AQUATIC ECOSYSTEM RESEARCH
A Freshwater Conservation Company

Ball Pond

2021 Water Quality Monitoring

Prepared for the
Ball Pond Advisory Commission
New Fairfield, CT
December 17, 2021

Cover photograph by Maureen Dangelo.

EXECUTIVE SUMMARY

Aquatic Ecosystem Research (AER) was engaged by the Ball Pond Advisory Committee (BPAC) to assess water quality using data collected in 2021 from Ball Pond by members of the community and Town Officials of New Fairfield. Data and sample collections occurred on April 26, May 27, June 21, July 27, August 25, September 30, and October 28. A summary of data collected and our assessments are provided below. AER was also requested to compile and report on data collected in a CyanoMonitoring program and in a cyanotoxin monitoring program. Dates of those sampling events and our assessments are provided within. Recommendations are provided at the end of the report.

- Ball Pond was stratified on each water quality sampling date.
    - Relative resistance to mixing was strong (RTRM>80) on each date with the exception of April 26th.
    - Anoxic conditions were common in the hypolimnion.
        - Oxygen concentrations of <1mg/L occupied the area from the 9m stratum to the bottom (15m) on May 27th.
        - Those concentrations were measured from the 8m strata to the bottom on August 25th.
        - Oxygen concentrations in the hypolimnion increased to >6mg/L by October 28th.

- Some trophic variables were noncongruent with others.
    - Secchi disk transparencies were reflective of eutrophic conditions from April 26th through July 27th; and, of mesotrophic conditions from August 8th through October 28th.
        - Average conditions were characteristic of late-mesotrophic productivity.
    - Average chlorophyll-*a* concentrations were characteristic of mesotrophic productivity.
        - Actual measurements ranged from 1.5µg/L on June 21st to 14.7µg/L on September 30th.
    - Total phosphorus concentrations were characteristic of eutrophic conditions.
        - Average epilimnetic concentrations were 34µg/L with early season concentrations higher than mid to late season concentrations except for the September 30th measurement, which was similar to the early season epilimnetic concentrations.
        - Metalimnetic concentrations mostly paralleled epilimnetic concentrations.
            - June 21st and August 27th metalimnetic concentrations were notably higher than epilimnetic concentrations.
            - The season average was 48 µg/L.
        - The hypolimnetic average of 187µg/L was significantly higher than the other strata.

      - Concentrations increased from April 26th through July 27th / August 25th before decreasing precipitously by September 30th.
  - Total nitrogen levels in the epilimnion and metalimnion were also found to have the potential to support eutrophic algal productivity.
    - Hypolimnetic total nitrogen concentrations were 2 to 3x greater than epilimnetic and metalimnetic concentrations.
      - The hypolimnetic total nitrogen was largely ammonia in many samples.
    - Redfield ratios were strongly indicative of phosphorus limitation in the epilimnion.
      - Ratios became progressively lower with depth, with the hypolimnetic average nearly indicative of nitrogen limitation.
  - Carlson TSI calculations were applied to Secchi, chlorophyll, and total phosphorus data, and corroborated the trophic incongruencies.

- Epilimnetic pH, alkalinity, and calcium levels were high compared to other lakes.
  - This combination of chemical factors allows for the potential of coprecipitation of phosphorus.
    - This would explain the lower chlorophyll concentrations relative to the high total phosphorus levels.
  - Average hypolimnetic alkalinity was significantly higher than epilimnetic and metalimnetic averages.
    - Concentrations increased through the early season and remained high from June 21st through October 28th.
      - Elevated hypolimnetic alkalinity provides another line of evidence of internal loading of phosphorus in the hypolimnion.

- Specific conductance in the epilimnion averaged 416µS/cm, which is very high in comparison to other lakes.
  - An unusually wide range of epilimnetic levels were measured over the season.
  - Variability in epilimnetic specific conductance was not explained by potential precipitation.

- Much of the 2021 data was focused on cyanobacteria dynamics at Ball Pond.
  - The CyanoMonitoring Program provided insight into the cyanobacteria populations at Ball Pond.
    - Picoplankton-size cyanobacteria were, at times, a large component of the cyanobacteria community.
    - Shifts in the deep-water site BFC phycocyanin concentrations and BFC cyanobacteria population growth rates were not as episodic as those observed at the shoreline sampling sites.
      - These differences may reflect buoyancy regulation and localized wind driven cell concentration.
  - Microcystin levels were measured weekly from July 14th through September 2nd.

    - Concentrations never reached a level of concern.
  - A very concentrated layer of cyanobacteria was detected on September 3rd below the thermocline.

- Nutrient export from the watershed and internal loading contribute to the phosphorus budget.
  - Based on available data, it is not possible to determine the influence of either the watershed or the lake bed on the trophic status of the lake.

- Since 1993, specific conductance has increased considerably.
  - This phenomenon needs further investigation.
  - Increasing salts in lakes may have negative ecosystem health impacts, alter spring mixing patterns, and – potentially – the hypolimnetic oxygen recharge.

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INTRODUCTION

Ball Pond is an 82.5-acre natural kettle lake located in New Fairfield, CT. The lake's origins are geologically tied to the retreat of the Laurentide Ice Sheet some *ca* 10,000 to 12,000 years before present. The lake now is 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).

The lake is spring or groundwater fed. It also receives stormwater runoff from the watershed. 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 watershed is relatively small and the lake/watershed have 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 a glacial erratic that is potentially providing the carbonate influence to the system (J. Mellett, personal communication, December 4, 2021).

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	35	52	9	35	15	417
1970	33	18	24	33	25	506
1990	33	15	15	33	32	600

Analyses of historical land cover in the watersheds of thirty Connecticut lakes was performed by Field et.al. (1996) and the results for the Ball Pond watershed are 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) exports 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.

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 Ball Pond average Secchi 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.

Figure 1. Photograph of a surface cyanobacteria bloom taken at Ball Pond on August 13, 2021. Photo credit: Elissa Johnson, 2021.

High concentrations of phosphorus – like those found in Ball Pond – predispose waterbodies to cyanobacteria algal blooms, which can diminish the value of various services that the lake provides. Blooms also have the potential to pose health risks to people and pets that come in contact with algal blooms due to the toxic compounds synthesized by some genera of cyanobacteria (CT DPH & CT DEEP 2019, USEPA 2020). Cyanobacteria blooms have been documented at Ball Pond (Fig. 1).

Other lines of evidence that Ball Pond has experienced cultural eutrophication and other anthropologically induced water quality changes are archived by microalgae fossils chronologically layered in the sediments of the lake. In the 1990s, a paleolimnological investigation of 23 Connecticut lakes was conducted whereby siliceous microfossils from two algal taxa – scaled chrysophytes and diatoms – were quantified in sections of sediment cores; those data were used as input to statistically significant inference models to estimate 100-year changes in water quality characteristics (Siver et. al. 1999). Inferred increases in specific conductance at Ball Pond were among the highest of the 23 lakes. Inferred nutrient statuses and pH also increased over time based on fossilized algal data.

Norvell (1982) reported on the phosphorus dynamics in Ball Pond and the feasibility of inactivating soluble reactive phosphorus (SRP) with aluminum salts. The report characterized the lake as eutrophic with much of the phosphorus budget in the form of soluble reactive phosphorus that was derived through internal loading process occurring in lake sediments during periods of anoxia. Norvell concluded that Ball Pond was a good candidate for treatment with an aluminum salt to reduce soluble phosphorus levels.

Cultural eutrophication is one of two important lake management concerns at Ball Pond. The other is management of aquatic invasive plants, including *Myriophyllum spicatum* (Eurasian watermilfoil). A history of plant management is provided in Stevens (2017) and management techniques used at Ball Pond in the past included diver assisted suction harvesting, benthic barriers, and hand-raking.

In 1997, a biological control program that leveraged triploid grass carp (*Ctenopharyngodon idella*) was initiated. The State permit for the release of the non-native fish was conditioned on regular monitoring of the plant community, water quality, and fisheries in the lake. Data from those monitoring efforts between 1997 and 2014 were compiled, analyzed, and reported on by June-Wells et. al. (2017). Findings included a significant reduction in *M. spicatum* biomass, but no reduction in plant species richness. They also reported no significant change in water quality or fish density/diversity, but noted a reduction in fish species richness over the study period. Since 2019, there has been an alarming reduction in plant biomass and richness (T. Simpkins, personal communication, December 5, 2021). There are concerns that the triploid grass carp may have been overstocked, which lead to reduced aquatic plant cover.

Active management of the lake has been overseen by the BPAC and includes a water quality monitoring program and aquatic plant monitoring/management. In 2021, AER was contracted by the BPAC to compile and evaluate the 2021 water quality data. Those data included standard limnological field and laboratory data (e.g., nutrient levels), levels of the cyanobacteria toxin microcystin, and data compiled in 2021 using protocols in a Cyanomonitoring program. Cyanomonitoring is a national program developed by the Cyanobacteria Monitoring Collaborative (CMC 2021) led by the US EPA.

Figure 2. Locations of the deep-water, water quality/cyanobacteria monitoring site, and the two shoreline cyanobacteria monitoring sites on Ball Pond.

METHODS

A once-monthly water quality monitoring plan was established by the Town of New Fairfield and the Ball Pond Advisory Committee (BPAC) to collect field data and water samples at Ball Pond between the months of April and October. In addition, the BPAC was awarded a grant to conduct biweekly cyanobacteria monitoring. The monthly sampling dates were as follows: April 26, May 27, June 21, July 27, August 25, September 30, and October 28. Additionally, the biweekly sampling dates were June 18, June 25, July 5, July 10, July 23, August 8, August 20, September 3, and September 17.

Monthly sampling consisted of visiting one deep water site (41.4618909, -73.52452372; Fig. 2) where the following data were collected:

- Secchi disk transparency was measured with a standard 20cm Secchi disk in feet and converted to meters
- Temperature (°C), dissolved oxygen (mg/L), conductivity (µS/cm), and pH (SU) were measured at 0.5m below the surface and at each meter from 1m to 15m of depth.

In addition, water samples were collected from the epilimnion at one meter of depth, the metalimnion (variable depth), and at 1m above the sediment-water interface (hypolimnion; ~14m) using a horizontal Van Dorn sampler. Those samples were kept in an iced cooler below 5°C until delivery to HydroTechnologies, LLC, a Connecticut State certified laboratory located in New Milford, CT. Those samples were analyzed for total phosphorus, total Kjeldahl nitrogen, nitrate, nitrite, ammonia, alkalinity, and calcium. One additional sample was collected at 1m of depth for analysis of chlorophyll-*a*, which was also conducted by HydroTechnologies, LLC.

During biweekly sampling, three independent sites were visited where water sample collections occurred (Fig. 2). Those sites were: 1) the same deep-water site where monthly sampling was conducted: 2) the public boat launch on the southern tip of the lake (41.457543, -73.522169); and 3) a private residential dock on the eastern cove of the lake (41.464863, -73.520086). At the deep site, Secchi transparency was measured in the same manner as done during the monthly sampling. At each of the three sites, two water samples were collected: One marked as WLW (for whole-lake-water) and one marked as BFC (for bloom forming cyanobacteria). The WLW sample was collected at the deep site by integrating the top 3m of the water column with a weighted vertical tube sampler. That sample was placed into a brown plastic bottle to prevent sunlight from stimulating algal cell growth and stored in an iced cooler.

At the two nearshore sites (Fig.2), the sample bottle was manually submerged to an arm’s length into the water to collect the WLW samples. The BFC samples at all three sites were taken using a 53µm plankton net to collect concentrated algal samples, which were placed into identical brown plastic bottles. All six samples were allowed to rest for two hours; then, subsamples of each were transferred to individual sample vials and frozen. An additional vial was filled with the concentrate from the net sample from each site for use in isolating picoplankton[1], which was by performed by running the sample through a 50µm mesh filter.

Frozen samples were allowed to thaw before being placed into clear glass samplers and analyzed with a fluorometer to measure concentrations of phycocyanin and chlorophyll-*a* (both in units of µg/L). Additionally, water from each site was placed in a Pocket ZAPPR[2] where organisms in the sample could separate, i.e., bloom forming cyanobacteria surfaced while zooplankton migrated to the bottom of the device. Once separated, bloom forming algae at the surface of the Pocket ZAPPR™ were analyzed under a microscope to identify the genera of cyanobacteria present at each site.

Field, laboratory, and algae data were conveyed to AER for analyses. Temperature profile 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).

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[1] Algae of ≤2µm in diameter.

[2] See http://lim-tex.com/products/pocket-zappr/

PROFILE DATA

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

Temperature and Oxygen

Water temperature data provides a view into the thermal characteristics of the lake and the patterns of stratification resulting from temperature/density differences between depth-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 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 aerobic organisms in freshwater systems. As concentrations decrease below that threshold, conditions become stressful for many forms of life. Minimum oxygen requirements for fisheries in Connecticut's lakes and ponds 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) from the sediments to the interstitial waters and – then, by diffusion – to the waters above the sediments.

The surface temperature on April 26th was 12°C, which remained constant with depth to 6m where it decreased to 10.3°C. The temperature then decreased rapidly to 5.5°C by 10m of depth and remained constant from that stratum to the bottom (15m, Fig. 3). The upper boundary of the metalimnetic layer was located between 5 and 6m of depth with a thermocline between the 6 and 7m strata. The oxygen concentration at the surface was 12.8mg/L, which steadily decreased to 7.2mg/L at the thermocline. There was an increase in oxygen concentration 1m below the thermocline (10.2mg/L), which then steadily decreased to 1.7mg/L at the bottom. It is worth noting the reduced oxygen levels below the thermocline early in the season.

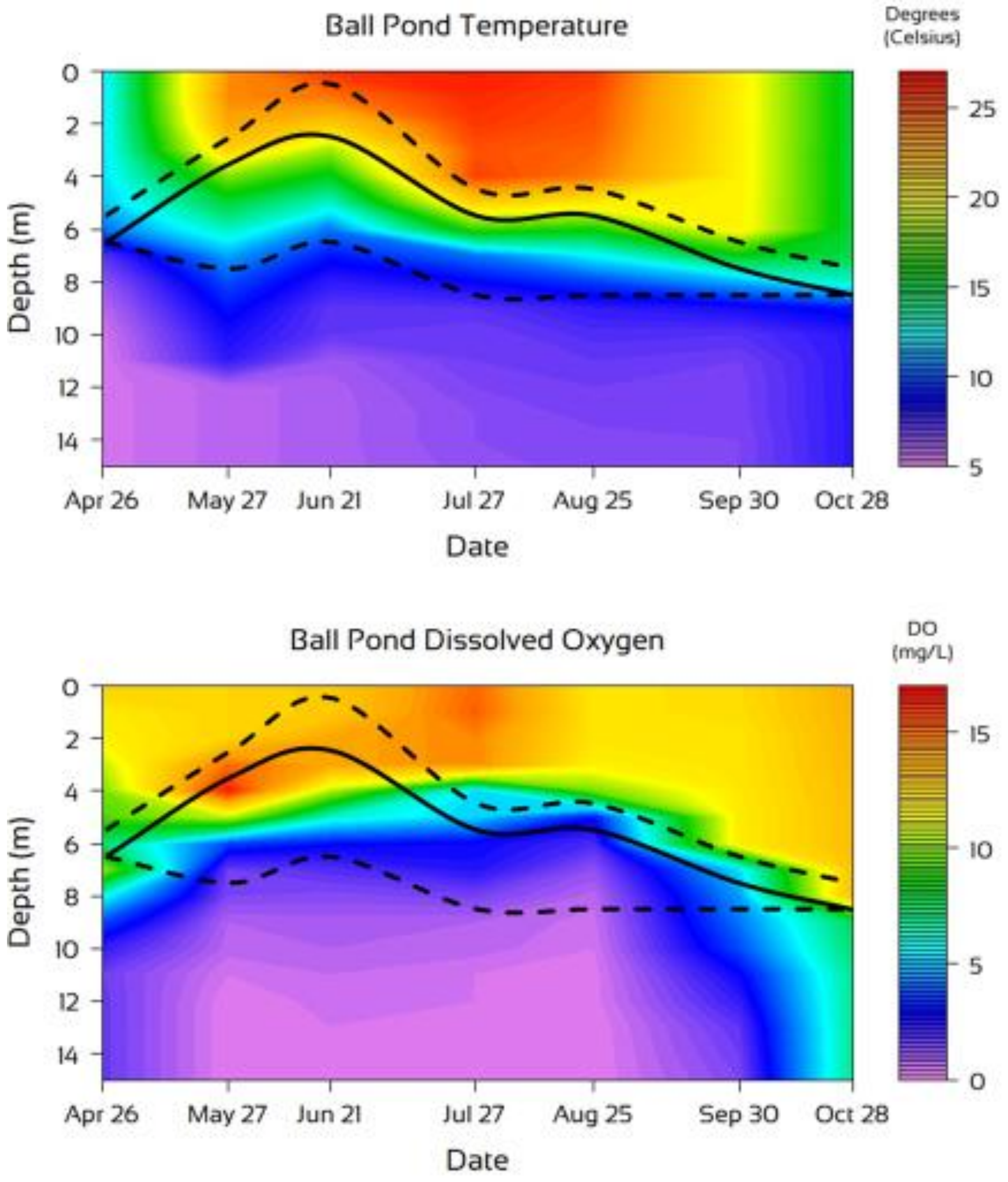


Figure 3. Isopleth plots of water column temperature (top panel) and dissolved oxygen (bottom panel) for Ball Pond in 2021. The dashed black line represents the upper or lower boundary of the metalimnion; the solid black line represents the thermocline.

By May 27, surface temperatures had nearly doubled and the metalimnetic layer had expanded greatly with the upper boundary situated between 2 and 3m of depth including with a thermocline between 3 and 4m of depth (Fig. 2). The temperature declined steadily to the thermocline where the temperature measured 17.8°C then declined steadily with depth to the bottom where the temperature was 5.9°C. Oxygen concentration – once again – increased below the thermocline, rising from 12.6mg/L at the surface to 16.5 at 4m of depth. Afterwards, oxygen concentration decreased to 1.6mg/L by 7m of depth then steadily decreased to anoxic levels at the bottom.

By June 21st, the thermocline had shifted to between 2 and 3m of depth – its highest position in the water column for the season. The metalimnetic layer also was at its widest, spanning the strata from 0.5m to 6m of depth. The temperature followed the same pattern as earlier months, diminishing slightly at the thermocline before steadily decreasing to 6°C at the bottom. Oxygen levels also followed the previous pattern; increasing to 14mg/L at the thermocline before dropping sharply to anoxic levels, which were contiguous to the sediment-water interface.

Between July 27th and August 25th, the water column profile was consistent where the metalimnetic layer and the thermocline were positioned between the 5 and 6m stratum. The greatest season surface temperature of 26.3°C occurred on July 27th; hypolimnetic temperatures also increased slightly to 6.5°C. The temperature changes in the August 25th water column were like those observed in the July 27th water column; but the temperatures were lower. The pattern of the highest oxygen concentration in the metalimnion was not observed on July 27th or during any other sampling event during the 2021 season. Instead, oxygen concentration slowly decreased with depth before a precipitous decrease at the thermocline followed by continued to decrease to <1mg/L from 9m to the bottom.

On the final sampling dates of September 30th and October 28th, the location of upper metalimnetic boundary and thermocline were situated at deeper depths in the water column while the lower metalimnetic boundary remained constant (Fig. 3). Above the metalimnion, temperatures on September 30th were approximately 20°C; and on October 28th epilimnetic temperatures were approximately 15°C. Temperatures at the 15m stratum gradually increased over time and reached their maximum of 8.1°C on October 28th. Oxygen concentrations in the deepest parts of the sampling site increased to >1mg/L by September 30th, and to 6.9mg/L by October 28.

TROPHIC DATA

Most data collected 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 concentration, Secchi transparency, 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 variables including the quantity of inorganic and organic particulate material in the water column that absorbs or reflects light. Secchi disk transparency is inversely related to algal productivity.

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. Ergo, there is a depth where oxygen produced from algal photosynthesis is equaled to the oxygen consumed via algal cellular respiration. That depth is referred to as the compensation point; it is commonly estimated by multiplying the Secchi disk transparency by 2.

Measurements included those taken during monthly sampling trips between April and October as well as during biweekly sampling events taken between late June and mid-September. Secchi transparency was generally lower in the first half of the season with six of the first eight measures being below 2m of transparency; the lowest measurement of 1.37 meters was recorded on July 5th (Fig. 4). After, Secchi transparency increased in a manner where six of the seven readings taken on or after August 8th exceeded 3m and the maximum reading of 3.66m measured on September 17th. The season average transparency was 2.42 meters and the summer average (July – September) was 2.60m. Both averages are indicative of a lake with late mesotrophic productivity (Table 1).

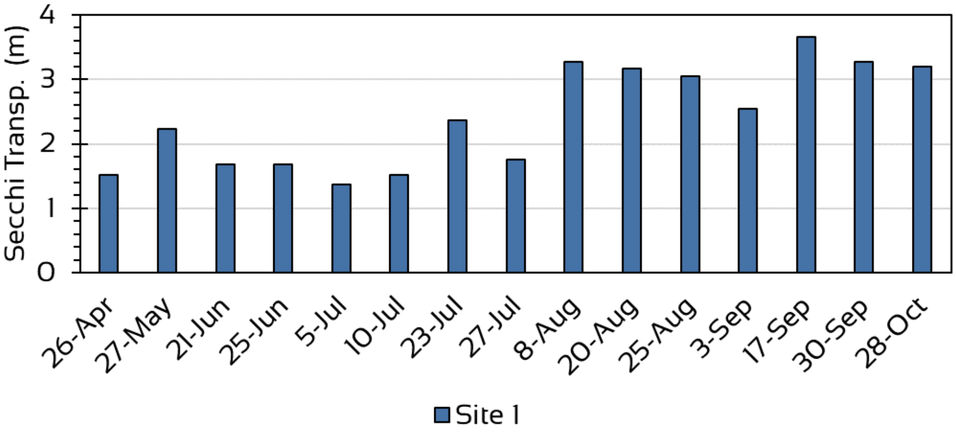


Figure 4 Secchi disk transparency (Transp.) at the deep-water site on Ball Pond during the 2021 season.

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 light energy required for photosynthesis is greatest.

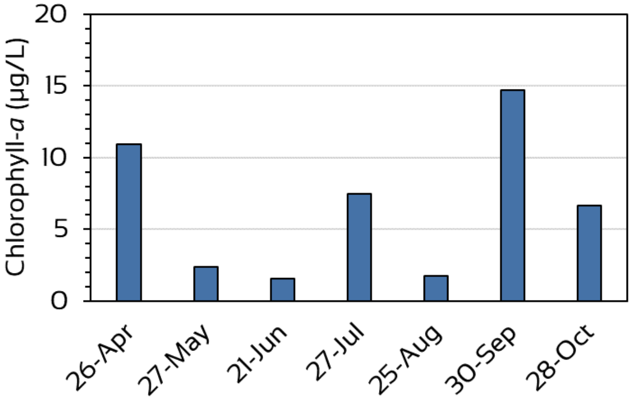


Figure 5. Chlorophyll-*a* concentrations measured Ball Pond in 2021.

Chlorophyll-*a* concentrations varied widely throughout the season at Ball Pond. On April 26th, the concentration was 10.9µg/L, which was the second highest across the sampling season (Fig. 3). The season high of 14.7µg/L was measured in the sample collected on September 30th. Concentrations were below 2.5μg/L on May 27th and June 21st. A similar concentration was also measured on August 25th. The concentrations on July 27th and October 28th of 7.47μg/L and 6.67μg/L respectively, were between the season highs and lows. The season average chlorophyll-*a* concentration of 6.48μg/L was suggestive of a mesotrophic system.

Total Phosphorus

Algae and cyanobacteria require a variety of macro and micronutrients. 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 maximum size of the algal population. In most Limnological studies, total phosphorus is measured, which is the sum of particulate and dissolved forms of phosphorus.

The epilimnetic total phosphorus minimum, recorded on October 28th, was 19μg/L; the maximum was 46μg/L, which was recorded on June 21st (Figure 6). The season average level of 34.3μg/L was suggestive of eutrophic conditions; individual sample concentrations spanned mesotrophic to eutrophic conditions.

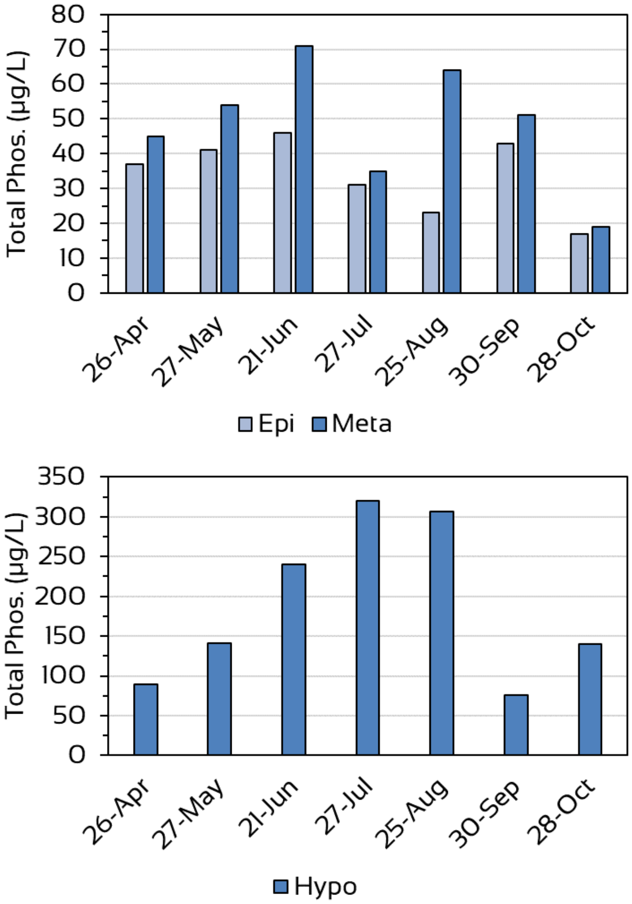


Figure 6. Total phosphorus (Phos.) concentrations in the epilimnion (Epi; top panel) and metalimnion (Meta; top panel) and hypolimnion (Hypo; bottom panel) measured in Ball Pond in the 2021 season.

The metalimnetic minimum and maximum concentrations were 17 and 71μg/L; those measurements occurred on the dates corresponding to epilimnetic minimum and maximum levels. The average value was 48.1μg/L, which was not significantly different from that of the epilimnion ($p>0.05$). Metalimnetic phosphorus concentrations generally followed the same pattern when compared to the epilimnion in the early part of the season with concentrations increasing until June 21st then decreasing through the July samples. Metalimnetic concentrations diverged from epilimnetic levels by August 25th when the former increased to the second highest concentration of the season while the latter continued to decrease (Fig. 6). Concentrations in both strata were elevated on September 30th before decreasing to season lows by October 28th.

The average total phosphorus concentration in the hypolimnion was 187.4µg/L and significantly higher than the epilimnetic and metalimnetic averages ($p<0.005$). The minimum hypolimnetic concentration was 76µg/L (September 30th); the maximum was 320µg/L from the July 27th sample. The hypolimnetic concentrations steadily increased from the start of the season through July 27th and remained near the maximum level through August 25th. By September 30th, concentrations had sharply decreased to 76µg/L before increasing to 140µg/L by October 28th, which was nearly identical to the concentration in the May 27th sample.

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 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 biologically derived nitrogen-rich proteins in the water column, it is useful in assessing the productivity of the lentic 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.

Nitrogen constituents were analyzed in samples collected at one meter below the surface, in the metalimnetic strata, and approximately 0.5m from the bottom during each sampling event. Due to a change in laboratory analyst in October, a higher minimum detection limit was used for TKN. The detection limit was higher than the concentrations found in the epilimnetic and metalimnetic samples collected on September 30th and October 28th; October concentrations were reported as <0.5mg/L. Those data are being excluded from our assessment of total nitrogen.

Ammonia and nitrate were detected infrequently in the epilimnetic samples. Only in the June 21st sample was any ammonia detected (0.2mg/L). Nitrate was detected twice: At 0.07mg/L on April 26th; and at 0.042mg/L on September 30th. At no point was nitrite detected in the epilimnion or elsewhere in the water column. Epilimnetic TKN levels were between 0.5 and 1.0mg/L between April 26th and August 25th; the season average was 0.72mg/L (Figure 7). The minimum concentration was indicative of a late mesotrophic lake, while the maximum and average were indicative of a eutrophic lake.

Ammonia, nitrate, or nitrite were not detected in the metalimnetic strata. The minimum metalimnetic TKN concentration of 0.40mg/L was detected on July 27, while May 27th and June 21st both had the season maximum concentrations of 0.80mg/L. The five-month average for metalimnetic TKN was 0.66mg/L.

Ammonia accounted for a large portion of the total nitrogen in the hypolimnetic samples. Ammonia was measured at >1.0mg/L in most months with a maximum of 2.0mg/L on August 25th and a minimum of 0.6 on April 26th. Nitrite was not detected at any point, but nitrate was detected three times with each concentration between 0.057mg and 0.06mg/L throughout the sampling season (Fig. 5). At least half of the TKN (April – August) was in the form of ammonia and had a maximum concentration of 2.4mg/L, and a minimum of 1.1mg/L. Because the TKN in October exceeded the minimum detection limit, a value of 1.8 was recorded, but for consistency that measurement was excluded from the calculation of the average, which was 1.62mg/L.

CHEMICAL DATA

There are a number of chemical variables that provide useful information in assessing changes in lakes. Many also have an influence on the biology of the lake. In this assessment, pH, alkalinity,

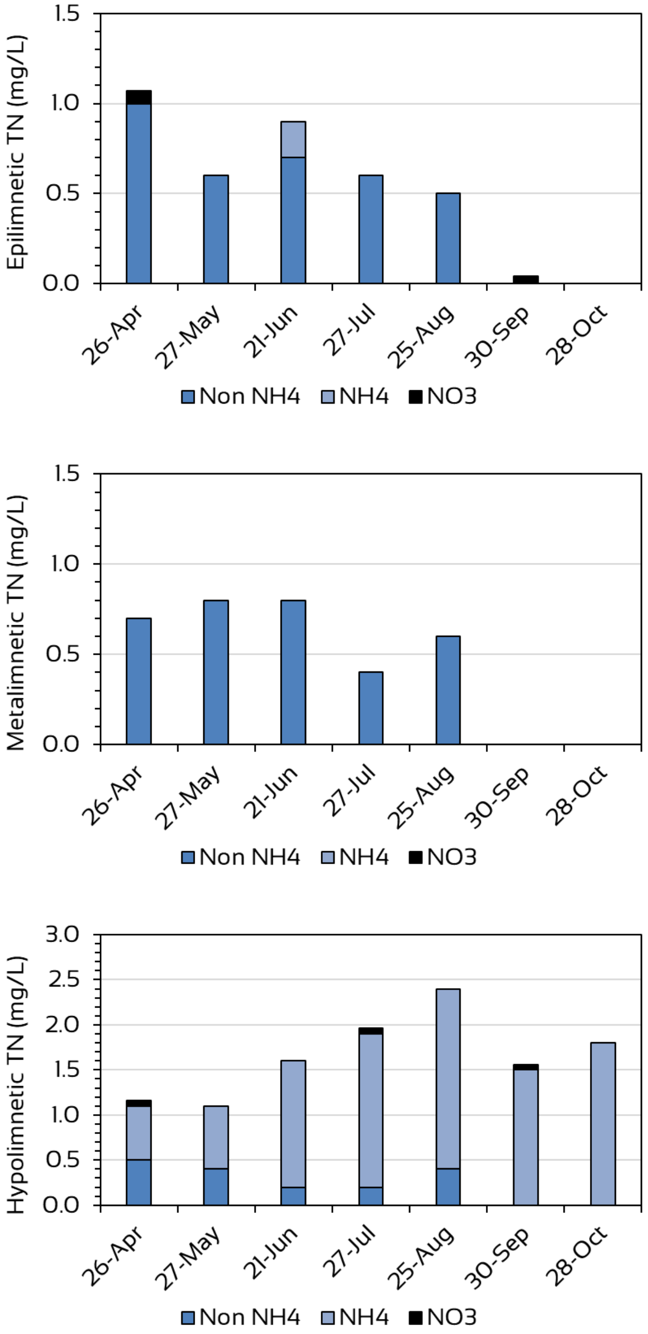


Figure 7. Total nitrogen (TN) concentrations in the epilimnion (top panel), metalimnion (middle panel) and hypolimnion (bottom panel) of Ball Pond in 2021. Total nitrogen is separated by nitrate (NO3), ammonia (NH4), and other non-ammonia TKN (Non NH4). Note: TKN data was not used for September 30th and October 28th due to the high minimum detection limit used for those samples.

calcium, and conductivity were examined. Other variables not analyzed here but have been in the past include sodium, potassium, magnesium, chloride, and sulfate. (Canavan and Siver 1994, 1995).

Alkalinity

Alkalinity is a measure of lake waters 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).

On April 26, the epilimnetic alkalinity was 80mg/L and below the seasonal epilimnetic average of 82.3mg/L. The season epilimnetic maximum was 88mg/L and measured in the July 27th sample. The maximum was followed by the season minimum of 78mg/L in August 25th. September 30th and October 28th concentrations were both identical to the April 26th measurement.

Metalimnetic alkalinity was typically similar to that of the epilimnion with the greatest difference observed on May 27th when the epilimnetic level was 6mg/L greater than metalimnetic level; and, on June 27th and August 25th when metalimnetic levels were 6mg/L greater (Fig. 8). Metalimnetic alkalinity was greater than epilimnetic concentrations on four of the seven sampling dates, but the averages of the two strata were not significantly different (p.0.05). The metalimnetic seasonal average alkalinity was 83.6mg/L.

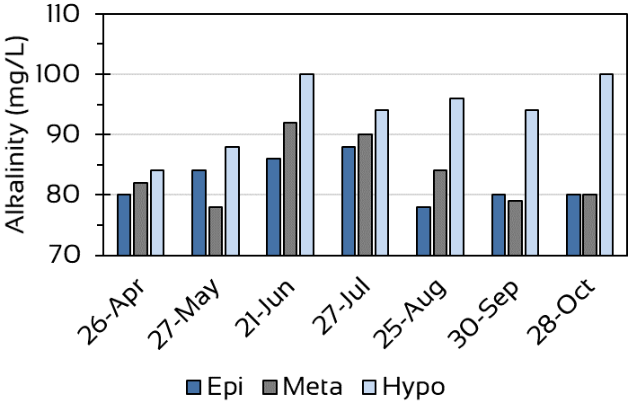


Figure 8. Alkalinity concentrations in the epilimnion (Epi), metalimnion (Meta), and hypolimnion (Hypo) of Ball Pond measured in 2001.

Hypolimnetic alkalinity was greater than epilimnetic and metalimnetic levels on each sampling date (Fig. 6). The hypolimnetic average was 93.7mg/L and significantly higher that the averages of the other strata ($p<0.05$). Concentrations on April 26th of 84mg/L gradually increased the season maximum of 100mg/L measured from the June 21st sample. That concentration would be measured in the October 28th sample. All hypolimnetic concentrations between the two dates were >90mg/L.

pH

The normal pH of surface waters of lakes in the Northeast can range from approximately 6 to 10 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; blue-green algae have adaptive advantages over other algal groups in those conditions because 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.

The difference in pH between the epilimnetic and hypolimnetic stratum is largely due to the concentration of carbon dioxide in the two strata. Atmospheric carbon dioxide diffuses into the water and forms carbonic acid, which is a weak acid but one that nonetheless decreases pH. In the upper strata of the water column where photosynthesis is occurring, carbon dioxide is used in photosynthetic process, resulting in the production of energy storage products (e.g., carbohydrates) and oxygen. Photosynthesis decreases with depth so carbon dioxide levels are higher. Carbon dioxide is also a metabolic byproduct of cellular respiration. Cellular respiration occurs in both the epilimnion by the aerobic organisms and in the hypolimnion by aerobic organisms until oxygen is used up. Then anaerobic organisms become more dominant and utilize other molecules for their cellular respiration needs. This combination of factors enriches the hypolimnion with carbon dioxide levels, which result in lower pH levels.

Epilimnetic pH was ≥9 SU from April 26th through August 25th, and 8.9 SU on September 30th. The pH decreased to 8.6 SU by October 28th. The season average was 9.0 SU.

The season average in the metalimnion was 8.7 SU and not significantly different from the epilimnetic average ($p>0.05$). The level of 8.5 SU on April 26th increased to the season metalimnetic maximum of 9.1 SU on May 27th and June 21st before decreasing to 8.4 SU by October 28th.

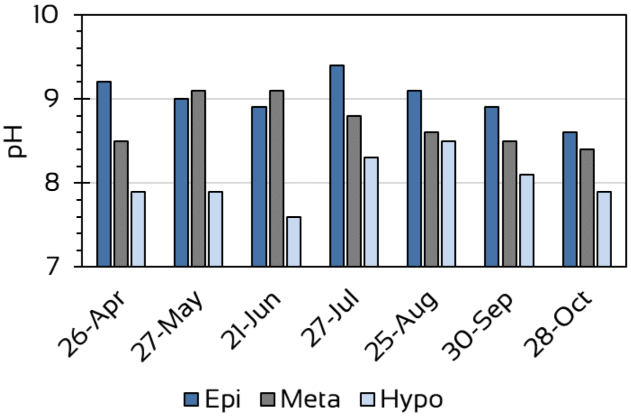


Figure 9. The pH levels in the epilimnion (Epi), metalimnion (Meta), and hypolimnion (Hypo) of Ball Pond measured in 2001.

The hypolimnetic pH average of 8.0 SU was significantly lower ($p<0.005$) than pH averages of the epilimnetic and metalimnetic strata. The hypolimnetic pH of 7.9 SU was measured on the first two sampling events before decreasing to the season minimum of 7.6 SU on June 21st (Fig. 9). Levels increased to the season maxima of 8.5 SU by August 25th before decreasing to 7.9 SU by October 28th (Fig. 7).

Specific Conductance

Conductivity is a surrogate measurement for 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 conductivity, which were measured in microsiemens per cm (μS/cm). We report below on specific conductance, which is the same as conductivity but standardized to a set water temperature (25°C). Temperature influences conductivity and – in the field – temperature varies with depth and 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. 10). Specific conductance was only measured down to 11m of depth in the water column; so, the deepest values recorded were treated as hypolimnetic for the purpose of drawing comparisons across the water column.

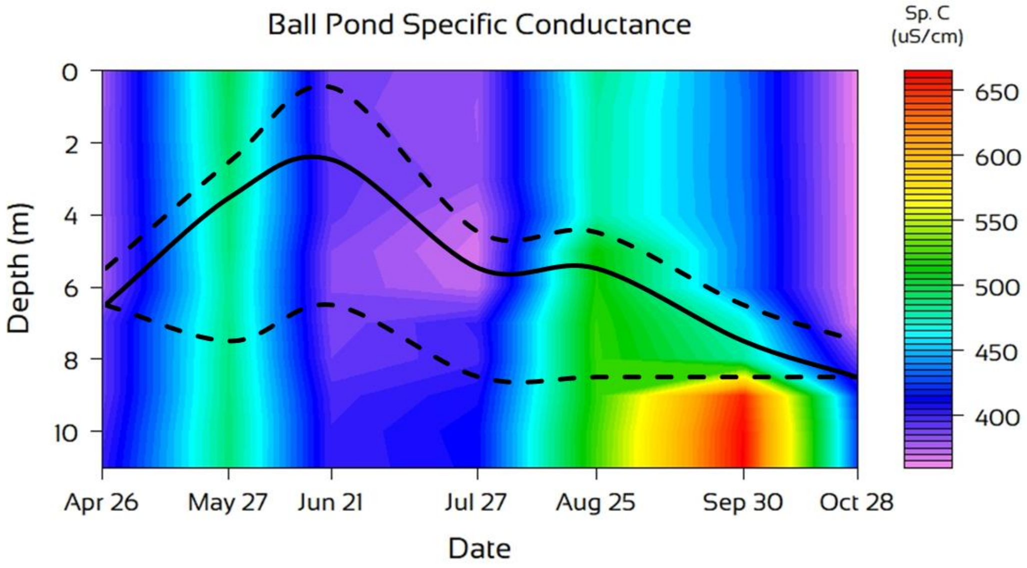


Figure 10. Isopleth plots of water column specific conductance for Ball Pond in 2021. The dashed black line represents the upper or lower boundary of the metalimnion; the solid black line represents the thermocline. Note conductivity data was not collected between 11 and the maximum depth of 15m of at the site.

The Ball Pond water column from the surface down to 11m of depth exhibited a wide range of specific conductance levels (Fig. 10). The water column was largely homogenous in regard to specific conductance on April 26th with an epilimnetic measurement of 377µS/cm and a hypolimnetic measurement of 402µS/cm. The differences in specific conductance levels throughout the water column remained <25µS/cm on May 27th, June 21st, and July 27th, as well. Across these first four months, a minimum value of 367µS/cm was recorded on April 26th; and, the maximum value was 497µS/cm measured May 27th.

By August 25th, epilimnetic and hypolimnetic specific conductances were more divergent, with measured levels of 484µS/cm and 526µS/cm, respectively. The greatest difference in epilimnetic and hypolimnetic levels occurred on September 30th when epilimnetic levels were 434µS/cm and hypolimnetic levels were 663µS/cm. By October 28th, levels throughout the water column had decreased; but, epilimnetic and hypolimnetic were still divergent with measurements of 362 and 424µS/cm, respectively.

Calcium Concentrations

There are numerous dissolved metals, minerals, and salts in lake water. The base cations – positively charged ions – are sodium, potassium, magnesium, and calcium. The important anions – negatively charged ions – include chloride, sulfate, and the alkalinity ions (carbonate and bicarbonate).

Many of the ions play important roles for the organisms living in the water. For example, some species of cyanobacteria have a high sodium requirement for photosynthesis, bicarbonate transport, nitrogen fixation/nitrate reduction, and uptake of phosphate. Ions are also useful in assessing ecosystem change; For example, increases in ions like sodium and chloride might indicate a high influence by deicing salt-laden storm water draining to the lake.

Calcium is biologically important for maintenance of the structural and functional integrity of cell membranes. It is also very important to shell-forming organisms and generally can be used to assess the likelihood of organisms forming sustainable populations; there are those organisms that require a minimum of 20mg/L and those that can survive in less (Wetzel 2001). The invasive Zebra mussel (*Dreissena polymorpha*) has a high calcium requirement; and, concentrations

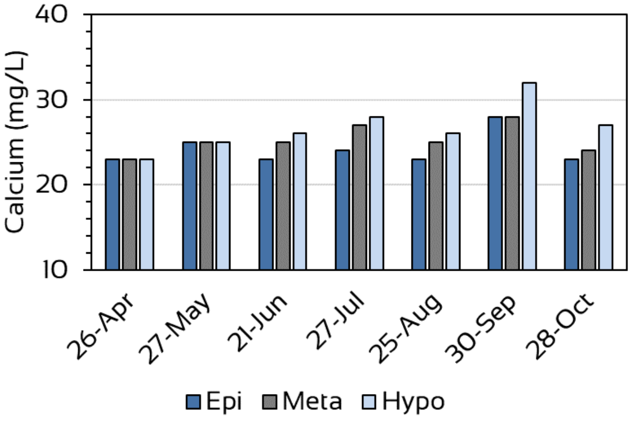


Figure 11. Calcium concentrations in epilimnion (Epi), metalimnion (Meta), and hypolimnion (Hypo) of Ball Pond in 2021.

from 25 to 30mg/L have been characterized as providing a freshwater system with moderate potential for colonization by this mollusk (Whittier et.al. 2008).

Calcium concentrations exhibited a high degree of consistency across dates and depths (Fig. 9). Averages in the epilimnion, metalimnion, and hypolimnion were 24.1, 25.3, and 26.7mg/L, respectively. There were no significant differences ($p>0.05$) among the season averages of all strata. There was a slight positive trend over time from April 26th to September 30th, particularly in the metalimnetic and hypolimnetic strata. Concentrations decreased in all strata between September 30th and October 28th (Fig. 11).

INVESTIGATIONS INTO BALL POND CYANOBACTERIA

As noted above, some trophic variables (e.g., total phosphorus) suggest that Ball Pond is a eutrophic lake. As such, the lake is susceptible to cyanobacteria blooms; and blooms are known to occur. Large blooms can have deleterious ecological impacts, particularly when cells senesce and decompose causing oxygen loss in the water and in worst case scenarios, fish kills. Of equal or perhaps more importance, some populations of cyanobacteria are capable of synthesizing highly toxic intercellular compounds. Ingestion of substantive amounts of toxic cyanobacteria or direct exposure to toxins in the water once cells lyse can pose severe risk to human and pet health (USEPA 2021).

Due to BPAC's success in applying for a grant from the State's Aquatic Invasive Species Grant Program, and support from the Town of New Fairfield with matching funds, instrumentation to study the cyanobacteria community in Ball Pond was purchased. The protocols used by Elissa Johnson of the BPAC and David MacAskill of Western Connecticut State University for the study were developed by the USEPA-led Cyanobacteria Monitoring Collaborative (CMC 2021).

In 2021, Ball Pond became fifth lake in Connecticut in the last five years to take part in the Western Connecticut State University Microcystin Monitoring Program. This program, supervised by faculty researcher Dr. Edwin Wong, provides lake communities the opportunity to have water samples tested for levels of the microcystin cyanotoxin. Microcystin is a peptide toxin that is the cyanotoxin most commonly monitored in surface waters.

CyanoMonitoring and Fluorimetry

The protocols are part of the CyanoMonitoring program and were deveped to understand how cyanobacteria respond to environmental conditions. They provide researchers and citizen scientists the methods to gather the data necessary to understand how and why cyanobacteria blooms occur. The program ultimately looks to create predictive models for harmful cyanobactera algal blooms. Protocols were developed for collections of samples from waterbodies, separating cyanobacteria into size factions, and measuring two photosynthetic pigments – chlorophyll-*a* and phycocyanin – as surrogates for direct biovolume measurements.

The two size factions of cyanobacteria used for pigment analyses are the larger bloom-forming cyanobacteria (aka BFCs) and picoplankton, which are smaller (cells of ≤2µm in diameter) that are not readily identifiable with standard microscopy. Pigments were also measured in the whole lake water (WLW) samples, which contain both size factions.

The photosynthetic compounds were measured with fluorimetry. 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 purchased through the grant emits wavelengths that interacts with both chlorophyll-*a* and phycocyanin. The fluorimeter also measures the intensity of light fluoresced back from the cells. The instrument is calibrated to provide estimates of pigment concentrations based on the intensity of the fluoresced light. The two pigments are chlorophyll-*a* and phycocyanin. Chlorophyll-*a* is the primary photosynthetic pigment for photosynthesis and contain within all algae and cyanobacteria. Phycocyanins is almost exclusively found in cyanobacteria.

Another component of the instrumentation purchased was a microscope to identify and photograph the genera of cyanobacteria in the collected samples. All data has been compiled in Appendix B. In addition, those data have been conveyed to Nancy Leland, a researcher with the University of New Hampshire Center for Freshwater Biology who is affiliated with the Cyanobacteria Monitoring Collaborative.

The USEPA recommends to CyanoMonitoring practicioners to calculate growth rates using the formula:

$$\mu\ d^{-1} = \ln(F_2/F_1)/(t_2 - t_1)$$

where $\mu\ d^{-1}$ is growth in micrograms per day; F_2 is the fluorescence at time 2 (t_2); and F_1 is the fluorescence at time 1 (t_1). We were also advised to use the growth rates to explain the actual pigment measurements (Nancy Leland, personal communication, December 13, 2021). For purposes here, we have focused on phycocyanin, plotted concentrations and growth rates together for the whole water samples, BFC samples, and pico cyanobacteria samples.

Initial phycocyanin concentrations at the deepwater site (aka Site 1), were highest at the start of the monitoring on Ball Pond on June 18th (Fig. 12). Those concentrations appear to be driven by the BFC faction. The two bloom formers observed on June 18th were *Aphanizomenon spp*. and *Dolichospermum spp*. Cell concentrations decreased by June 25th and growth fluctuated some through July 23rd before increasing by August 8th. The August 8th growth was largely the pico cyanobacteria. That appeared to be a short lived episodic event as pico cyanobacteria growth and biomass decreased by substatively decreased by August 20th and fluctuated for the remainder of the sampling period. Over the period from July 23rd through September 17th BFC growth slowly increased.

Similar to the deep water site, highest phycocyanin concentrations were measured during the early part of the monitoring effort on Ball Pond. A notable increase in growth occurred at both shoreline sites between July 5th and July 10th that was driven by BFCs (Fig. 13). Site 2 did not appear to experience periods of notable growth after July 10th with the exception of pico cyanobacteria growth between August 20th and September 3rd.

Site 3 appeared modestly more susceptible to periods of increased growth by BFCs, e.g., between July 23rd to August 8th. Site 3 also exhibited the substantial increase in growth by the pico cyanobacteria between August 20th and September 3rd as was observed at Site 2 (Fig. 13). Concentration and growth rate patterns of the pico cyanobacteria were similar at the two shoreline sites while whole lake water and BFC sample characteristics were more discrete.

Table 2 lists BFC cyanobacteria genera observed on each sampling event. Common to the first four weeks – June 18th to July 10th – was the importance of *Aphanizomenon spp.*; its importance greatly diminished afterwards.

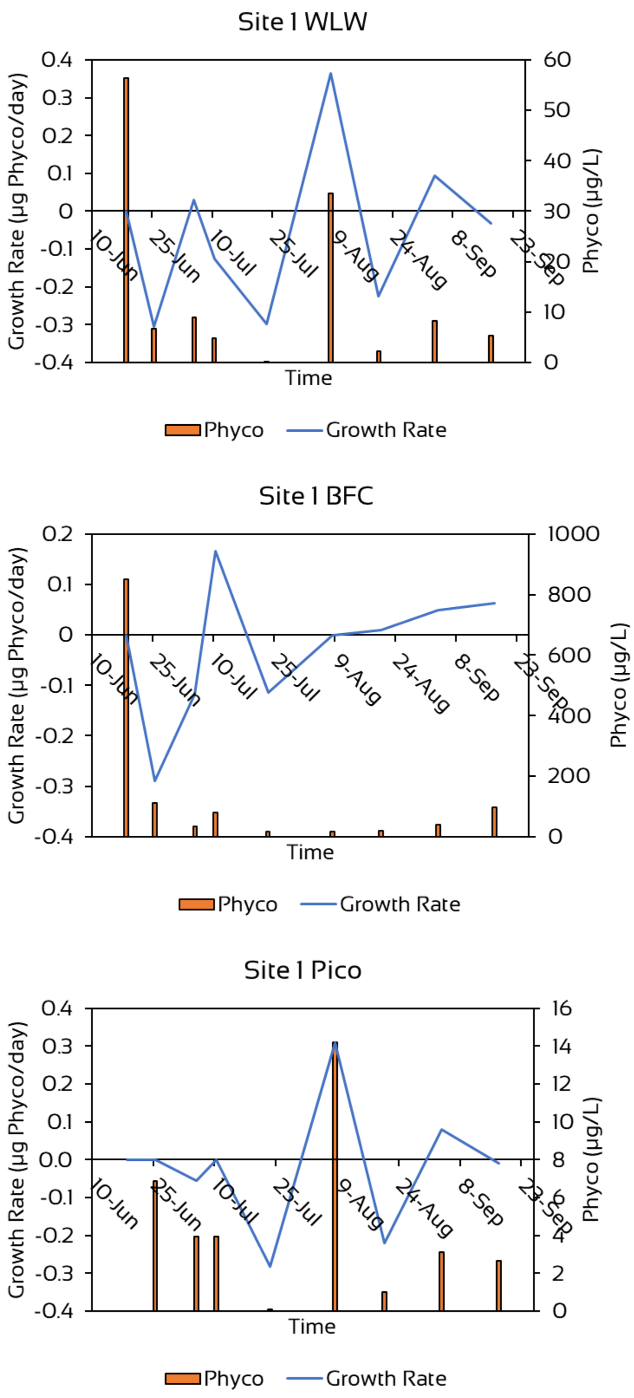


Figure 12. Growth rate of cyanobacteria and phycocyanin concentrations in whole lake water (WLW) samples, bloom forming cyanobacteria (BFC) samples, and pico-cyanobacteria samples from the deep-water site (Site 1) of Ball Pond in 2021.

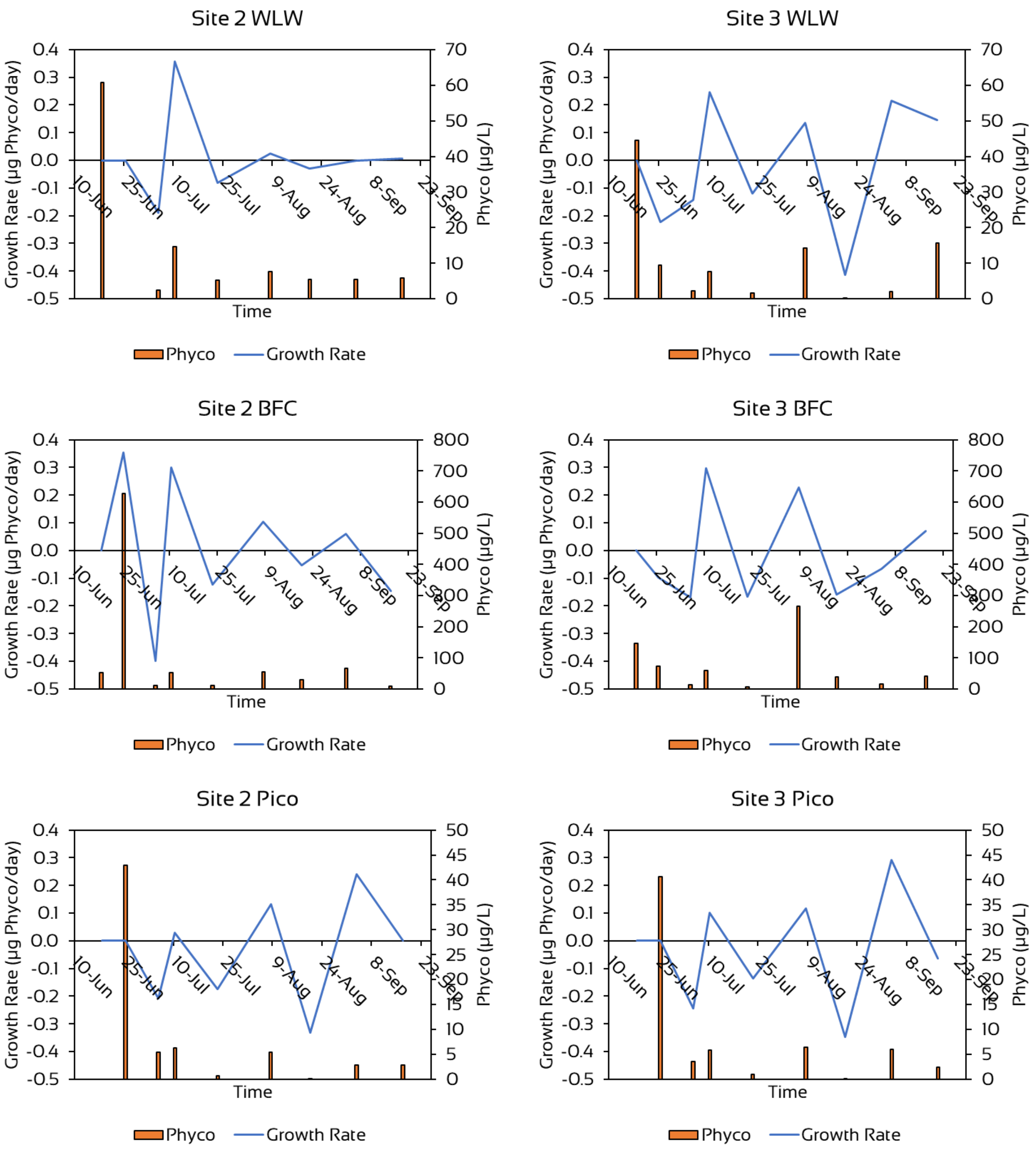


Figure 13. Growth rate of cyanobacteria and phycocyanin concentrations in whole lake water (WLW) samples, bloom forming cyanobacteria (BFC) samples, and pico-cyanobacteria samples from the shoreline sites (Site 2 and Site 3) of Ball Pond in 2021.

Dolichospermum spp. was observed in samples collected during seven of the nine sampling summer season sampling events (Table 2). Four of the nine sampling events revealed the presence of *Microcystis spp*. Other cyanobacteria genera were present in one or two of the nine samples analyzed. All genera in Table 2, but *Gomphosphaeria spp*. are considered toxigenic in scientific literature (Cheung et. al. 2013, CT DPH and CT DEEP 2019, USEPA 2021).

Table 2. Observation of the bloom-forming cyanobacteria genera in samples collected from Ball Pond in 2021. See Appendix C. Cyanobacteria Image Gallery for photographs of specimens.

Date	Cyanobacteria genera
18-Jun	*Aphanizomenon, Dolichospermum*
25-Jun	*Aphanizomenon, Dolichospermum Woronichinia*
5-Jul	*Aphanizomenon, Dolichospermum, Microcystis*
10-Jul	*Aphanizomenon, Microcystis.*
23-Jul	*Woronichinia*, some *Gomphosphaeria*.
8-Aug	*Dolichospermum, Vorticella* (Zooplankton)
20-Aug	A single *Microcystis* found; sparse *Dolichospermum*
3-Sep	*Dolichospermum, Microcystis*
17-Sep	*Dolichospermum*

WCSU Cyanotoxin Monitoring Program

There are at least nine different known toxins that are produced by the cyanobacteria genus. Several of those have numerous known congeners e.g., microcystin has 80 to 90 congeners (Cheung et. al. 2013, CT DPH & CT DEEP 2019, USEPA 2014, 2021). Microcystin is considered the most pervasive in freshwater systems and the Microcystin-LN congener is considered one of the most toxic of all the cyanotoxins.

The State of Connecticut has developed guidance for municipal health departments when cyanobacteria blooms occur in recreational freshwaters. A qualitative, visual ranking system for monitoring conditions at public beaches is recommended. Quantitative approaches for assessing algal bloom conditions include determinations of cyanobacteria cell densities.

If a freshwater resource is closed because of public health concerns related to a cyanobacteria bloom, then the State recommends an analysis of microcystin levels in samples collected from the site. A recommended threshold of 8µg/L is used under which conditions are considered safe for reopening. In 2016, a program was developed at Western Connecticut State University by Dr. Edwin Wong where microcystin concentrations from local waterbodies could be assessed.

Table 3. Results of microcystin analyses of samples collected at Ball Pond in 2021.

Date	Microcystin (µg/L)
14-Jul	0.186
21-Jul	0.22
28-Jul	0.105
4-Aug	0.079
11-Aug	0.068
18-Aug	0.194
25-Aug	0.052
2-Sep	0.16

In 2021, weekly samples were collected from Ball Pond between July 14th and September 2nd and analyzed. Results are presented in Table 3. Microcystin levels were all <1µg/L. It is important to recognize that samples collected at Ball Pond were not surface blooms, which can have much higher microcystin concentrations.

September 3rd Cyanobacteria Profile

On September 3rd, AER water quality field instrumentation was loaned out to the BPAC and used during the cyanobacteria monitoring event at the deep-water site. In addition to the standard variables of temperature, dissolved oxygen, and conductivity, the AER multiprobe contains a fluorimeter set at a wavelength to fluoresce phycocyanin and determine a relative concentration at each stratum from the surface to the bottom of the water column. The measure is relative since the fluorimeter is not calibrated to a primary standard.

The water column was stratified with very strong resistance to mixing at the thermocline. Relative phycocyanin concentrations were low from the surface down to a depth of 6m. At the 7m stratum, the concentration increased markedly and – by the 8m stratum – was nearly 4X that of the 6m stratum. After 8m of depth, the relative concentration decreased at a rate similar to the rate it increased above. Another smaller increase was detected between 11 and 12m of depth. The 12m stratum was the deepest in the water column where measurements were taken that day.

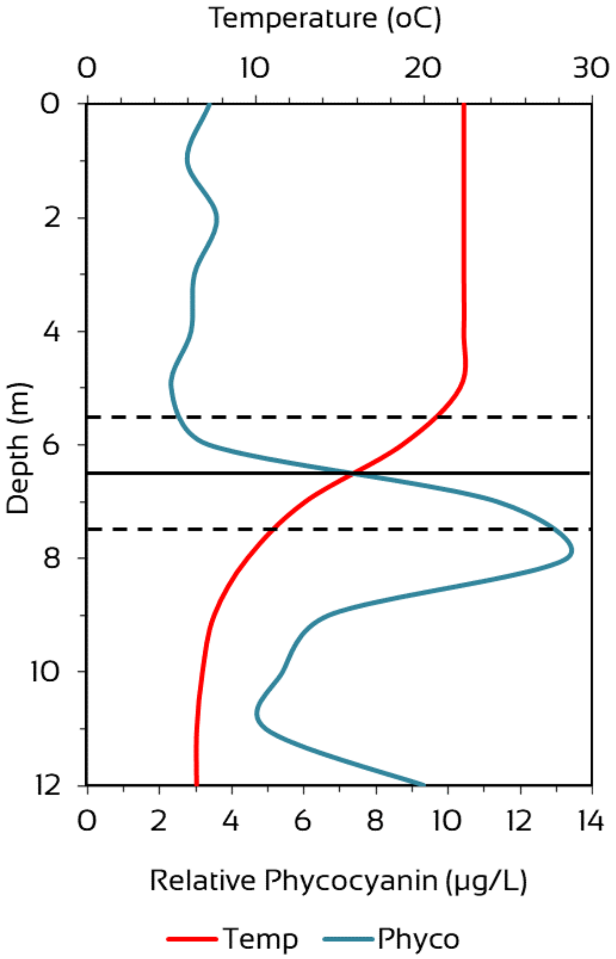


Figure 14. Profiles of temperature and relative phycocyanin concentration in the Ball Pond water column on September 3, 2021. The dashed black lines represent the location of the upper and lower metalimnetic boundary; the solid black line represents the thermocline.

DISCUSSION

Trophic Dynamics

Season average epilimnetic total phosphorus and total nitrogen concentrations suggest the lake supports eutrophic-level algal productivity. At deeper strata of the water column, nutrient levels could theoretically support highly-eutrophic productivity. Limnologists frequently use the Redfield ratio of 16 (16:1 nitrogen to phosphorus) to determine whether nitrogen or phosphorus is limiting in a freshwater system (Redfield 1958). The ratio is molar-based and when converted to mass, 7.2µg/L is the threshold. Values lower than the aforementioned threshold are indicative of nitrogen limitation while ratios above 7.2µg/L indicate phosphorus limitations. Nitrogen limitation favors cyanobacteria productivity due to the ability of some cyanobacteria to harvest elemental nitrogen dissolved into the water from the atmosphere, aka nitrogen fixation. Other algae taxa do not possess this ability.

Based on mass, epilimnetic ratios between April 26th and August 25th were between 15 and 29, had an average of 21, and were indicative of phosphorus limitation. Ratios decreased in lower strata. Based on metalimnetic nutrient concentrations, ratios were between 9 and 16, and the average was 12; and hypolimnetic ratios were between 7 and 13, and the average was 8. As noted above, a concentrated stratum of cyanobacteria was observed below the thermocline and lower metalimnetic boundary. Redfield ratios suggest there may be at times adaptive advantages for cyanobacteria at lower strata of the water column including elevated nutrient levels.

Although epilimnetic total phosphorus could support eutrophic productivity, particularly in the first four months of the sampling season, average chlorophyll-*a* concentrations were indicative of mesotrophic productivity. Secchi disk transparencies were indicative of eutrophic productivity up through July 27th, but indicative of mesotrophic productivity afterwards.

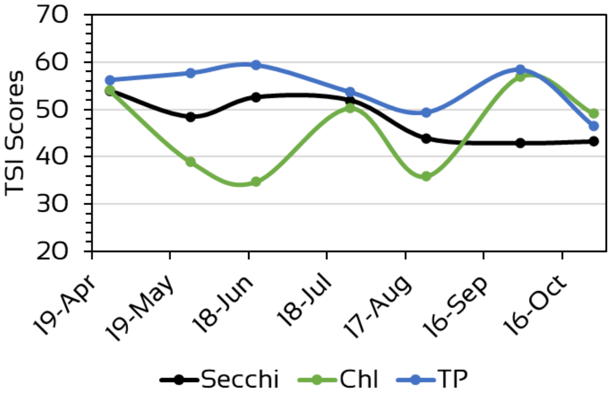


Figure 15. Carlson (1977) trophic scores for Secchi transparency, chlorophyll-a concentration, and epilimnetic total phosphorus measured in Ball Pond during the 2021 season between April 26th and October 28th.

To confirm some of these trophic dynamics, we applied the Carlson trophic state indices to the Ball Pond chlorophyll, Secchi, and total phosphorus data. Carlson (1977) developed indices that transform 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. While there is a transformation for total nitrogen, we did not apply it to the Ball Pond data since total phosphorus was limiting and there was not a full season of total nitrogen data available as explained earlier.

TSI scores on April 26th were very similar for all three variables (Fig. 15). Afterwards and until June 18th, Secchi transparency scores were lower, but not as low as the chlorophyll-*a* scores. By July 27th, the total phosphorus score decreased some, while Secchi and chlorophyll-*a* scores increased to the level of the total phosphorus score. By August 25th scores once again show chlorophyll-*a* biomass at a concentration below those that total phosphorus concentrations would suggest could support. Secchi transparency also exhibited higher trophic characteristics than chlorophyll-*a*. On September 30th, chlorophyll-*a* scored at the same level as total phosphorus and Secchi transparency scored lowest. By October 28th, scores converged to similar levels (Fig. 15).

Coprecipitation?

For nearly half of the sampling season, algal biomass in the form of chlorophyll-*a* was notably lower than could be supported by the total phosphorus levels. An important question to ask is why? A lake's trophic dynamics can be influenced by calcium concentrations in the water. High calcium concentration in lakes with high pH can result in limited phosphorous availability to the algae via the process of coprecipitation (Wetzel 2001). Simply stated, at high pH levels and calcium concentrations, phosphorus will bind with calcium carbonate, precipitate out of the water column as calcite, and become unavailable to algae.

The pH levels measured at Ball Pond this season were well within the range necessary for the coprecipitation reaction. Calcium and calcium carbonate levels, in the form of alkalinity, were also high in comparison to other lakes. In fact, levels in Ball Pond in the 1990s including the relative concentrations of other base cations and anions, grouped Ball Pond in cluster analysis with lakes of the Marble Valley region of Connecticut (e.g., East Twin Lake and Lake Wononscopomuc), which also have high pH, alkalinity and other ion concentrations (Table 4; Canavan and Siver 1995).

Under the coprecipitation scenario, Secchi disk transparency may also not accurately characterize trophic conditions if the precipitating calcite is absorbing and reflecting light thereby reducing Secchi disk transparency. In summary, the true trophic nature of a lake influenced by coprecipitation may be difficult to assess. The biomass of algae and cyanobacteria at Ball Pond is regularly low relative to concentrations of total phosphorus. If coprecipitation renders total phosphorus even more limiting, and then a discontinuation of coprecipitation occurs, more frequent and intense algae blooms may result. It may be prudent to consider measuring free phosphate alongside total phosphorus to further resolve this phenomenon.

Table 4. Comparisons of the 2021 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**		
		2021 Mean	**1993 Mean**	**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	34	22	27	42	31	10	57	33	9	334	33
Chlorophyll-*a*	µg/L	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	2.4	2.6	2.0	4.9	3.3	1.7	7.6	3.5	0.9	7.6	3.3
pH	SU	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/mhos	417	283	180	317	258	25	188	96	24	317	102
Alkalinity	mg/L	82	64	54.5	120.5	90	23.7	44	21	0	120.5	14.5
Chloride (Cl^-)	mg/L	---	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	24.1	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	---	6.6	5.9	15.2	9.8	1	5.2	4.1	0.2	15.2	2.5
Sodium (Na^+)	mg/L	---	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	1.2	2.7	1.9	0.2	0.9	0.5	0.4	2.7	1.2

Phosphorus Sources

The elevated epilimnetic total phosphorus concentrations measured from April 26th through June 21st suggest high phosphorus export from the watershed to the lake. Epilimnetic phosphorus concentration, during that period, was similar to the estimated 1990 epilimnetic levels based on land cover (Table 1). It is likely that current land cover has seen an increase in residential land at the expense of agricultural and forested land, which would increase the 1990 estimate.

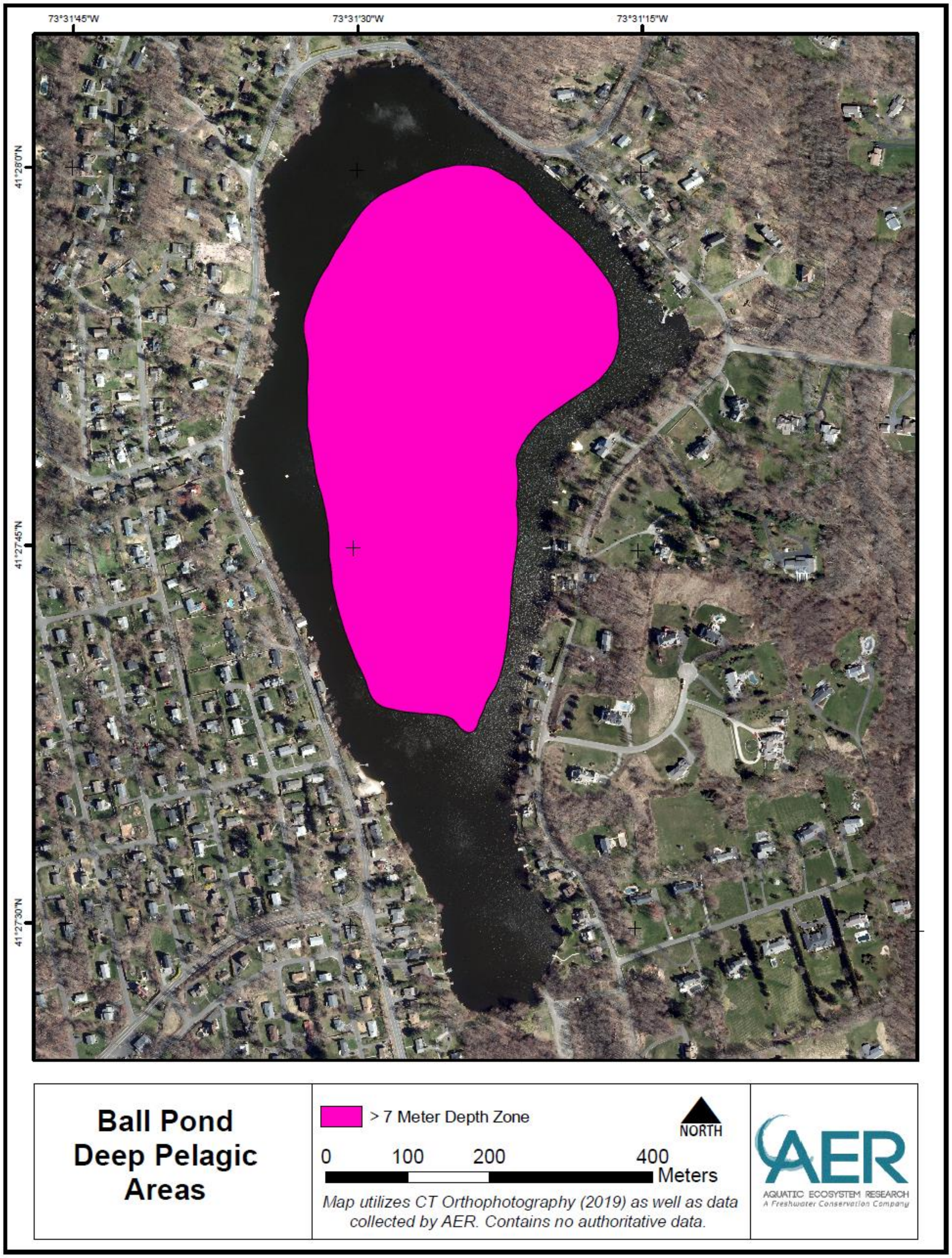
The steep increase in hypolimnetic total phosphorus from April 26th to August 25th (Fig. 6), along with the protracted anoxic environment (Fig. 3) and elevated alkalinity after June 21st (Fig. 8) strongly suggest a strong influence of internal loading of phosphorus to the lake's phosphorus budget. The reduction in hypolimnetic total phosphorus on September 30th was likely a result of the mixing the phosphorus into higher strata of the water column. Epilimnetic and metalimnetic concentrations were elevated on September 30th.

The area of the lake bottom where loading of phosphate is most likely to occur was determined by oxygen profile data collected this season. A threshold of ≤2mg/L was used to a delineate portions of the water column that become anoxia. That threshold was regularly exceeded at 7m of depth. The area of the lake bottom that were ≥7m deep were mapped (Fig. 16) and totaled (42.8 acres).

Conductivity Trends

In Table 4, summary water quality variables from Ball Pond in 2021, from Ball Pond in 1993, from lakes in two of the five geological regions of Connecticut (Canavan and Siver 1990s), and from the 60 lakes in that State-wide survey have been compiled. The two geological regions are those which would presumably have the strongest influence on the chemistry of Ball Pond. As noted earlier, Ball Pond was grouped with the Marble Valley lakes in the Canavan and Siver study because of the lake's ionic chemistry. However, bedrock geology maps do not support Ball Pond being situated in an extension of the Marble Valley, even though the lake's chemistry might lead one to that conclusion. The idea of a glacial erratic of calcium carbonate composition embedded in the watershed's surficial materials is a viable theory for the calcium influence in Ball Pond (J. Mellett, personal communication, December 4, 2021).

Of all the variables measure at Ball Pond in 1993 and 2021, specific conductance appears to have changed the greatest. The Ball Pond surface specific conductance in 2021 exceeded measurements in surface waters of all lakes from the 1990s survey (Table 4). Increases in specific conductance are being reported in many lakes in Snowbelt regions including New England. Many of those increases have been associated with increased use of deicing salts used in the winter (Kelly et. al. 2019). In addition to these increases occurring in waterbodies, they are also occurring in groundwater and wells.



Ball Pond Deep Pelagic Areas

Map utilizes CT Orthophotography (2019) as well as data collected by AER. Contains no authoritative data.

Figure 16. Area of the bottom of Ball Pond located in waters 7 meters deep or deeper. That total area is 42.8 acres.

High concentrations of salts used in deicing product (e.g., sodium chloride) can have adverse impacts on aquatic ecosystem and also on human health. Additionally, high concentrations accumulated at the bottom of the lake can prevent complete spring turnover and prevent replenishment of oxygen to lower depths (Kelly et. al. 2019). That could increase the importance of internal loading in the lake's nutrient budget.

Stormwater runoff from roads and residential areas is one mechanism by which salts, nutrients and other pollutants travel from land to lakes. Inputs of groundwater polluted with high ion concentrations is another.

Lastly with regards to specific conductance, the high degree of variability in epilimnetic waters was notable and is not common. Specific conductance increases or decreases of >100µS/cm occurred between April 26th and May 27th, May 27th and June 21st, and July 27th and August 28th. Increases of >40µS/cm were also noted between August 25th and September 30th, and between September 20th and October 28th.

To test if specific conductance in surface waters were related to precipitation levels, Pearson Correlation Tests were performed using specific conductivity and total precipitation in the prior 30 days, 10 days, and 5 days. There were no strong correlations between specific conductance and the three precipitation variables.

Observation from CyanoMonitoring

Our assessment of the data collected by the BPAC through the CyanoMonitoring program at Ball Pond should be considered preliminary. As noted, the data has been conveyed to researchers associated with the Collaborative and their assessment of the data will be important.

This work has brought into focus the intermittent importance of pico-size cyanobacteria in the system. The August 8th increase in phycocyanin and cyanobacteria growth at the deep-water site was largely due to the pico cyanobacteria.

Differences in growth rates and phycocyanin concentration of the BFCs at the deep-water site vs the shoreline sites were notable. At the deep-water site, there was much less variability, particularly after July 23rd, whereas the shoreline sites were characterized by the variability throughout the season. This may be illustrating the nature of cyanobacteria blooms and influences of wind. Even a small amount of cyanobacteria that becomes positively buoyant, but gets gently pushed to a shoreline by a gentle breeze, can result in increases in phycocyanin concentration and cell density.

These preliminary results are also useful in understanding the nature of cyanobacteria at Ball Pond. There did not appear to be any sustained growth or high sustained levels of phycocyanin at either the deep-water or shoreline sites. Events were more episodic. This may be due to the BFC cyanobacteria population's ability to regulate buoyancy. Understanding the variables related to why and/or when populations are positively or negatively buoyant will only come about by data collection efforts such as this.

RECOMMENDATIONS

Based on this assessment of 2021 data, the following recommendation are presented for consideration.

Water quality monitoring is a key component of successful lake management programs for reasons that include detecting shifts in water quality, particularly at lakes where management efforts (e.g., biological control of aquatic invasive plants) have occurred. These should be continued at Ball Pond with the following changes.

1. Deepest readings of temperature and dissolved oxygen varied from 11 to 15m of depth. The AER field instrumentation used on September 3rd recorded the coordinates of the deep-water site and have been projected on to a map of the lake (Fig. 17). The location of the deep-water sampling site should be changed to the deepest part of the lake, and coordinate data collected with a GPS so all subsequent visits will be to the same and deepest location on the lake.

2. Conductivity measurements never collected beyond 11m of depth. Fluxes in deeper waters are diagnostic of chemical changes occurring there, including solubilizing of iron phosphate. Measuring conductivity, along with temperature and dissolved oxygen down to the bottom is recommended.

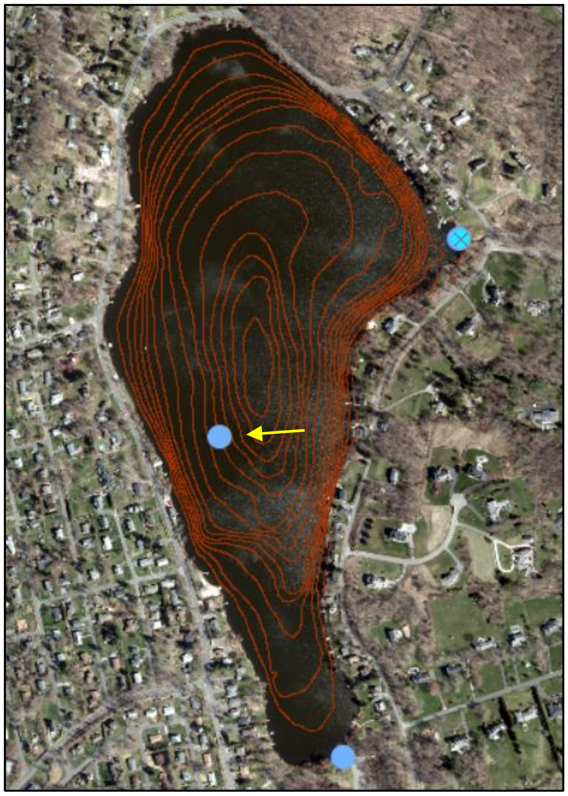


Figure 17. Location of the deep-water site (yellow arrow) based on the AER field instrumentation used on September 3, 2021.

3. Other variables that should be considered in future data collections include profiles of oxidation-reduction potential, profiles of relative phycocyanin concentrations, concentrations of sodium, potassium, magnesium, chloride, and sulfate in epilimnetic waters; and, free phosphate (PO_4^-), iron, and manganese from epilimnetic and hypolimnetic samples.

The phosphorus dynamics at Ball Pond are unclear. Efforts should be given in providing clarity.

4. Develop a protocol to determine if and where coprecipitation is rendering phosphorus limiting to algal growth.

5. Develop a plan and cost estimate to establish a nutrient budget for the lake. This will be critical for the development of a lake management plan.

The causes and impacts of the increased and highly variable specific conductance at Ball Pond should be explored.

6. Start water quality monitoring in March, even if it is to just measure temperature, oxygen, and conductivity in the water column. The question to answer is, "Does Ball Pond completely mix and does oxygen become enriched to the bottom during the winter?"

7. Develop a plan and cost estimate to understand the chemistry of groundwater and spring waters entering Ball Pond.

8. Develop a plan and cost estimate to gauge changes to the watershed since 1990 and the impact of those changes on water quality.

The CyanoMonitoring has already begun to provide useful insights into cyanobacteria dynamics at Ball Pond. This program should be continued with the following recommendations.

9. Get feedback from the researchers of Cyanobacteria Monitoring Collaborative on the 2021 data.

10. Incorporate weather data into our data collection (air temperature, wind speed, etc.)

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APPENDIX A. FIELD AND LABORATORY DATA

Temp = Temperature; HDO = Optical Dissolved Oxygen; Cond = Conductivity; Alk = Alkalinity; Ca = Calcium; NH4 = Ammonia; TKN = total Kjeldahl nitrogen; TP = Total Phosphorus; Chl-a = Chlorophyll-*a*.

26-Apr	**Depth (m)**	**Temp (°C)**	**HDO (mg/L)**	**Cond (µS/cm)**	**pH**
	Surface	11.9	13.8	284	---
	0.5	12	12.8	284	9.2
	1	11.9	11.9	284	---
	2	11.9	11.7	284	---
	3	11.9	10.6	284	---
	4	11.9	9.8	284	---
	5	11.6	9.3	281	---
	6	10.3	7.2	272	8.5
	7	7.4	10.2	261	---
	8	6.4	5.8	253	---
	9	5.9	3.7	250	---
	10	5.5	2.3	250	---
	11	5.4	1.6	252	7.9
	12	5.5	1.7	---	---

27-May	**Depth (m)**	**Temp (°C)**	**HDO (mg/L)**	**Cond (µS/cm)**	**pH**
	Surface	23.7	12.5	486	---
	0.5	23.7	12.6	485	9
	1	23.9	12.6	484	---
	2	23.1	12.6	476	---
	3	21.4	15.1	457	---
	4	17.8	16.5	421	9.1
	5	15.2	10.7	396	---
	6	13.3	3.6	376	---
	7	11.1	1.6	357	---
	8	9.8	1.4	346	---
	9	9	0.8	339	---
	10	8.4	0.7	335	---
	11	8	0.4	330	7.9
	12	5.9	0.2	---	---

21-Jun	Depth (m)	Temp (°C)	HDO (mg/L)	Cond (µS/cm)	pH
	Surface	25.9	12.9	395	---
	0.5	25.9	12.9	395	8.9
	1	24.3	12.9	382	---
	2	21.7	14	365	---
	3	18.2	14	342	---
	4	15.6	10.6	322	---
	5	13.1	6.2	298	---
	6	10.4	3	278	9.1
	7	9	1.9	269	---
	8	8	1.3	264	---
	9	7.3	0.9	264	---
	10	7.2	0.8	265	---
	11	6.3	0.6	---	---
	12	6.1	0.5	---	7.6
	13	6.1	0.4	---	---
	14	6.1	0.4	---	---

27-Jul	Depth (m)	Temp (°C)	HDO (mg/L)	Cond (µS/cm)	pH
	Surface	26.6	14.8	391	9.4
	0.5	26.3	15.1	390	---
	1	26	15.3	387	---
	2	25.7	14.6	385	---
	3	25.1	14.6	382	---
	4	25.5	5.4	375	---
	5	21.5	5.2	343	---
	6	16.8	2.8	314	8.8
	7	10.4	2.5	290	---
	8	8.7	1.5	275	---
	9	7.4	0.8	272	---
	10	7	0.7	272	---
	11	7	0.4	271	8.3
	12	6.8	0.4	---	---
	13	6.6	0.3	---	---
	14	6.6	0.3	---	---
	15	6.5	0.2	---	---

25-Aug	Depth (m)	Temp (°C)	HDO (mg/L)	Cond (μS/cm)	pH
	Surface	25.9	12.1	496	9.1
	0.5	25.8	12	491	---
	1	25.3	12.1	483	---
	2	25.1	12.1	481	---
	3	24.7	11.7	477	---
	4	24.2	9.8	472	---
	5	20.4	3	469	8.6
	6	16.1	2	429	---
	7	12.3	1.2	395	---
	8	9.6	0.7	369	---
	9	8	0.5	352	---
	10	7.5	0.4	350	---
	11	7.2	0.3	348	---
	12	7	0.3	---	8.5
	13	6.9	0.2	---	---
	14	6.7	0.2	---	---

30-Sep	Depth (m)	Temp (°C)	HDO (mg/L)	Cond (μS/cm)	pH
	Surface	20.1	12.6	392	---
	0.5	20.2	12.4	394	8.9
	1	20.2	12.3	395	---
	2	20.2	12.1	395	---
	3	20.2	12.1	395	---
	4	20.2	12	396	---
	5	20.1	11.9	396	---
	6	20.1	11.9	395	---
	7	15.9	5.4	390	---
	8	11.3	4.6	357	8.5
	9	8.4	4.2	447	---
	10	7.4	3.7	440	---
	11	7	2.8	436	---
	12	6.9	2.3	---	---
	13	6.9	1.8	---	8.1
	14	6.8	1.6	---	---
	15	6.8	1.4	---	---

28-Oct	Depth (m)	Temp (°C)	HDO (mg/L)	Cond (µS/cm)	pH
	Surface	15.3	13.5	295	8.6
	0.5	15.3	13.7	295	---
	1	15.3	13.7	295	---
	2	15.3	13.6	295	---
	3	15.2	13.5	295	---
	4	15.2	13.4	295	---
	5	15.2	13.3	295	---
	6	15.2	13.3	295	---
	7	15.1	13.3	295	---
	8	13.1	13.3	302	8.4
	9	9	7.5	290	---
	10	8.1	7.3	288	7.9
	11	---	6.9	---	---

Date	Stratum	Alk (mg/L)	Ca (mg/L)	NH4 (mg/L)	TKN (mg/L)	Nitrate (mg/L)	TP (mg/L)	Chl-a (µg/L)	Secchi (m)
26-Apr	Epi	80	23	0	1	0.07	0.037	10.9	1.52
26-Apr	Meta	82	23	0	0.7	0	0.045	---	---
26-Apr	Hypo	84	23	0.6	1.1	0.06	0.089	---	---
27-May	Epi	84	25	0	0.6	0	0.041	2.35	2.22
27-May	Meta	78	25	0	0.8	0	0.054	---	---
27-May	Hypo	88	25	0.7	1.1	0	0.141	---	---
21-Jun	Epi	86	23	0.2	0.9	0	0.046	1.53	1.68
21-Jun	Meta	92	25	0	0.8	0	0.071	---	---
21-Jun	Hypo	100	26	1.4	1.6	0	0.24	---	---
27-Jul	Epi	88	24	0	0.6	0	0.031	7.47	1.75
27-Jul	Meta	90	27	0	0.4	0	0.035	---	---
27-Jul	Hypo	94	28	1.7	1.9	0.06	0.32	---	---
25-Aug	Epi	78	23	0	0.5	0	0.023	1.42	3.05
25-Aug	Meta	84	25	0	0.6	0	0.064	---	---
25-Aug	Hypo	96	26	2	2.4	0	0.306	---	---
30-Sep	Epi	80	28	0	0	0.042	0.043	14.73	3.28
30-Sep	Meta	79	28	0	0	0	0.051	---	---
30-Sep	Hypo	94	32	0	0	0.057	0.076	---	---
28-Oct	Epi	80	23	0	0	0	0.019	6.67	3.20
28-Oct	Meta	80	24	0	0	0	0.017	---	---
28-Oct	Hypo	100	27	1.8	1.8	0	0.14	---	---

APPENDIX B. CYANOMONITORING DATA

Size/Site	Date (#)	Date	Phyco µg/L	Ln (Phyco)	Growth Rate µg/day
BFC Site 1	44365	18-Jun	850.2	6.75	0
BFC Site 1	44372	25-Jun	112.4	4.72	-0.2891
BFC Site 1	44382	5-Jul	34.54	3.54	-0.1180
BFC Site 1	44387	10-Jul	79.44	4.38	0.1666
BFC Site 1	44400	23-Jul	17.97	2.89	-0.1143
BFC Site 1	44416	8-Aug	17.76	2.88	-0.0007
BFC Site 1	44428	20-Aug	20.06	3.00	0.0101
BFC Site 1	44442	3-Sep	39.58	3.68	0.0485
BFC Site 1	44456	17-Sep	95.8	4.56	0.0631
BFC Site 2	44365	18-Jun	52.79	3.97	0.0000
BFC Site 2	44372	25-Jun	627.39	6.44	0.3536
BFC Site 2	44382	5-Jul	11.67	2.46	-0.3985
BFC Site 2	44387	10-Jul	52.16	3.95	0.2995
BFC Site 2	44400	23-Jul	10.41	2.34	-0.1240
BFC Site 2	44416	8-Aug	54.47	4.00	0.1034
BFC Site 2	44428	20-Aug	28.46	3.35	-0.0541
BFC Site 2	44442	3-Sep	67.27	4.21	0.0614
BFC Site 2	44456	17-Sep	8.74	2.17	-0.1458
BFC Site 3	44365	18-Jun	145.24	4.98	0.0000
BFC Site 3	44372	25-Jun	73.56	4.30	-0.0972
BFC Site 3	44382	5-Jul	13.56	2.61	-0.1691
BFC Site 3	44387	10-Jul	59.72	4.09	0.2965
BFC Site 3	44400	23-Jul	6.86	1.93	-0.1665
BFC Site 3	44416	8-Aug	264.41	5.58	0.2282
BFC Site 3	44428	20-Aug	39.37	3.67	-0.1587
BFC Site 3	44442	3-Sep	15.87	2.76	-0.0649
BFC Site 3	44456	17-Sep	41.88	3.73	0.0693

Size/Site	Date (#)	Date	Phyco µg/L	Ln (Phyco)	Growth Rate µg/day
WLW Site 1	44365	18-Jun	56.36	4.03	0
WLW Site 1	44372	25-Jun	6.65	1.89	-0.3053
WLW Site 1	44382	5-Jul	8.95	2.19	0.0297
WLW Site 1	44387	10-Jul	4.76	1.56	-0.1263
WLW Site 1	44400	23-Jul	0.1	-2.30	-0.2971
WLW Site 1	44416	8-Aug	33.49	3.51	0.3634
WLW Site 1	44428	20-Aug	2.25	0.81	-0.2250
WLW Site 1	44442	3-Sep	8.32	2.12	0.0934
WLW Site 1	44456	17-Sep	5.39	1.68	-0.0310
WLW Site 2	44365	18-Jun	60.76	4.11	0.0000
WLW Site 2	44372	25-Jun			
WLW Site 2	44382	5-Jul	2.46	0.90	-0.1886
WLW Site 2	44387	10-Jul	14.61	2.68	0.3563
WLW Site 2	44400	23-Jul	5.18	1.64	-0.0798
WLW Site 2	44416	8-Aug	7.69	2.04	0.0247
WLW Site 2	44428	20-Aug	5.39	1.68	-0.0296
WLW Site 2	44442	3-Sep	5.39	1.68	0.0000
WLW Site 2	44456	17-Sep	5.81	1.76	0.0054
WLW Site 3	44365	18-Jun	44.61	3.80	0.0000
WLW Site 3	44372	25-Jun	9.37	2.24	-0.2229
WLW Site 3	44382	5-Jul	2.25	0.81	-0.1427
WLW Site 3	44387	10-Jul	7.69	2.04	0.2458
WLW Site 3	44400	23-Jul	1.62	0.48	-0.1198
WLW Site 3	44416	8-Aug	14.19	2.65	0.1356
WLW Site 3	44428	20-Aug	0.1	-2.30	-0.4129
WLW Site 3	44442	3-Sep	2.04	0.71	0.2154
WLW Site 3	44456	17-Sep	15.66	2.75	0.1456

Size/Site	Date (#)	Date	Phyco µg/L	Ln (Phyco)	Growth Rate µg/day
Pico Site 1	44365	18-Jun			
Pico Site 1	44372	25-Jun	6.86	1.93	
Pico Site 1	44382	5-Jul	3.93	1.37	-0.0557
Pico Site 1	44387	10-Jul	3.93	1.37	0.0000
Pico Site 1	44400	23-Jul	0.1	-2.30	-0.2824
Pico Site 1	44416	8-Aug	14.19	2.65	0.3097
Pico Site 1	44428	20-Aug	1	0.00	-0.2210
Pico Site 1	44442	3-Sep	3.09	1.13	0.0806
Pico Site 1	44456	17-Sep	2.67	0.98	-0.0104
Pico Site 2	44365	18-Jun			
Pico Site 2	44372	25-Jun	42.93	3.76	
Pico Site 2	44382	5-Jul	5.39	1.68	-0.2075
Pico Site 2	44387	10-Jul	6.23	1.83	0.0290
Pico Site 2	44400	23-Jul	0.64	-0.45	-0.1751
Pico Site 2	44416	8-Aug	5.39	1.68	0.1332
Pico Site 2	44428	20-Aug	0.1	-2.30	-0.3323
Pico Site 2	44442	3-Sep	2.88	1.06	0.2400
Pico Site 2	44456	17-Sep	2.88	1.06	0.0000
Pico Site 3	44365	18-Jun			
Pico Site 3	44372	25-Jun	40.62	3.70	
Pico Site 3	44382	5-Jul	3.51	1.26	-0.2449
Pico Site 3	44387	10-Jul	5.81	1.76	0.1008
Pico Site 3	44400	23-Jul	1	0.00	-0.1354
Pico Site 3	44416	8-Aug	6.44	1.86	0.1164
Pico Site 3	44428	20-Aug	0.1	-2.30	-0.3471
Pico Site 3	44442	3-Sep	6.02	1.80	0.2927
Pico Site 3	44456	17-Sep	2.46	0.90	-0.0639

APPENDIX C. CYANOBACTERIA IMAGE GALLERY

The following are images of cyanobacteria specimens from Ball Pond collected during the CyanoMonitoring Program. All photographs were taken by Elissa Johnson of the BPAC.

A. *Aphanizomenon spp*. collected in a plankton tow on June 18, 2021.

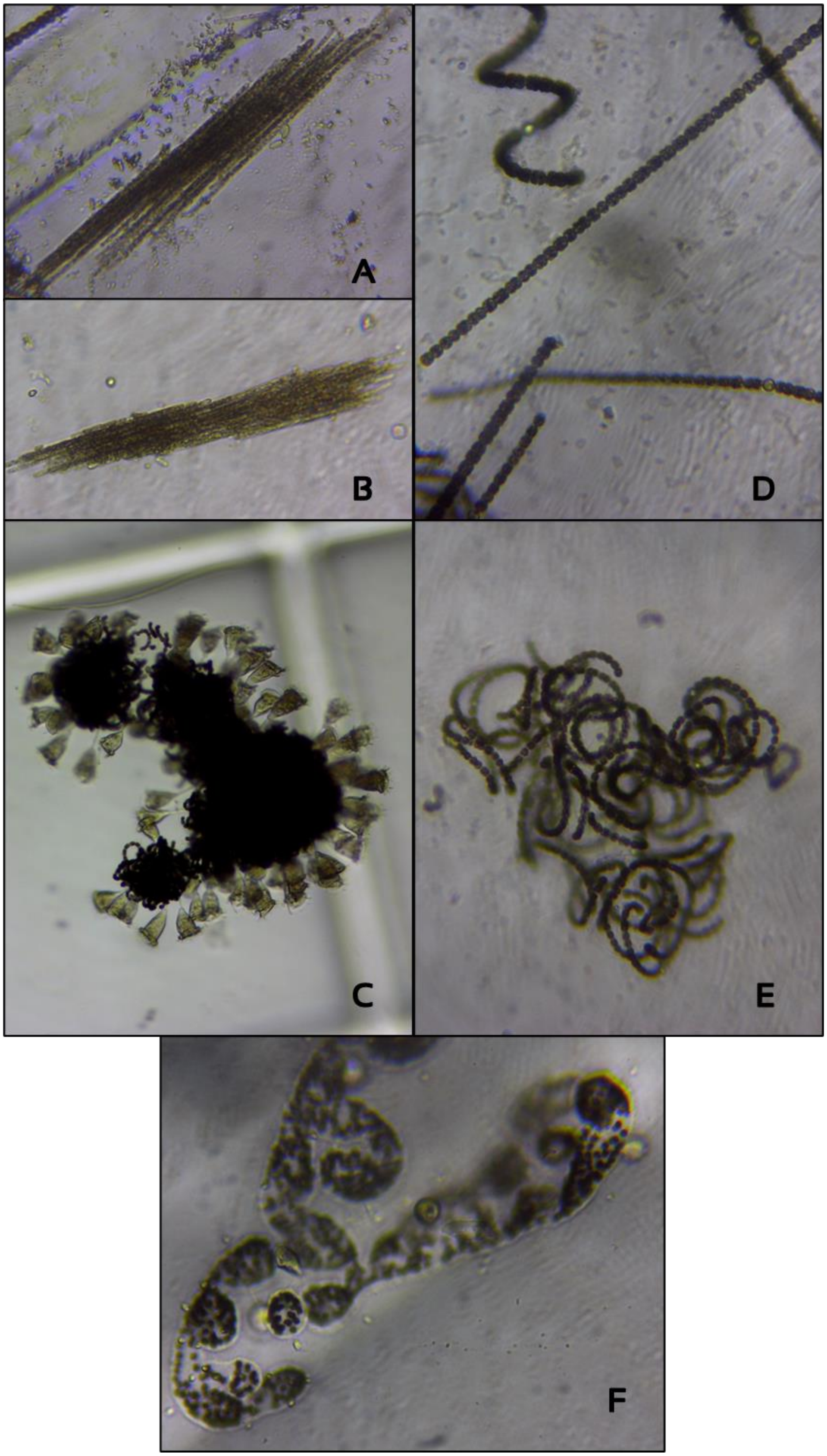
B. *Aphanizomenon spp*. collected from the bloom-forming cyanobacteria (BFC) sample faction from the deep-water site (Site 1) on June 25, 2021.

C. *Dolichospermum c.f. lemmermannii* with an attached colony of the zooplankton *Vorticella spp*. collected from the BFC sample faction of the deep-water site on September 17, 2021.

D. *Dolichospermum spp*. collected in a plankton tow at Site 2 on June 18, 2021.

E. *Dolichospermum spp*. collected from the BFC sample faction from Site 2 on June 25, 2021.

F. *Microcystis spp.* collected from the deep-water (Site 1) site on July 10, 2021.


A
B
D
C
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F