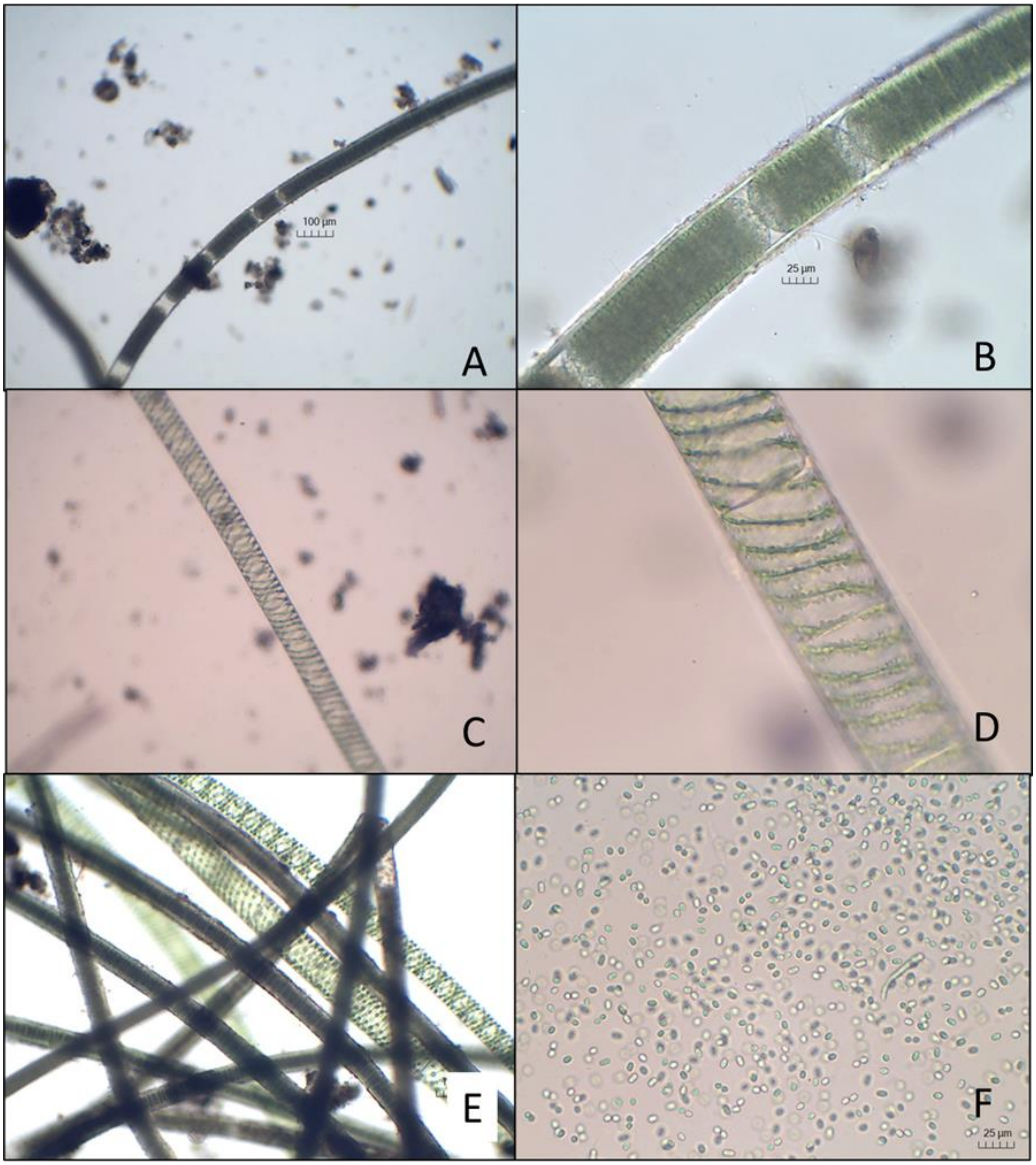

Figure 18. Micrographs of algal specimens collected from Ball Pond on August 14, 2022. A) the Cyanophyte *Lyngbya spp*. (total mag 100X); B) Lyngbya spp. (total mag. 400X); C) the Chlorophyte *Spirogyra spp*. (total mag. 100X); D) *Spirogyra spp*. (total mag. 100X); E) mix of *Lyngbya spp*. and *Spirogyra spp*. (total mag. 100X); F) the Cyanophyte *Aphanothece spp*. (total mag. 400X).

WHAT DID WE LEARN?

Water quality monitoring programs provide baseline data to asses changes over time. In some instances, changes and/or conditions are particularly noteworthy, and deserving of additional focus. Below we have discussed several lake characteristics and/or changes over time at Ball Pond worthy of additional discussion.

Increasing Salt Content

Last year, we reported a considerable increase in specific conductance from 1993 to 2021. In order to understand the driving factors, we recommended analyses of base cations, chloride and alkalinity in the 2022 season. Above, we provided graphic representation of the results of those analyses on a milliequivalent/L basis (Fig. 10). In Table 4, we provide a comparison of averaged data collected in 1993 to that collected in the last two years, including ion data.

In Figure 19, the percent increase in base cations, chloride, and alkalinity from 1993 to 2022 were graphically depicted. With the exception of potassium, all measured ion concentrations have increased. However, the two ions that have increased the most and at relatively the same rates are sodium and chloride. Increases of 81% and 83% were calculated for sodium and chloride, respectively over the study period. Calcium and magnesium increased by 23% and 24%, respectively. Alkalinity anions increased by 32%.

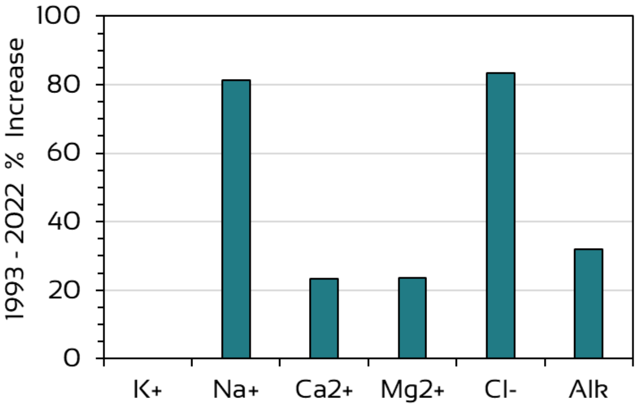

Figure 19. Percent increase in base cation, chloride, and alkalinity anions from 199.3 to 2022. K+ = potassium; Na+ = sodium; Ca2+ = calcium; Mg2+ = magnesium; Cl- = chloride; and Alk = alkalinity anions.

Average specific conductance at the surface of the lake has increased since 1993 from 283 to 413 µS/cm or by 46%. Since 1993, the collective average percent increase of the base cations, chloride, and alkalinity measured in this investigation was very similar at 49%.

Increasing salt levels in lakes is widespread in the Northeast and in snowbelt regions of the country, has been attributed to the increased use of deicing salts on roads, and is a growing management concern for lakes (Kelly et. al. 2019). Increased salts can alter the biota, and can accumulate at the bottom, impeding or preventing complete turnover because of the elevated density of the "saltier" water. This could create a condition where full oxygenation of bottom waters could be prevented.

Table 4. Comparisons of the 2021, 2022 and 1993 season averaged water quality variables from Ball Pond to ranges observed in lakes located in the Marble Valley, Western Upland and in all geological regions in Connecticut from a Statewide survey of 60 lakes (Canavan and Siver 1995) conducted in the early 1990s. All measures with the exception of Secchi transparency were from samples collected at 1 meter depth.

Parameter	**Units**	**Ball Pond**			**Marble Valley**			**Western Uplands**			**60 Lake Set**		
		2022 Means	**2021 Means**	**1993 Means**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**
Total Nitrogen	μg/L	---	734	---	343	547	449	208	714	364	119	3831	439
Total Phosphorus	μg/L	13	34	22	27	42	31	10	57	33	9	334	33
Chlorophyll-*a*	μg/L	6.8	6.5	5.0	1.2	7.1	4.3	0.7	19.7	5.1	0.2	71.6	6.5
Secchi Disk	meters	2.7	2.4	2.6	2.0	4.9	3.3	1.7	7.6	3.5	0.9	7.6	3.3
pH	SU	8.9	9.0	8.7	7.8	8.3	8.2	4.6	8.1	7.2	4.6	8.8	7.1
Sp. Conductivity	μS/cm	413	417	283	180	317	258	25	188	96	24	317	102
Alkalinity	mg/L	84	82	64	54.5	120.5	90	23.7	44	21	0	120.5	14.5
Chloride (Cl$^-$)	mg/L	77.6	---	42.2	3.2	42.2	21.3	0.7	24.1	9.2	0.7	42.2	10.3
Calcium (Ca^{2+})	mg/L	24.4	24.1	19.7	16.6	28.8	22.8	2.8	11.4	6.8	1.2	28.8	7.6
Magnesium (Mg $^{2+}$)	mg/L	8.1	---	6.6	5.9	15.2	9.8	1	5.2	4.1	0.2	15.2	2.5
Sodium (Na$^+$)	mg/L	44.6	---	24.6	2.5	24.6	13.1	1.4	10.4	5.3	1.4	24.6	6.9
Potassium (K$^+$)	mg/L	2.7	---	2.7	1.2	2.7	1.9	0.2	0.9	0.5	0.4	2.7	1.2

Physical, Chemical, and Trophic Characteristics

For the last two years, Ball Pond was stratified early in the sampling season, i.e., by April 26th in 2021, and by April 20th in 2022. In both years, the April oxygen profiles revealed a clear gradient with concentrations decreasing with depth. By the May sampling event of both years, oxygen concentrations of <1 mg/L were observed in strata near the bottom. Oxidation-reduction potential was not measured in the water column in 2021; but from our 2022 data, ORP levels were low enough at the bottom in April for the release of phosphorus from the sediments to waters between soil particles, and then to the waters above that by diffusion.

Resultingly, phosphorus concentrations from samples collected near the bottom were highly elevated early in both seasons: 89 µg/L by April 26th of 2021, and 148 µg/L by May 18th of 2022. Hypolimnetic concentrations steadily increased over time in both seasons, exceeding 300 µg/L on July 27th and August 25th of 2021, and on July 20th and September 14th of 2022. Concentrations of 598 µg/L and 668 µg/L were reported for August 17th and October 12th of this season. Hypolimnetic alkalinity and ammonia concentrations followed similar patterns and were the result of similar biochemical processes resulting in the increases of hypolimnetic total phosphorus.

The nutrient and chemical levels of the samples collected near the thermocline were generally more comparable to epilimnetic levels than to hypolimnetic levels. For example, the average epilimnetic and metalimnetic total phosphorus concentrations in 2022 were 15 and 12 µg/L, respectively, and characteristic of a lake in an early mesotrophic to mesotrophic trophic state. Cyanobacteria and other algae cell concentration collected from epilimnetic waters at the deep-water site were generally low to moderate. However, the greatest cyanobacteria biomass in 2022 occurred not in the epilimnion, but from the strata between the thermocline and the lower metalimnetic boundary (Fig. 16).

Another physical characteristic worth noting was the strength of the resistance to mixing at the thermocline. With the exception of April 20th, the relative thermal resistance to mixing (RTRM) values at the thermocline were always >80, and characteristic of strong resistance to mixing (Siver et. al. 2018). The metalimnion itself appeared resistant to influences from the epilimnion and hypolimnion particularly based on specific conductance (Fig. 9). Metalimnetic specific

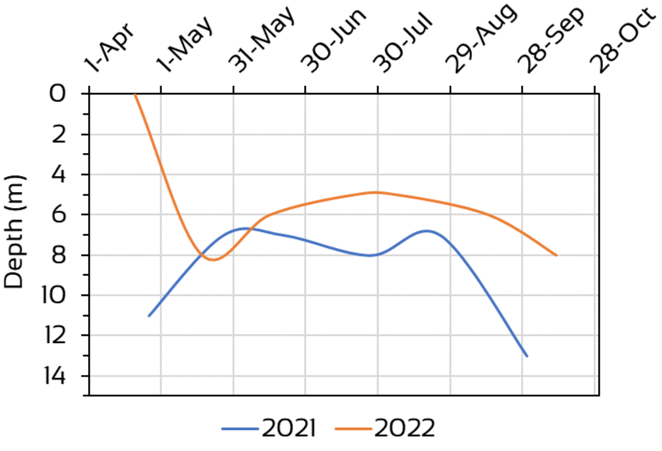

Figure 20. Upper boundary of the anoxic water mass (<2 mg/L) in 2021 and 2022. No data was available for October of 2021.

conductance appeared more stable, while the epilimnetic and hypolimnetic strata exhibited more change as the season progressed.

Also worth noting was the upper boundary of the anoxic strata in the last two years. Last year, a threshold of 2 mg/L of oxygen was used to differentiate anoxic waters from oxygenated waters. That boundary in 2021 was 7 meters of depth meaning that the top 7 meters of the water column always had oxygen concentrations >2 mg/L of oxygen; the area of the bottom of the lake below 7 meters of depth was 42.8 acres. In 2022, the boundary between anoxic and oxygenated waters was 5 meters of depth indicating that the anoxic waters occupied more of the of the water column in 2022 than in 2021. In Figure 21 we have provided a map of the 51.7 acres of the lake bottom that is below than 5 meters of depth, and theoretically the area where internal phosphorus loading is occurring.

Cyanobacteria and Algae Community

The Ball Pond algal community – particularly the cyanobacteria community – is complex and appears enigmatic. Near the surface of the open water, cyanobacteria cell concentrations were relatively low based on cell counts and relative phycocyanin measurements. Much higher relative phycocyanin concentrations were observed below the thermocline at the deep-water site starting in June, and reaching maximum concentration by August 17th (Fig. 16). The dominant cyanobacteria genus was filamentous *Planktothrix spp*.

Multiple incidents of intensive shoreline algae blooms have been documented over the last two years with photographs by volunteers from the Ball Pond community (Fig. 17). *Woronichinia spp*. has often been the dominant genus in those blooms. Other cyanophytes observed in the blooms have included *Aphanizomenon spp*., *Dolichospermum spp.*, and *Microcystis spp*. Common to all these planktonic genera is the ability to regulate buoyancy and to utilize atmospheric nitrogen, i.e., nitrogen fixation.

It is not necessarily conflicting to observe low open water cyanobacteria concentrations and simultaneously have intensive shoreline blooms. Imagine if most of a particular cyanobacteria species, e.g., *Woronichinia spp*., became positively buoyant and surfaced from waters across the lake. Even if the concentration across the lake was low, a gentle breeze could "sweep" much of it and concentrated it into one cove, resulting in an intensive surface bloom. We believe this occurs at Ball Pond.

The spatial distribution and productivity of cyanobacteria are influenced by a multitude of variables including levels of phosphorus and nitrogen, pH, carbon availability, patterns of mixing and stratification, and climatic factors. Kortmann (2015) described the vertical distribution as a function of the Compensation Depth (see *Secchi Transparency* section above) whereby stimulation of cyanobacteria growth and productivity were greatest near the surface when the Compensation Depth was above the metalimnetic layer. When the Compensation Depth is within the metalimnion, then the highest cyanobacteria concentrations are often found near the thermocline, as was often the case at Ball Pond (Fig. 16).

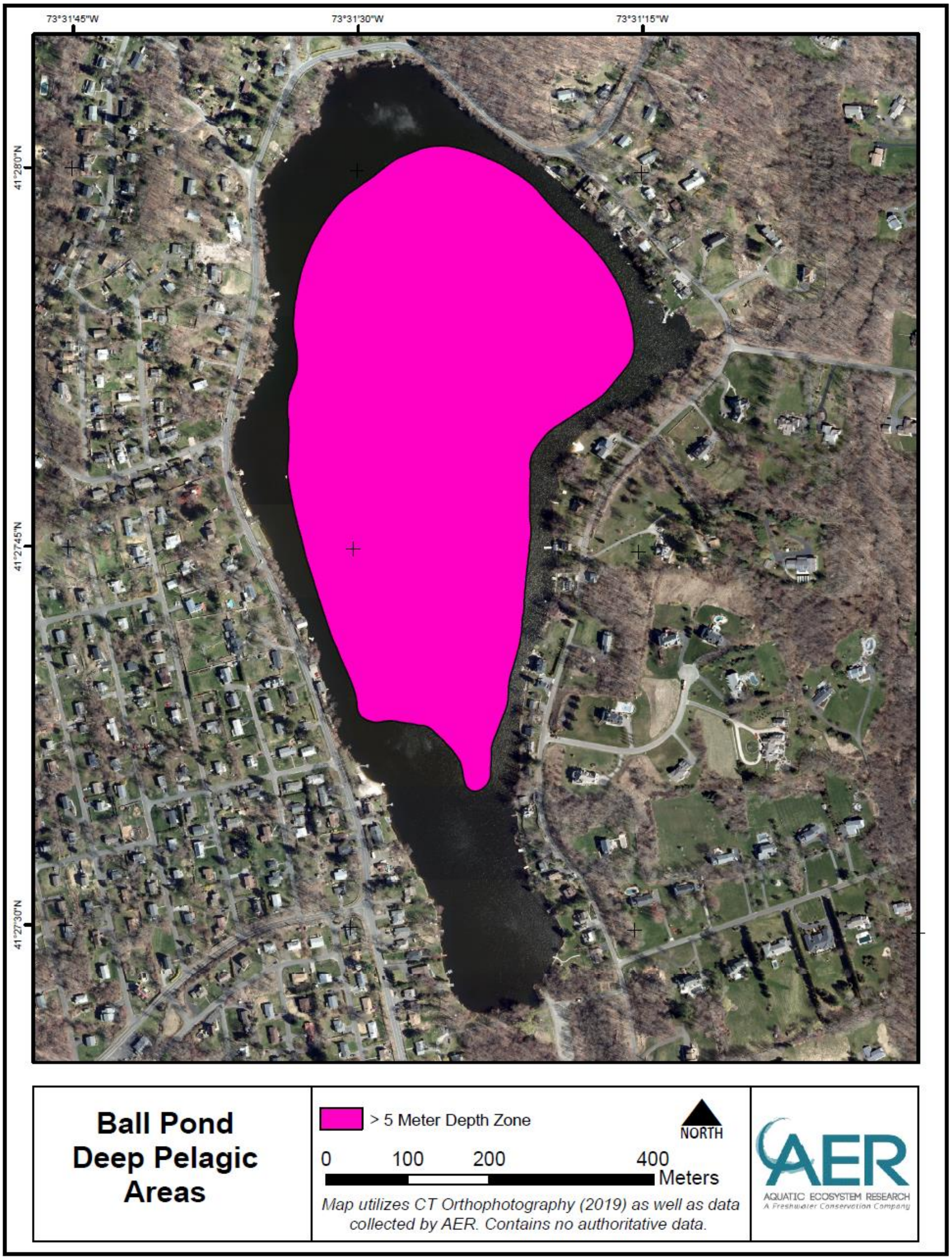

Figure 21. Area of the bottom of Ball Pond located in waters 5 meters deep or deeper. That total area is 51.7 acres.

Some of the photosynthetic pigments of cyanobacteria provide an adaptive advantage for utilizing wave-lengths of light that penetrate down to deeper depths for photosynthesize, whereas other taxa (e.g., Chlorophyta) cannot photosynthesize at deeper depths. That, along with the adaptive advantages of buoyancy regulation, gives cyanobacteria the ability to thrive in or near deeper waters that have higher concentrations of nutrients loading from bottom sediments under anoxic conditions. We have documented that waters near the bottom become highly enriched with nutrients at Ball Pond. Nutrient levels near the thermocline tended to be closer to epilimnetic levels. What we don't understood are nutrient concentrations up through the hypolimnion to the thermocline.

As or more disconcerting than the cyanobacteria blooms along the shoreline, or cyanobacteria concentrations found near the thermocline, was the benthic mats of *Lyngbya spp*. that appeared to cover much of the littoral zone and the cyanotoxin concentrations in those benthic mats. Saxitoxin levels of >1.6 µg/L in the one sample collected on August 14th were more than twice the acceptable level for State of Ohio. Species of benthic *Lyngbya spp*. have been characterized as becoming more problematic across the US, aggressive colonizers, and capable of shading and outcompeting other primary producers (Willis et. al. 2020).

Seasonal Trophic Dynamics

Last year we reported on incongruities among the trophic variables of Secchi disk transparency, chlorophyll-*a* concentration, and total phosphorus concentration. We noted that total phosphorus levels observed in 2021 should have supported more algal growth and resulted in higher than observed chlorophyll-*a* concentrations, and lower than observed Secchi disk transparencies. We graphically displayed the incongruities using the Carlson Index (Carlson 1977) that transforms trophic data onto a scale from 0 to 100 so that trophic variables that are initially measured in different units and/or scales, can be compared on the same scale.

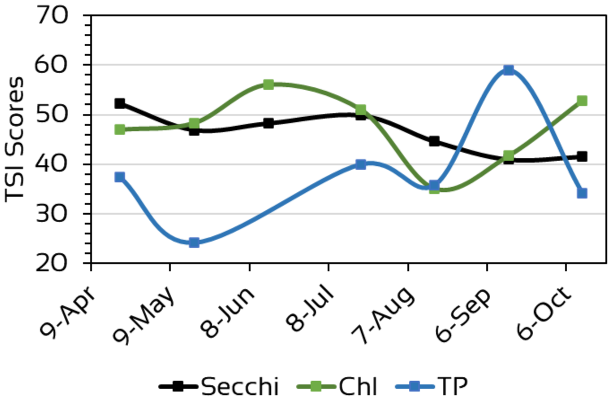

Figure 22. Carlson (1977) trophic scores for Secchi transparency, chlorophyll-a concentration, and epilimnetic total phosphorus measured in Ball Pond during the 2022 season between April 20th and October 12th.

This season, epilimnetic total phosphorus levels were, on average, lower than that observed last year, while chlorophyll-*a* levels were higher than what we would expect, and Secchi disk transparencies were lower than what we would expect based on total phosphorus levels. Those relationships are graphically displayed again using the Carlson Index (Fig. 21).

In both 2021 and 2022, Secchi disk transparencies increased as the season progressed. This was despite total phosphorus concentrations that could support greater productivity as observed in 2021, or increasing epilimnetic concentrations over time as observed this season. This raises the question, "What are the most important drivers of algal productivity at Ball Pond?"

CONCLUSIONS AND RECOMMENDATIONS

If one were to assess historical changes over the last 30 years based on average epilimnetic data, one could conclude that there are increases in the salt content of the lake, but little changes in the trophic characteristics (Table 4). From the trophic perspective, annual Secchi transparency and chlorophyll-*a* concentrations have not significantly changed. Moreover, the 2022 average epilimnetic total phosphorus was lower (better) than the 2021 and 1993 averages.

Despite those data, shoreline cyanobacteria blooms and highly elevated cyanobacteria biomass below the thermocline are common and likely related. Buoyancy regulation by the cyanobacteria is what maintains an elevated biomass, largely of *Planktothrix spp*., below the thermocline, and also results in shoreline cyanobacteria blooms, which have been dominated by *Woronichinia spp*. Below we have provided several recommendations to begin to address the cyanobacteria issues at Ball Pond.

- *Community Bloom Watch on Ball Pond*

  Currently there is a small group of residents who have reported and photo-documented shoreline blooms. We recommend formalizing a Community Cyanobacteria Bloom Watch on Ball Pond. The development of data on shoreline bloom events, including locations, dates, extent, and weather conditions (including wind direction) could be important in understanding the variables associated with blooms and also create the necessary public awareness to develop the momentum to mitigate the problem.

  In 2021, the BPAC purchased a microscope and the accessories to photo-document the dominant genera in the blooms. Former BPAC members had developed the necessary microscopic techniques and learned to identify the major cyanobacteria genera. AER reported on these efforts in our 2021 report. This type of data should also be incorporated into a Community Bloom Watch program.

- *Modification of the Cyanotoxin Monitoring Program*

  The microcystin monitoring program at Ball Pond, in conjunction with Western Connecticut State University, provides excellent information for the community for making informed decisions regarding the recreational use of the lake. The program could be expanded to measure toxin levels in the surface bloom, where cyanobacteria concentrations are typically much higher.

  It was fortuitous that research on saxitoxins in lakes occurred at WCSU in 2022. The findings of elevated saxitoxin levels in the benthic *Lyngbya spp*. mat on August 14th was concerning, even if it was one sample. There was one other sample collected two weeks later when saxitoxin levels were within the acceptable levels for Ohio.

  Saxitoxin testing should be incorporated into the annual lake management program and expanded to include several sites that are sampled on a regular basis during the summer. Additionally, a thorough literature search on mitigating benthic cyanobacteria communities in lakes should be undertaken.

- *Understanding Phosphorus Levels Below the Thermocline*

  As described above, phosphorus is released from bottom sediments under anoxic conditions and creates high concentrations in the strata near the bottom. Phosphorus concentrations near the thermocline and one meter below the surface are often similar. What is not understood are concentration gradients between the bottom strata and the thermocline. Understanding concentrations, below the thermocline or lower metalimnetic boundary down to the depth of the hypolimnetic sample could shed light on the high cyanobacteria concentrations near the thermocline and possibly in the shoreline booms.

  Understanding phosphorus dynamics throughout the water column with higher resolution than the current epilimnetic, metalimnetic and hypolimnetic sampling regime should be developed in conjunction with a phosphorus budget study.

- *Sediment Phosphorus Fractions*

  It is highly possible that much of the phosphorus budget of Ball Pond is driven by internal loading. While addressing watershed-generated phosphorus with best management practices and education is important, it will also be important to understand phosphorus in the lake sediment, particularly in the area of the bottom that is anoxic for a protracted period of time (Fig. 21).

  Quantifying the phosphorus fractions (e.g., phosphorus bound to iron, aluminum, organics, etc.) in the sediments that experience protracted periods of anoxia is an important step in planning for phosphorus sequestering with alum. Ball Pond has been identified as a candidate for this type of effort since at least the early 1980s (Norvell 1982).

- *Examination of Use of Deicing Salts and BMPs*

  The specific conductance and ion concentrations at Ball Pond are clearly increasing. The measured ion concentrations that have increased the most are sodium and chloride, which implicate increased use of deicing salts on roads. Since Ball Pond is largely spring fed, we believe the groundwater ion concentrations should be tested to understand contributions from that source.

  We additionally recommend that the BPAC review the web pages of the Carey Institute on road salts at https://www.caryinstitute.org/our-expertise/freshwater/road-salt. There, a report entitled *Road Salt: The Problem, The Solution, and How to Get There* can be downloaded and also reviewed. Additionally, a Western Connecticut State University seminar that occurred on October 17, 2022 featured Vicky Kelly, author of the report. It also featured Robert Wyant, Highway Superintendent for the Town of Rhinebeck NY, who presented "*An introduction to available resources and expert support.*" The seminar was recorded and available at https://www.wcsu.edu/biology/lake-symposium-2022-recordings/ and should be viewed by the Committee. From there, planning on how to reduce salt concentrations used in the Ball Pond watershed should be undertaken.

- *Water Quality Monitoring Program*

  The water quality monitoring over the last two years has served an important role in understanding current conditions at Ball Pond, and how those conditions have changed from the past. We believe this program should be continued, particularly if management initiatives are implemented. Regular water quality monitoring will provide a means of gauging efficacy of those management efforts.

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APPENDIX A. FIELD AND LABORATORY DATA

Temp = Temperature; DO = Dissolved Oxygen; Rel Phyco = relative phycocyanin; Spec C = specific conductance; ORP = oxidation-reduction potential; Alk = Alkalinity; Epi = epilimnion; Meta = metalimnion; Hypo = hypolimnion

April 20, 2022

Depth (m)	Temp (°C)	DO (mg/L)	DO (%)	Rel Phyco (µg/L)	Spec C (µS/cm)	ORP (mV)	pH (SU)
0.5	9.5	11.74	105.9	9.02	399.9	278.2	9.61
1	9.45	11.92	107.4	3.95	399.5	280.7	9.53
2	9.43	11.92	107.3	6.26	399	282.1	9.42
3	9.35	11.93	107.2	6.31	398.6	282.8	9.35
4	9.35	11.9	106.9	6.43	398.4	283.1	9.32
5	9.22	11.61	104	5.96	398.5	285.2	9.22
6	9.06	11.44	102	5.89	398.8	286.8	9.14
7	8.6	11.34	100	5.5	399.4	288	9.1
8	7.19	9.4	80.1	5.37	402	293.9	8.84
9	6.97	7.59	64.3	4.44	403.4	298.8	8.65
10	6.82	6.77	57.2	3.76	404.4	301.6	8.51
11	6.72	6.79	57.2	3.85	405.4	302.1	8.51
12	6.65	5.87	49.4	3.74	406.3	157.5	8.38
13	6.62	5.9	49.5	3.92	406.3	150.6	8.34
14	6.6	4.97	41.7	4.48	407	103.5	9.06

May 18, 2022

Depth (m)	Temp (°C)	DO mg/L	DO %	Rel Phyco (µg/L)	Spec C (µS/cm)	ORP (mV)	pH (SU)
0.5	18.76	10.42	115.2	3.84	400.4	247.7	8.76
1	18.74	10.44	115.4	3	400.4	248.5	8.74
2	18.61	10.49	115.6	3.49	400.4	249	8.73
3	13.48	11.73	115.9	4.83	401.6	254.1	8.66
4	12.59	10.04	97.2	4.62	402.6	264.9	8.23
5	12.09	8.53	81.7	4.6	402.8	271.5	8.21
6	11.37	6.28	59.1	4.62	402.6	277.9	8.55
7	10.29	3.14	28.9	3.75	403.2	285.7	8.24
8	9.29	0.67	6	3	403.4	289.3	8.11
9	8.31	0.44	3.8	3.45	406.7	288.6	8.51
10	7.68	0.23	2	3.64	410.6	280.6	8.98
11	7.43	0.15	1.3	3.34	412	270.2	9.18
12	7.24	0.1	0.8	3.9	413.5	258.7	9.27
13	7.13	0.05	0.4	3.66	415.3	221.5	9.36
14	7.04	0.04	0.3	3.61	416.6	195.9	9.39
15	6.99	0.03	0.3	3.73	417.3	181	9.42

June 15, 2022

Depth (m)	Temp (°C)	DO mg/L	DO %	Rel Phyco (µg/L)	Spec C (µS/cm)	ORP (mV)	pH (SU)
0.5	24.01	10.19	124.8	5.17	404.5	272.5	8.77
1	23.82	10.35	126.3	5.55	404.1	269.6	8.79
2	23.64	10.45	127.1	6.21	404.1	269.9	8.76
3	22.29	8.5	100.7	5.88	404.2	278.3	8.4
4	17.06	5.38	57.4	3.32	407.1	296	7.6
5	13.81	5.12	51	3.57	404.4	297.9	7.6
6	11.78	0.81	7.7	9.82	404.1	308	7.33
7	10.76	0.31	2.8	5.99	406.4	310.2	7.33
8	9.57	0.22	1.9	6.2	409.3	311.3	7.34
9	8.43	0.15	1.3	6.55	414.1	312.9	8.03
10	7.8	0.09	0.7	2.54	417.2	291.7	8.92
11	7.37	0.08	0.6	2.04	420.8	278.4	9.04
12	7.23	0.06	0.5	2.07	422.6	263.6	9.12
13	7.15	0.05	0.5	2.05	424.2	246.8	9.18
14	7.13	0.04	0.3	2.51	425	204.5	9.24
15	7.12	0.04	0.3	2.67	425.3	182.8	9.27

July 20, 2022

Depth (m)	Temp (°C)	DO mg/L	DO %	Rel Phyco (µg/L)	Spec C (µS/cm)	ORP (mV)	pH (SU)
0.5	27.4	9.18	119.6	3.02	421.1	279.8	8.76
1	26.92	9.34	120.6	3.19	420.3	277.2	8.78
2	26.4	9.8	125.5	3.16	418.7	274.4	8.79
3	25.37	7.37	92.5	5.2	419.4	283.1	8.45
4	22.11	1.48	17.5	7.22	413.9	308.4	7.41
5	16.33	1.31	13.8	8.11	405.1	309.4	7.45
6	12.7	0.52	5	20.39	403.7	318.7	7.24
7	10.66	0.19	1.7	8.08	406.2	321.7	7.2
8	9.4	0.11	1	5.72	411.4	323.5	7.22
9	8.47	0.07	0.6	3.63	420.1	315.6	8.25
10	7.94	0.05	0.4	2.3	424.8	294.7	8.8
11	7.67	0.04	0.4	2.51	426.5	275.5	8.97
12	7.49	0.03	0.3	2.1	428.5	228.8	9.11
13	7.42	0.03	0.2	2.09	429.8	196.6	9.15
14	7.33	0.03	0.2	2.04	432.8	150	9.17
15	7.31	0.03	0.2	2.26	433.1	122	9.17

August 17, 2022

Depth (m)	Temp (°C)	DO mg/L	DO %	Rel Phyco (µg/L)	Spec C (µS/cm)	ORP (mV)	pH (SU)
0.5	25.09	7.48	93.4	2.42	430.6	295	8.38
1	25.09	7.38	92.1	2.06	430.6	295.1	8.38
2	25.08	7.35	91.8	2.83	430.6	295.1	8.38
3	25.07	7.29	91.1	2.62	430.6	295.2	8.38
4	24.55	5.82	72	2.85	428.3	304.4	8.05
5	21.22	1.47	17.1	3.22	415.3	321.2	7.34
6	15.09	0.79	8	4.69	404.1	325.9	7.28
7	11.99	0.74	7.1	27.16	402.5	329.2	7.22
8	9.73	0.35	3.2	22.17	414.2	332.9	7.56
9	8.42	0.22	1.9	7.66	429.3	314.8	8.69
10	7.96	0.14	1.2	5.49	433.3	289.9	8.98
11	7.71	0.09	0.8	5.66	435.5	260.4	9.08
12	7.55	0.08	0.7	5.36	437.9	248.6	9.09
13	7.51	0.06	0.5	5	439.3	219.5	9.11
14	7.46	0.04	0.4	4.5	440.3	187.6	9.12

September 14, 2022

Depth (m)	Temp (°C)	DO mg/L	DO %	Rel Phyco (µg/L)	Spec C (µS/cm)	ORP (mV)	pH (SU)
0.5	22.97	8.24	98.9	5.36	420.2	298.9	8.52
1	22.96	8.2	98.4	1.96	420.2	300.8	8.44
2	22.96	8.19	98.3	2.7	420.1	302.4	8.39
3	22.96	8.15	97.8	2.56	420.1	303.7	8.36
4	22.76	6.69	80	2.95	420.9	316.7	7.98
5	22.12	4.3	50.8	2.47	420.7	329.7	7.59
6	18.58	0.14	1.5	5.5	412.7	340.7	7.23
7	13.98	0.05	0.5	8.48	404	343.1	7.25
8	10.51	0.02	0.2	16.37	416.2	349.2	7.19
9	8.87	0.01	0.1	11.08	432.3	349.7	7.37
10	8.35	0.02	0.1	5.78	435.9	324.2	8.4
11	8.09	0.02	0.2	4.92	438.3	302.3	8.48
12	7.94	0.02	0.2	4.57	440.2	274	8.53
13	7.72	0.02	0.2	4.05	443.5	253.1	8.53
14	7.62	0.03	0.2	3.52	446.2	-0.5	8.51

October 12, 2022

Depth (m)	Temp (°C)	DO mg/L	DO %	Rel Phyco (µg/L)	Spec C (µS/cm)	ORP (mV)	pH (SU)
0.5	15.47	9.36	96.6	3.22	414.7	303.7	10.15
1	15.4	9.31	95.9	3.34	414.5	306.1	9.61
2	15.21	9.21	94.5	3.39	414.8	309.6	8.97
3	15.14	9.07	92.9	3.35	414.8	313	8.47
4	15.1	8.94	91.5	3.76	414.8	314.8	8.24
5	15.08	8.79	89.9	2.9	414.8	317.1	8.09
6	15.03	8.63	88.2	3.33	414.9	318.6	8.01
7	14.83	6.67	67.8	2.62	415.1	325.4	7.69
8	13.71	1.06	10.5	2.55	415.1	335.6	7.24
9	9.88	0.23	2.1	7.01	434.3	344.8	7.22
10	8.61	0.14	1.2	5.35	444.6	338.1	8.12
11	8.19	0.1	0.8	4.36	446.9	323.3	8.38
12	7.9	0.08	0.7	4.18	451.8	308.3	8.46
13	7.83	0.06	0.5	4.1	452.7	289.1	8.52
14	7.8	0.06	0.5	4.65	455.2	278.1	8.53
15	7.74	0.05	0.4	4.79	459.8	266.1	8.55

Biologicals

	20-Apr	18-May	20-Jun	20-Jul	17-Aug	14-Sep	12-Oct
Secchi Transparency	1.72	2.48	2.26	2.02	2.91	3.75	3.60
Avg. Rel. Phyco	6.39	3.79	5.70	3.60	2.50	3.10	3.30
Cyanobacteria cells	9203	3804	1343(6	2109	727	2754	
Chlorophyll-a	5.3	6.08	13.5	8.06	1.56	3.09	9.69

Units: Secchi disk transparency in meters; Average Relative Phycocyanin in µg/L; Cyanobacteria cells in cells/mL; and Chlorophyll-a in µg/L

Total phosphorus (µg/L)

Strata	20-Apr	18-May	15-Jun	20-Jul	17-Aug	14-Sep	12-Oct
Epi	10	4	0	12	9	45	8
Meta	10	6	2	22	12	7	41
Hypo	10	148	257	443	596	401	668

Total Kjeldahl Nitrogen (mg/L)

Strata	20-Apr	18-May	15-Jun	20-Jul	17-Aug	14-Sep	12-Oct
Epi	0	1.01	0.77	0.60	1.06	1.31	0.60
Meta	0	0.93	0.69	0.66	0.60	1.02	0.66
Hypo	0	1.50	2.39	0.60	2.83	2.49	3.93

Ammonia (mg/L)

Strata	20-Apr	18-May	15-Jun	20-Jul	17-Aug	14-Sep	12-Oct
Epi	0.00	0.00	0.00	0.00	0.00	0.35	0.27
Meta	0.00	0.00	0.00	0.00	0.17	0.16	0.66
Hypo	0.00	1.06	1.45	2.10	2.99	2.09	3.52

Alkalinity (mg/L)

Strata	20-Apr	18-May	15-Jun	20-Jul	17-Aug	14-Sep	12-Oct
Epi	78	280	84	84	84	86	90.0
Meta	77	40	96	82	80	84	92.0
Hypo	77	92	92	80	108	92	122.0

	pH (SU)						
Strata	**20-Apr**	**18-May**	**15-Jun**	**20-Jul**	**17-Aug**	**14-Sep**	**12-Oct**
Epi	9.5	8.7	8.8	8.8	8.4	8.4	9.6
Meta	7.2	8.7	8.4	7.4	7.3	7.2	7.2
Hypo	6.6	9.4	9.3	9.2	9.1	8.5	8.6

Ion data from samples collected at 1 meters of depth

Date	Potassium		Sodium		Calcium	
	mg/L	meq/L	mg/L	meq/L	mg/L	meq/L
20-Apr	5.0	0.13	48.0	2.1	24.0	1.2
18-May	2.5	0.06	44.5	1.9	24.9	1.2
15-Jun	2.1	0.05	42.0	1.8	23.8	1.2
20-Jul	2.2	0.06	44.2	1.9	24.0	1.2
17-Aug	2.4	0.06	44.5	1.9	25.0	1.2
14-Sep	2.3	0.06	44.5	1.9	24.4	1.2
12-Oct	2.5	0.06	44.7	1.9	24.6	1.2

Date	Magnesium		Chloride		Alkalinity	
	mg/L	meq/L	mg/L	meq/L	mg/L	meq/L
20-Apr	7.6	0.6	80.0	2.3	78	1.56
18-May	8.2	0.7	75.6	2.2	280	5.60
15-Jun	8.6	0.7	72.9	2.1	84	1.68
20-Jul	8.3	0.7	77.4	2.2	84	1.68
17-Aug	6.6	0.6	80.0	2.3	84	1.68
14-Sep	7.7	0.6	79.0	2.3	86	1.72
12-Oct	8.2	0.7	78	2.2	90	1.80

APPENDIX B. ALGAE COUNT DATA

April 20, 2022

Taxa	*Genus / species*	Cells / mL	%	Taxa cells / mL	Taxa %
Cyanophyta	*Aphanizomenon sp.*	0	0.0	9203	59.0
	Dolichospermum sp.	17	0.1		
	Planktothrix sp.	9186	58.9		
	Microcystis sp.	0	0.0		
	Woronichinia sp.	0	0.0		
Chlorophyta	*Anikistrodesmus sp.*	17	0.1	1814	11.6
	Elakatothrix sp.	17	0.1		
	Mougeotia sp.	33	0.2		
	Oocystis sp..	67	0.4		
	Scenedesmus sp.	1548	9.9		
	Selenastrum sp.	83	0.5		
	Sphaerocystis sp.	17	0.1		
	Staurastrum sp.	17	0.1		
	Tetraedron sp.	17	0.1		
Chrysophyta	*Chrysosphaerella sp.*	0	0.0	416	2.7
	Dinobryon sp.	17	0.1		
	Mallomonas sp.	17	0.1		
	Uroglenopsis sp.	383	2.5		
Bacillariophyta	*Asterionella sp.*	17	0.1	3744	24.0
	Aulocoseria sp.	0	0.0		
	Cyclotella sp.	3262	20.9		
	Fragilaria sp.	17	0.1		
	Synedra sp.	449	2.9		
Dinophyceae	*Ceratium sp.*	0	0.0	33	0.2
	Peridinium sp.	33	0.2		
Cryptophyceae	*Cryptomonas sp.*	283	1.8	283	1.8
Euglenophyceae	*Euglena sp.*	0	0.0	17	0.1
	Trachelomonas sp.	17	0.1		
	Unknown	83	0.5	83	0.5
Taxa identified 21	*Totals*	15594	100	15594	100

May 18, 2022

Taxa	*Genus / species*	Cells / mL	%	Taxa cells / mL	Taxa %
Cyanophyta	*Aphanizomenon sp.*	249	3.9	3804	59.6
	Dolichospermum sp.	0	0.0		
	Planktothrix sp.	3555	55.7		
	Microcystis sp.	0	0.0		
	Woronichinia sp.	0	0.0		
Chlorophyta	*Anikistrodesmus sp.*	8	0.1	1564	24.5
	Elakatothrix sp.	93	1.5		
	Oocystis sp..	47	0.7		
	Mougeotia sp.	16	0.2		
	Scenedesmus sp.	1182	18.5		
	Selenastrum sp.	78	1.2		
	Staurastrum sp.	47	0.7		
	Tetraedron sp.	93	1.5		
Chrysophyta	*Chrysosphaerella sp.*	0	0.0	16	0.2
	Mallomonas sp.	8	0.1		
	Uroglenopsis sp.	8	0.1		
Bacillariophyta	*Asterionella sp.*	0	0.0	864	13.5
	Aulocoseria sp.	16	0.2		
	Cyclotella sp.	832	13.0		
	Fragilaria sp.	8	0.1		
	Synedra sp.	8	0.1		
Dinophyceae	*Ceratium sp.*	0	0.0	39	0.6
	Glenodinium sp.	23	0.4		
	Peridinium sp.	16	0.2		
Cryptophyceae	*Cryptomonas sp.*	86	1.3	86	1.3
Euglenophyceae	*Euglena sp.*	0	0.0	8	0.1
	Trachelomonas sp.	8	0.1		
	Unknown	0	0.0	0	0.0
Taxa identified 20	*Totals*	6379	100	6379	100

June 15, 2022

Taxa	*Genus / species*	Cells / mL	%	Taxa cells / mL	Taxa %
Cyanophyta	*Aphanizomenon sp.*	1545	10.6	13436	92.4
	Dolichospermum sp.	11873	81.6		
	Planktothrix sp.	0	0.0		
	Microcystis sp.	0	0.0		
	Woronichinia sp.	17	0.1		
Chlorophyta	*Anikistrodesmus sp.*	35	0.2	590	4.1
	Closterium sp.	278	1.9		
	Gloeocystis sp.	17	0.1		
	Oocystis sp..	0	0.0		
	Mougeotia sp.	17	0.1		
	Pediastrum sp.	139	1.0		
	Scenedesmus sp.	104	0.7		
Chrysophyta	*Chrysosphaerella sp.*	0	0.0	139	1.0
	Mallomonas sp.	104	0.7		
	Uroglenopsis sp.	35	0.2		
Bacillariophyta	*Asterionella sp.*	0	0.0	139	1.0
	Cyclotella sp.	139	1.0		
Dinophyceae	*Ceratium sp.*	0	0.0	87	0.6
	Peridinium sp.	87	0.6		
Cryptophyceae	*Cryptomonas sp.*	35	0.2	35	0.2
Euglenophyceae	*Euglena sp.*	0	0.0	87	0.6
	Trachelomonas sp.	87	0.6		
	Unknown	35	0.2	35	0.2
Taxa identified 15	*Totals*	14547	100	14547	100

July 20, 2022

Taxa	*Genus / species*	Cells / mL	%	Taxa cells / mL	Taxa %
Cyanophyta	*Aphanizomenon sp.*	255	2.7	2109	22.4
	Dolichospermum sp.	1854	19.7		
	Planktothrix sp.	0	0.0		
	Microcystis sp.	0	0.0		
	Woronichinia sp.	0	0.0		
Chlorophyta	*Anikistrodesmus sp.*	0	0.0	6836	72.5
	Closterium sp.	1020	10.8		
	Coelastrum sp	278	2.9		
	Gloeocystis sp.	1946	20.6		
	Oocystis sp..	834	8.8		
	Scenedesmus sp.	1854	19.7		
	Selenastrum sp.	46	0.5		
	Tetraedron sp.	857	9.1		
Chrysophyta	*Chrysosphaerella sp.*	0	0.0	116	1.2
	Mallomonas sp.	70	0.7		
	Uroglenopsis sp.	46	0.5		
Bacillariophyta	*Asterionella sp.*	0	0.0	116	1.2
	Cyclotella sp.	93	1.0		
	Synedra sp.	23	0.2		
Dinophyceae	*Ceratium sp.*	0	0.0	23	0.2
	Glenodinium sp.	23	0.2		
	Peridinium sp.	0	0.0		
Cryptophyceae	*Cryptomonas sp.*	46	0.5	46	0.5
Euglenophyceae	*Euglena sp.*	0	0.0	46	0.5
	Trachelomonas sp.	46	0.5		
	Unknown	139	1.5	139	1.5
Taxa identified 16	*Totals*	9431	100	9431	100

August 17, 2022

Taxa	*Genus / species*	Cells / mL	%	Taxa cells / mL	Taxa %
Cyanophyta	*Aphanizomenon sp.*	414	7.8	727	13.7
	Chroococcus sp.	121	2.3		
	Dolichospermum sp.	182	3.4		
	Planktothrix sp.	0	0.0		
	Microcystis sp.	10	0.2		
	Woronichinia sp.	0	0.0		
Chlorophyta	*Anikistrodesmus sp.*	20	0.4	2353	44.2
	Closterium sp.	20	0.4		
	Coelastrum sp	545	10.2		
	Cosmarium sp.	61	1.1		
	Elakatothrix sp.	20	0.4		
	Gloeocystis sp.	1282	24.1		
	Oocystis sp..	101	1.9		
	Pediastrum sp.	10	0.2		
	Scenedesmus sp.	222	4.2		
	Staurastrum sp.	10	0.2		
	Tetraedron sp.	61	1.1		
Chrysophyta	*Chrysosphaerella sp.*	0	0.0	81	1.5
	Uroglenopsis sp.	81	1.5		
Bacillariophyta	*Asterionella sp.*	0	0.0	2020	38.0
	Aulocoseria sp.	10	0.2		
	Cyclotella sp.	1999	37.6		
	Synedra sp.	10	0.2		
Dinophyceae	*Ceratium sp.*	0	0.0	20	0.4
	Glenodinium sp.	20	0.4		
	Peridinium sp.	0	0.0		
Cryptophyceae	*Cryptomonas sp.*	101	1.9	101	1.9
Euglenophyceae	*Euglena sp.*	0	0.0	20	0.4
	Trachelomonas sp.	20	0.4		
	Unknown	0	0.0	0	0.0
Taxa identified					
22	*Totals*	5322	100	5322	100

September 14, 2022

Taxa	*Genus / species*	Cells / mL	%	Taxa cells / mL	Taxa %
Cyanophyta	*Aphanizomenon sp.*	415	10.5	2754	69.7
	Aphanocapsa sp.	58	1.5		
	Dolichospermum sp.	188	4.8		
	Lyngbya sp.	6	0.2		
	Planktothrix sp.	0	0.0		
	Microcystis sp.	2086	52.8		
	Woronichinia sp.	0	0.0		
Chlorophyta	*Anikistrodesmus sp.*	6	0.2	933	23.6
	Coelastrum sp	52	1.3		
	Gloeocystis sp.	52	1.3		
	Kirchneriella sp.	292	7.4		
	Oocystis sp..	26	0.7		
	Mougeotia sp.	13	0.3		
	Pediastrum sp.	104	2.6		
	Scenedesmus sp.	272	6.9		
	Selenastrum sp.	39	1.0		
	Tetraedron sp.	78	2.0		
Chrysophyta	*Chrysosphaerella sp.*	0	0.0	13	0.3
	Mallomonas sp.	13	0.3		
Bacillariophyta	*Asterionella sp.*	0	0.0	45	1.1
	Cyclotella sp.	45	1.1		
Dinophyceae	*Ceratium sp.*	0	0.0	19	0.5
	Peridinium sp.	19	0.5		
Cryptophyceae	*Cryptomonas sp.*	78	2.0	78	2.0
Euglenophyceae	*Euglena sp.*	0	0.0	26	0.7
	Trachelomonas sp.	26	0.7		
	Unknown	84	2.1	84	2.1
Taxa identified					
20	*Totals*	3953	100	3953	100