Bantam Lake

2023 Water Quality Monitoring Report

Bantam Lake Protective Association,
Morris, CT

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I. Executive Summary

The Bantam Lake Protective Association (BLPA) annually supports water quality monitoring as part of its lake management strategy. Brawley Consulting Group carried out the lake monitoring program in the 2023 season which differed from many seasons in the recent past in that (1) no copper sulfate treatments to manage cyanobacteria were undertaken, and (2) record rainfall occurred.

The lake exhibited varying degrees of stability which appeared related to site depth. The Center Lake Site, the deepest site, was the most stable with a thermocline detected in mid-May through mid-August, and again in September. The stratification at the shallower North Bay and Folly Point Sites was shorter in duration, while at the South Bay Site, the shallowest of the four sites, occurrences of a thermocline were rare. All sites but the South Bay Site exhibited extended periods of anoxic conditions near the bottom.

Season averages for standard trophic indicators were characteristic of mesotrophic to eutrophic conditions. Summer average Secchi transparency and epilimnetic total nitrogen concentration were within the ranges considered eutrophic (high algal productivity). Average summer chlorophyll-*a* concentration was within the late-mesotrophic range (moderate algal productivity). Average epilimnetic total phosphorus was characteristic of mesotrophic conditions but monthly levels were higher in the latter part of the season following loading from lake bottom sediments under anoxic conditions, which is characteristic of eutrophic lakes. The August through October epilimnetic average was significantly greater than the May through July average.

Average lake and Center Lake Site hypolimnetic total phosphorus average concentrations were significantly greater than corresponding epilimnetic averages. The same was not true for the North Bay and South Bay Sites, which were shallower and more prone to mixing. Lake average hypolimnetic total nitrogen was significantly greater than the corresponding lake averages for the epilimnion and metalimnion, and monthly levels were highest in July through September, concurrent with anoxic conditions, particularly at the deepest Center Lake Site.

The planktonic algal community was largely dominated by the cyanobacteria (aka blue-green algae). Bloom levels, and the highest concentrations, were measured in the beginning of the season which decreased to season lows by late June. Concentrations then increased and fluctuated between 20,000 to 100,000 cells/mL range for the balance of the season. That range corresponded with the Visual Rank Category 2 conditions from the CT DPH / CT DEEP Guidance document where it is described as indicating moderate risk to public health from cyanotoxins. However, actual microcystin toxin levels were never >1 µg/L and well below the 8 µg/L threshold for low-risk conditions used by the State and the US EPA.

Season average specific conductance near the surface was in line with averages over the last 5 years. The 2023 levels were highest early in the season and steadily decreased with time, presumably due to the increased flushing resulting from record rainfall. Elevated specific conductance levels were observed from 6 meters of depth to the bottom of the Center Lake Site and at the very bottom of the Folly Point Site and likely due to the chemically reduced environment resulting from anoxic conditions. Alkalinity exhibited a similar pattern with the seasonal average for surface waters in line with averages of the last 5 years and a gradual decrease from the beginning to the end of the season. Likewise, elevated levels were detected near the bottom of the Center Lake Site following protracted periods of anoxic conditions. Alkalinity and other data derived from samples analyzed in an environmental laboratory were not collected at the Folly Point Site.

Changes in historical water quality have been documented using historical studies from the 1930s, 1970s, and 1990s, and also based on a paleolimnological study that inferred changing conditions since the 1850s. Those studies indicated that Bantam Lake shifted from an oligotrophic to eutrophic lake and salt levels increased based on the surrogate measure of specific conductance. Trends in recent years – 2018 to 2023 – were examined using *Multiple Linear Regression* and *Analysis of Variance*. Results from those analyses indicated that Bantam is in a steady state, i.e., not trending, albeit a steady state that is conducive to high cyanobacteria productivity.

Cyanobacteria growth rates over the last three years were closely examined. Growth rates this year were more similar to those of 2021 than they were to those of 2022, even though copper sulfate treatments occurred in 2021 and 2022, but not 2023. Statistical analyses were performed on Center Lake growth rate data collected since 2019 and resulted in data outliers that were often concurrent with post copper sulfate treatments. Effective methods of assessing good management of cyanobacteria will become more necessary as different treatment methods are used.

The record rainfall during the 2023 monitoring season was examined and discussed in relation to water quality. Understanding impacts of changing climate will continue to become important as new conditions, e.g., lower average spring and summer wind speeds, earlier ice off and warmer springs, and precipitation extremes (draught or deluge), become more common.

Recommendations on future water quality initiatives are provided at the end of the report.

II. Introduction

Bantam Lake is a 966-acre waterbody located in the towns of Litchfield and Morris, Connecticut; and is the largest natural lake in the State. Geologically, it is situated in the Western Uplands of Connecticut (Bell 1985, Canavan & Siver 1995). That geological region has an erosion resistant, crystalline bedrock comprised of schists, gneiss, granite gneiss, and granofels (Healy & Kulp 1995). The watershed of Bantam Lake is 20,218 acres resulting in a watershed to lake ratio of approximately 21. In a 1995 survey, land use was characterized as mainly deciduous forest and agriculture lands with smaller areas of medium-density residential land use, wetlands, and coniferous forests (Healy & Kulp 1995). Much of the shoreline is lined with homes, beaches, and several camps. There is also a large tract of conservation land along the northern shoreline which is owned by the White Memorial Foundation (See Location Map, Fig 1.).

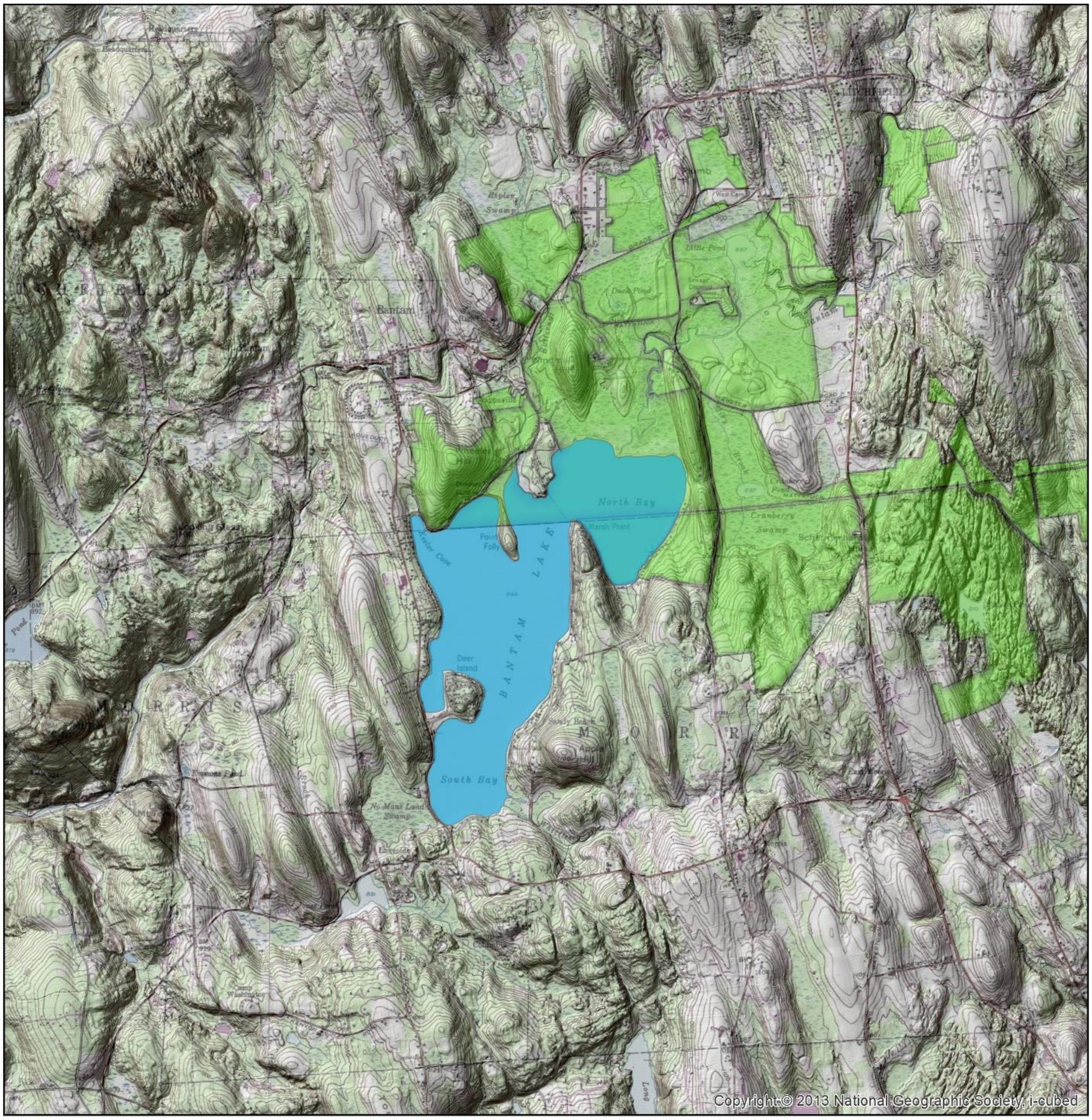
A. Historical Water Quality Studies

Earliest published assessments of Bantam Lake occurred in the late 1930s (Deevey 1940). That study and several others occurring over the next 70 years (Frink & Norvell 1984, Canavan & Siver 1994, 1995, Healy and Kulp 1995) included Bantam Lake as part of statewide surveys of Connecticut Lakes that used standard in-situ measurements and laboratory analyses of water samples to develop historical records of water quality. These studies resulted in important historical water quality baselines for many of Connecticut's lakes. Several of those statewide surveys have been compiled in Canavan and Siver (1994, 1995).

A paleolimnological study of Bantam Lake's water quality used statistically significant inference models and the remains of fossil bearing algae layered chronologically in a sediment core to estimate changes in water quality over time (e.g., trophic level, conductivity levels, and pH, over time; Siver 1993, Siver and Marsicano 1996). The oldest sediments in the Bantam sediment core dated back to *ca* 1857.

Based on the earliest fossil assemblages, Bantam Lake was oligotrophic (low primary/algal productivity) to early mesotrophic from *ca* 1857 through *ca* 1898 (Fig. 2). Subsequently, the lake's trophic status changed and by *ca* 1926, Bantam Lake was mesotrophic (moderate productivity). The lake became more eutrophic particularly between *ca* 1946 and *ca* 1964. The fossil assemblages near the top of the core dated to *ca* 1991 indicated that the lake had become eutrophic (high primary/algal productivity).

Bantam Lake continues to exhibit eutrophic characteristics including high levels of algal productivity that have become one of the primary management concerns of the Bantam Lake Protective Association (BLPA). High concentrations of cyanobacteria and bloom-like conditions are common between the midsummer and fall periods of the recreation season. This has resulted in the inclusion by the State of Connecticut of Bantam Lake in the State's list of impaired waterbodies, which cites algae, chlorophyll, and nutrients as the causes of impairments (CT DEEP 2020).



LOCATION MAP

Bantam Lake
Litchfield & Morris, CT

NOTES
(1) This map contains no authoritative data and is intended for planning purposes only; (2) The location and extent of features illustrated are based on GPS-collected field data as well as direct observations and are approximate only; (3) Basemap data sources include USGS topographic (USA TOPO) maps, 2016 orthophotography and road maps from ESRI and CT ECO map services.

Legend

🟦 Bantam Lake

🟩 White Memorial Foundion

SCALE

N

0 0.25 0.5 1 Miles

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July, 2023

Figure 1. Location map for Bantam Lake.

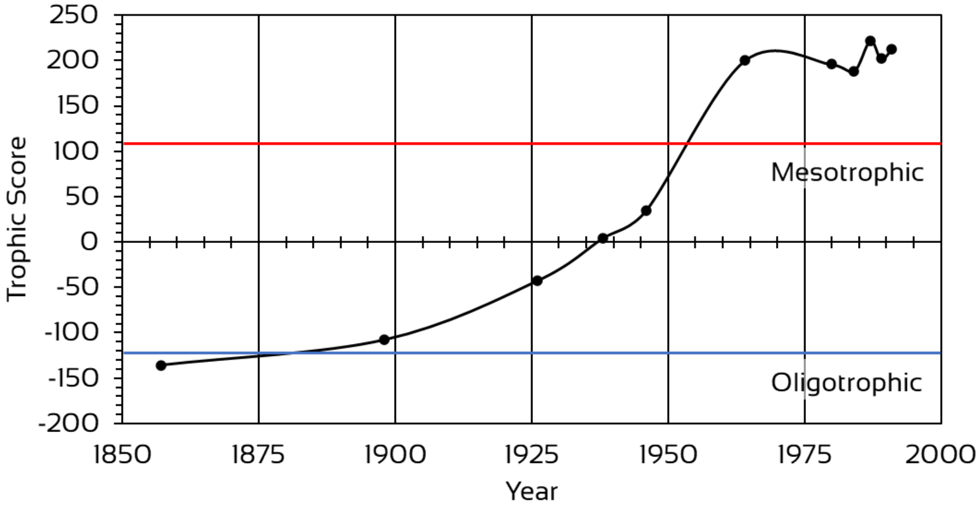


Figure 2. Reconstruction of Bantam Lake trophic status between *ca* 1857 and *ca* 1991. The blue horizontal line represents the division between oligotrophic and mesotrophic lakes; and the red horizontal line represents the division between mesotrophic and eutrophic lakes based on a trophic score (Siver and Marsicano 1996).

B. CT DEEP's TMDL Study and Watershed-Based Plan

Recent efforts at Bantam Lake by the Connecticut Department of Energy of Environmental Protection, in conjunction with the US EPA, and the BLPA included a *Total Maximum Daily Loading* (TMDL) *Study* and a *Watershed-Based Plan* (CT DEEP 2021). The TMDL study and watershed plan provide a wealth of information on: 1) the lake and watershed; 2) sources of the nutrients that impair the lake; and 3) measures to reduce nutrient export to the lake. Recommendations are also provided on future lake and watershed monitoring efforts.

C. Current Water Quality Concerns

Harmful algal blooms or HABs, have become a key issue in lake management over the last 20 years because of the risk they present to ecosystem and public health. In addition to depletion of oxygen from the water column following a bloom, many genera of cyanobacteria are potentially toxic. The cyanotoxins are generally grouped into one of several categories: hepatotoxin that cause liver damage, neurotoxins that have been associated with neurological disorders like amyotrophic lateral sclerosis (ALS), and others in groups classified as dermatoxins, cytotoxins, and endotoxins. The State of Connecticut provides a useful summary on cyanobacteria, the toxins they produce, and standards by which municipal health department can assess conditions at public beaches (CT DPH & CT DEEP 2019). In efforts to manage cyanobacteria growth and minimize risk, two copper sulfate treatments were undertaken during the 2022 season. The first occurred on July 9th and the second on August 24th.

III. Methods

D. Water Quality Monitoring

Four sampling sites were visited six times each between April and October of 2023 (See Fig. 3). Data and water sample collections occurred on: April 26th, May 25th, June 22nd, July 19th, August 18th, September 14th, and October 10th. Sites were identified as North Bay (NB), Center Lake (CL), Point Folly (PF), and South Bay (SB). Maximum depths were approximately 6 meters (m), 8m, 6.5m, and 4.5m at the NB, CL, FP, and SB sites, respectively.

During each site visit, Secchi transparency was measured with a 26cm diameter Secchi disk. Additionally, vertical profile data for six water column properties were collected using a Eureka Manta II Multiprobe. Profiled data were measured at 0.5m from the surface and at one-meter intervals down to 0.5m above the bottom and included the following variables: temperature (°C), dissolved oxygen (mg/L), percent oxygen saturation (% O2), specific conductance (µS/cm), pH, and relative cyanobacteria biomass. On three visits in 2023, data was not collected at PF (Table 1).

Water samples were collected at the NB, CL, and SB sites during visits and analyzed for the variables listed in Table 1. Samples collected in April – July were analyzed by York Analytical Laboratories in Newtown, CT. Those samples were stored in an ice-filled cooler until delivered later the same day to the laboratory. Samples collected in August – October were analyzed by the University of Connecticut Center for Environmental Science and Engineering (UCONN CESE) in Storrs, CT. Those samples were also kept on ice until frozen at BCG facilities before delivery later in week.

Water samples were collected using two different methods and at several depths in the water column. For nutrient and alkalinity analyses, samples were collected with a horizontal Van Dorn water sampler at 1 meter (m) below the surface (epilimnion), at approximately 0.5m above the sediment-water interface (hypolimnion), and at the thermocline, which was determined using vertical temperature profile data collected at each site on each sample date. For base cations of sodium (Na+), potassium (K+), calcium (Ca2+), magnesium (Mg2+), and the anion chloride (Cl-), samples were collected on three occasions during the season from 1m below the surface. For chlorophyll-*a*, a weighted tube sampler was used to collect and integrate water from the top three meters of the water column at the NB and CL sites.

E. Cyanobacteria Monitoring

Planktonic algae samples were collected fifteen times in 2023, including the dates when water quality data and samples were collected (Table 1). Samples for algae analyses were collected at the NB, CL, and SB sites by integrating the top three meters of the water column with a 3-meter-long sampling tube. Samples were treated with

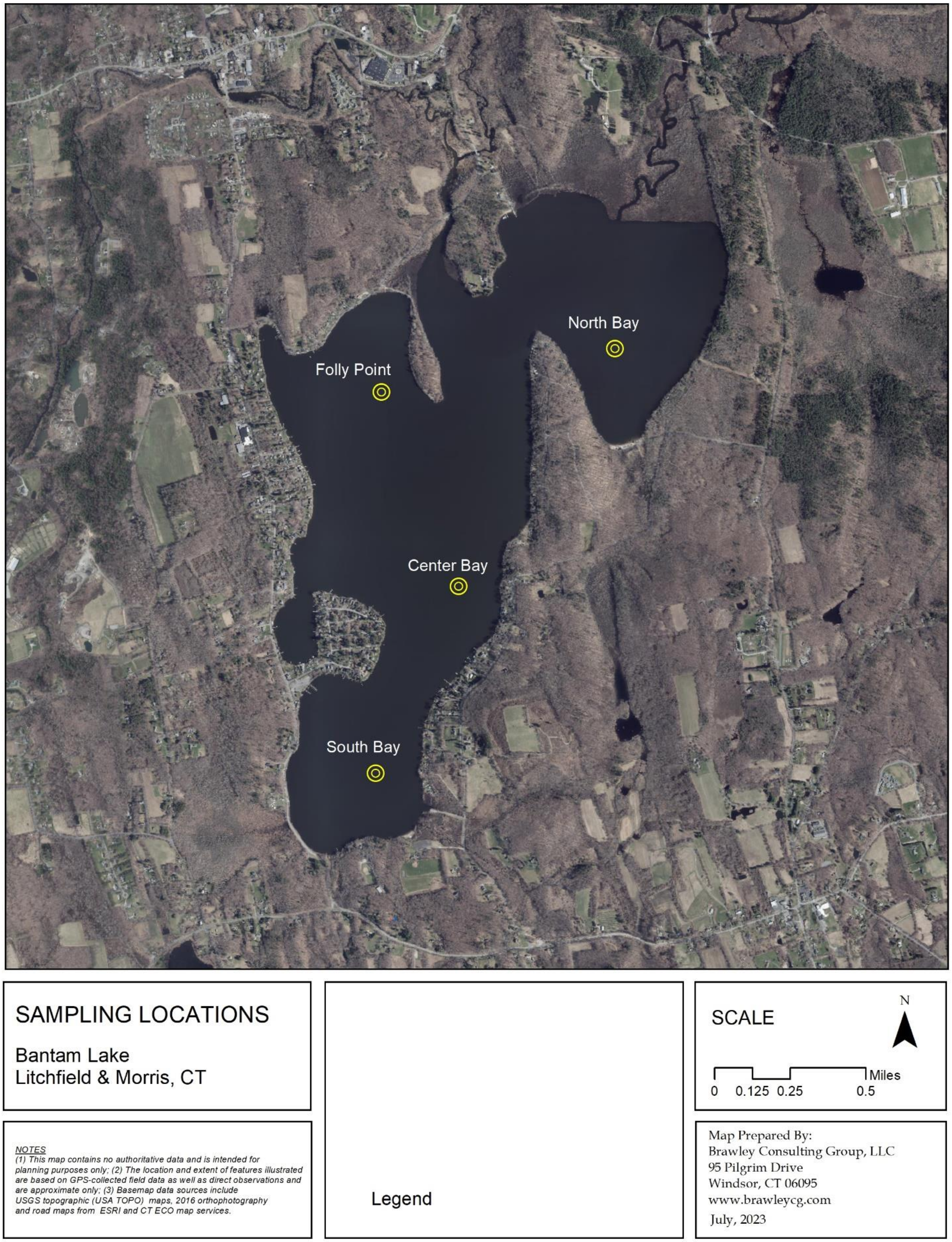
Lugol's solution and kept on ice. Samples were later treated with hydrostatic pressure back in the Brawley offices to collapse gas vesicles that might be creating positive buoyancy in cyanobacteria cells (Lawton et al. 1999).

When necessary, measured volumes of the preserved whole water samples were concentrated into smaller measured volumes with centrifugation and a vacuum pump / filtration flask system. This step was omitted when cyanobacteria concentrations were high based on a visual assessment at the lake or on low Secchi disk transparencies. A known portion of those concentrates or whole water samples were pipetted into a counting chamber and genus-level algal cell enumerations were performed by counting algae cells in a subset of fields within the counting chamber slide using an inverted Nikon Diaphot research microscope. Those counts were then corrected to be reflective of the whole sample.

Additionally, a 10µm plankton net was used to collect a concentrated algal sample from within the top 3m of the CL water column. Those samples were examined, and important genera photographed in the laboratory using a Wolfe DigiviTM CVM Microscope with Motic Images Plus 3.0 software.

Table 1. Summary of data collections for Bantam Lake in 2023 used in this report. NB = North Bay Site, CL = Center Lake Site, FP = Folly Point Site, and SB = South Bay Site.

2023 Dates	Profiles and Secchi	Algae	Nutrients & Alkalinity	Base Cations and Chloride	Chlorophyll
26-Apr-23	NB, CL, FP, SB	NB, CL, SB	NB, CL, SB	NB, CL, SB	NB, CL, SB
12-May-23	NB, CL, SB	NB, CL, SB			
25-May-23	NB, CL, FP, SB	NB, CL, SB	NB, CL, SB	NB, CL, SB	NB, CL, SB
9-Jun-23	NB, CL, FP, SB	NB, CL, SB			
22-Jun-23	NB, CL, FP, SB	NB, CL, SB	NB, CL, SB	NB, CL, SB	NB, CL, SB
6-Jul-23	NB, CL, FP, SB	NB, CL, SB			
19-Jul-23	NB, CL, FP, SB	NB, CL, SB	NB, CL, SB	NB, CL, SB	NB, CL, SB
28-Jul-23	NB, CL, SB	NB, CL, SB			
2-Aug-23	NB, CL, FP, SB	NB, CL, SB			
18-Aug-23	NB, CL, FP, SB	NB, CL, SB	NB, CL, SB	NB, CL, SB	NB, CL, SB
31-Aug-23	NB, CL, FP, SB	NB, CL, SB			
14-Sep-23	NB, CL, FP, SB	NB, CL, SB	NB, CL, SB	NB, CL, SB	NB, CL, SB
28-Sep-23	NB, CL, FP, SB	NB, CL, SB			
10-Oct-23	NB, CL, FP, SB	NB, CL, SB	NB, CL, SB	NB, CL, SB	NB, CL, SB
16-Oct-22	NB, CL, SB	NB, CL, SB			



SAMPLING LOCATIONS

Bantam Lake
Litchfield & Morris, CT

SCALE

NOTES
(1) This map contains no authoritative data and is intended for planning purposes only; (2) The location and extent of features illustrated are based on GPS-collected field data as well as direct observations and are approximate only; (3) Basemap data sources include USGS topographic (USA TOPO) maps, 2016 orthophotography and road maps from ESRI and CT ECO map services.

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July, 2023

Figure 3. Sampling Locations Map for Bantam Lake.

F. Cyanobacteria Monitoring

Samples for algae analyses were collected at the NB, CL, and SB sites by integrating the top three meters of the water column with a 3-meter-long sampling tube. Samples were treated with Lugol's solution and kept on ice. Samples were later treated with hydrostatic pressure back to collapse gas vesicles that might be creating positive buoyancy in cyanobacteria cells (Lawton et al. 1999).

When necessary, measured volumes of the preserved whole water samples were concentrated into smaller measured volumes with centrifugation and a vacuum pump / filtration flask system. This step was omitted when cyanobacteria concentrations were high based on a visual assessment at the lake or on low Secchi disk transparency. A known portion of those concentrates or whole water samples were pipetted into a counting chamber and genus-level algal cell enumerations were performed by counting algae cells in a subset of fields within the counting chamber slide using an inverted Nikon Diaphot research microscope. Those counts were then corrected to be reflective of the whole sample.

Additionally, a 10µm plankton net was used to collect a concentrated algal sample from within the top 3m of the CL water column. Those samples were examined, and important genera photographed in the laboratory using a Wolfe Digivi$^{\mathrm{TM}}$ CVM Microscope with Motic Images Plus 3.0 software. During each algae sample collection visit, Secchi transparency and vertical profile data were collected at NB, CL, FP, and SB sites.

IV. Profile Data

A. Isopleth Charts

We have displayed many of the data collected throughout the NB, CL, FP, and SB water columns as isopleths where a variable (e.g., temperature) is displayed as shades of colors throughout the water column at each depth and for all applicable collection dates. Values were then interpolated between depth and dates. Variables of the same value (and color) are connected between dates regardless of depth to create a theoretical representation of changes throughout the water column over time (Fig. 4-5).

B. Water Column Temperature & Stability

The water temperature profile data and isopleth charts provided a view into the thermal and oxygen dynamics of the lake including seasonal stratification resulting from temperature/density differences between depths. In shallow New England lakes, or shallow sites in a deep lake, stratification can occur. When a lake is thermally stratified, a middle transitional layer (known as the metalimnion) separates the upper warmer layer (epilimnion) from lower colder waters below (hypolimnion). Within the boundaries of the metalimnion is the thermocline, which is the stratum where the temperature/density change and resistance to mixing are the greatest. This stratification may be short in duration because wind energy can mix the water column. In deeper lakes or sites, stratification is not easily broken by wind energy.

An oxygen concentration of 5 mg/L is generally considered the threshold that delineates favorable very conditions for most aerobic organisms in freshwater systems. As concentrations decrease below that threshold, conditions become stressful for aquatic organisms. Minimum oxygen requirements for fisheries in Connecticut's lakes and ponds range from 4 to 5 mg/L for cold-water fish (e.g., trout), 2 mg/L for cool-water fish (e.g., walleye), and 1 to 2 mg/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 compared to conditions where oxygen is present. These anoxic conditions result in the dissolution of compounds (e.g., iron phosphate) in the sediments that can then dissolve in the interstitial waters and eventually into the waters above the sediments.

The water columns at the four sites exhibited differing degrees of seasonal stability with deeper sites exhibiting more stability (Fig.4). The CL site was the deepest and exhibited the most stability with a thermocline detected on all visits from mid-May to mid-August, then again in mid-September. The position of the thermocline did change regularly due to mixing/storm events and increasing air and water temperatures which peaked in mid-July. Resistance to mixing at the thermocline varied with the strongest resistance measured in late June and early July.

The water column at the shallowest of all sites, SB, was mostly mixed (i.e. unstable) throughout the season. A thermocline was detected in mid-May, early June, and in the mid- to late July sampling dates. The thermocline position changed from up higher in the water column to near the bottom of the water column, and resistance to mixing was never strong.

The NB and FP sites were similar in maximum depth (6 and 6.5 meters, respectively) and level of stability/instability. A thermocline was detected in mid- to late May, and then again from early July through mid-August at the NB site. At FP, the thermocline was observed in early June through mid-August. Resistance to mixing at the thermoclines of both sites was never strong.

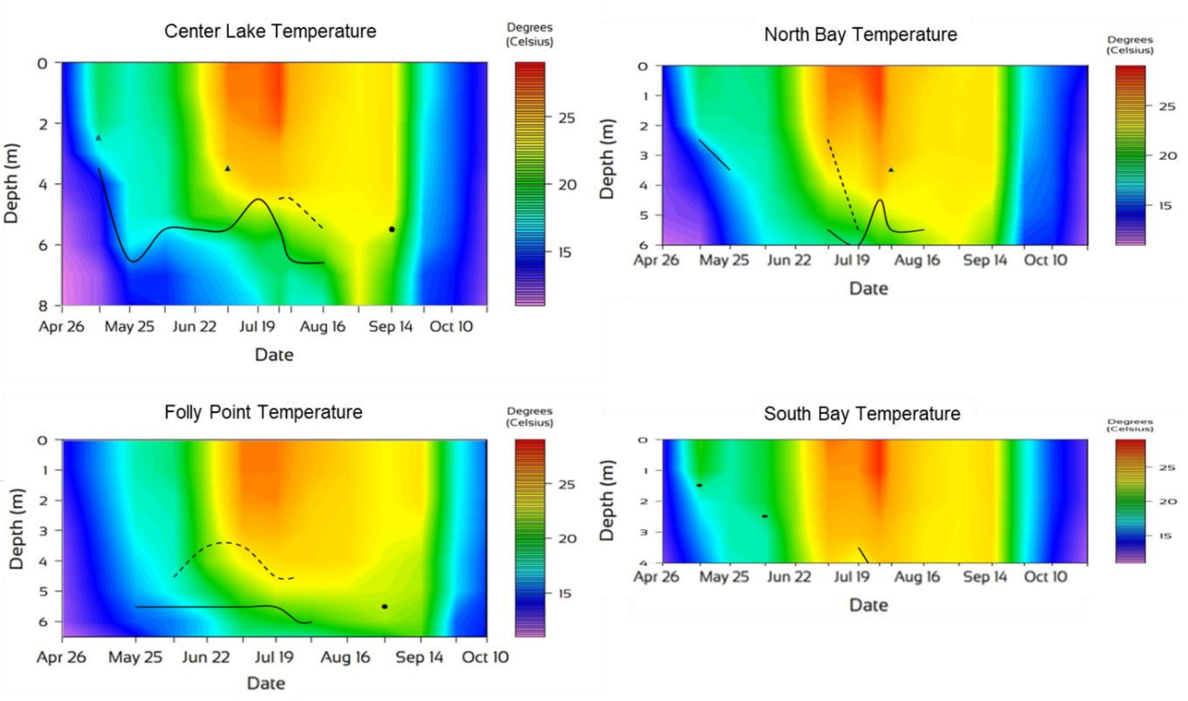

Figure 4 Temperature isopleth charts for the Center Lake, North Bay, Folly Point, and South Bay monitoring sites. The solid black lines and solid black circles represent the position of the thermocline. The black dashed lines and solid black triangles represent the upper and/or lower metalimnetic boundaries. Lines were used when a thermocline or metalimnetic boundary was observed in consecutive sampling events.

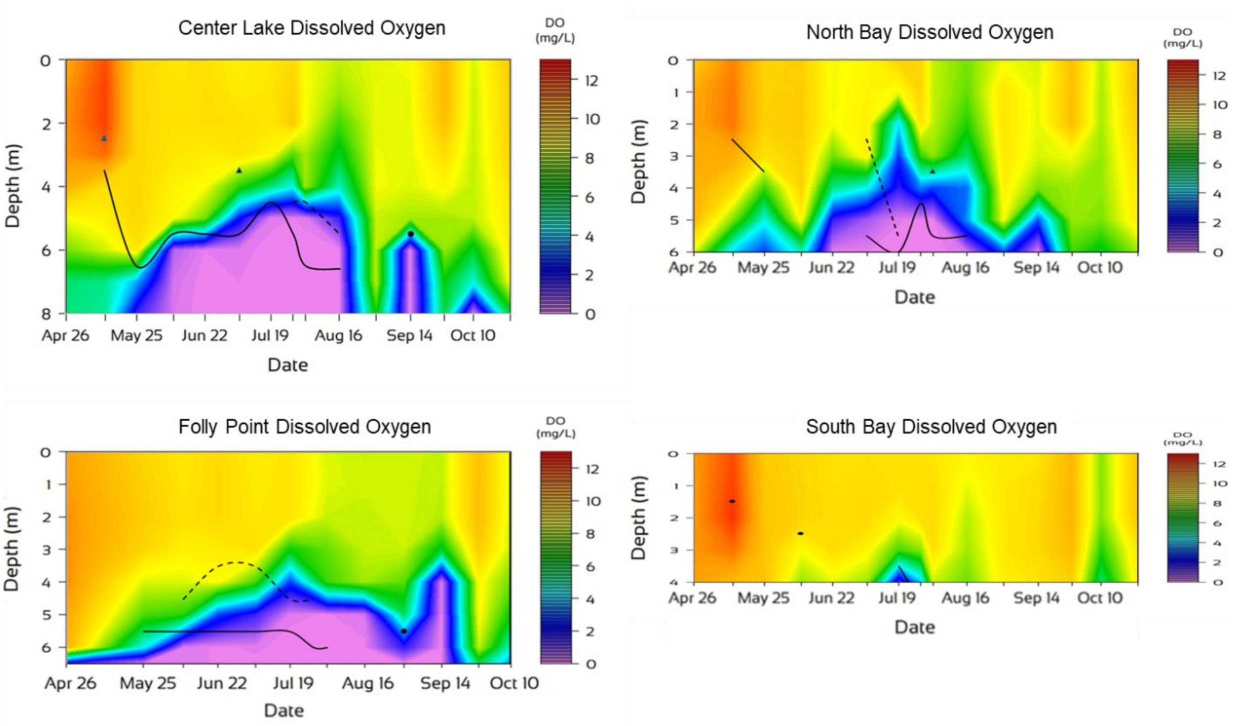

Figure 5. Dissolved oxygen isopleth charts for the Center Lake, North Bay, Folly Point, and South Bay monitoring sites. The solid black lines and solid black circles represent the position of the thermocline. The black dashed lines and solid black triangles represent the upper and/or lower metalimnetic boundaries. Lines were used when a thermocline or metalimnetic boundary was observed in consecutive sampling events.

C. Dissolved Oxygen

At NB, oxygen concentrations of >8 mg/L were measured throughout the water column in late April. By mid-May, when a thermocline was first detected, concentrations above 5 meters of depth remained high, but concentrations near the bottom had begun to decrease (Fig. 5). Depths with low oxygen concentrations expanded upward by late May. By early June, concentrations down to 5 m of depth were high. By late June, the first anoxic conditions were observed at the bottom of the water column which persisted through mid-August. Throughout July and into early August, concentrations of <1 mg/L were measured from 5 m of depth to the bottom. Anoxic and/or low oxygen levels were also measured <u>above</u> the thermocline during that time.

By mid-August at NB, oxygen levels in the upper portions of the water column had decreased while concentrations down to 5 m increased suggesting mixing of water masses. By late August, concentrations of >8 mg/L extended down to 5 m. The bottom of the water column exhibited concentrations of nearly 3 mg/L at that time. The bottom of the water column was anoxic again by mid-September. Afterwards and through the end of the season, concentrations >6-7 mg/L were measured throughout the water column.

Lower oxygen concentrations were measured in the bottom 2 meters of the water column in late April and mid-May at the CL site, while the upper 3-4 m of depth experienced seasonal highs. By early June and through early July, oxygen concentrations of <1 mg/L were measured in the bottom 2 m of the water column. That anoxic layer expanded upward to include depths below 5 m of depth. Those anoxic waters were only observed below the thermocline up until late July through mid-August when layers above the thermocline and to the upper metalimnetic boundary were anoxic (Fig. 5). It was during that time when epilimnetic oxygen concentrations were lowest for the seas

Oxygen concentrations were between 6-9 mg/L throughout the water column in late August, signifying a major mixing event just prior to that visit. By mid-September, the thermocline did reestablish between 5-6 m of depth with oxygen concentrations of <1 mg/L measured at and below 6 m. That pattern of mixing and increased concentrations at the bottom, followed by an anoxic layer at the bottom occurred again between late September and mid-October, with a difference being that the anoxic layer was at the very bottom. The other difference was that concentrations throughout the water column were lower. By late October, concentrations throughout the water column were 6-10 mg/L.

Oxygen concentrations at the bottom of FP were also decreasing by late April but weren't measured below 1 mg/L until late May. Those late May anoxic conditions were exhibited from 6 m of depth to the bottom and below the thermocline through early July. From mid-July through mid-August, concentrations of <1 mg/L extended from the bottom up to 5 m of depth which was above the thermocline. Stratification had technically broken down (based on RTRM scores) after early August, so those anoxic waters were not confined to below the thermocline or upper metalimnetic boundary. The late August mixing event did result in oxygen concentrations of >5 mg/L down to 5 m of depth, which decreased to <1 mg/L by the bottom. Concentrations of <1 mg/L were observed from 4 m of depth to the bottom in mid-September, even though the water column was not technically stratified. The SB water column contained high concentrations of dissolved oxygen through late June. Bottom concentrations were low between mid- to late July, but high on all sampling dates after.

V. Trophic Characteristics

Several of the water quality variables measured in this program were used to assess the trophic status of Bantam Lake. A lake's trophic status characterizes the level of primary productivity it can support and is determined by variables that limit or express algal productivity, including phosphorus and nitrogen concentrations, Secchi transparency, and chlorophyll-*a* concentrations (See Table 2). Lakes supporting very little algal productivity are typically clear and are referred to as oligotrophic lakes; lakes supporting high levels of productivity are more turbid and are termed eutrophic or highly eutrophic. It is generally those eutrophic or highly eutrophic lakes that experience regular and intense algal blooms. Lakes with characteristics between oligotrophic and eutrophic conditions can be described as one of several subcategories of mesotrophic conditions. Mesotrophic and even oligotrophic lakes can experience algal blooms but those are much less intense and infrequent.

Based on the trophic data collected and classification criteria in Table 2, the trophic status of Bantam Lake in 2023 was late mesotrophic to eutrophic**.**

Table 2. Trophic classification criteria used by the Connecticut Experimental Agricultural Station (Frink and Norvell, 1984) and the CT DEEP (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

A. Secchi Disk Transparency

Secchi disk transparency is a measure of how much light is transmitted through the water column. Light transmission is influenced by several variables including the quantity of inorganic and organic particulate material in the water column that absorbs or reflects light. In the open water environment, Secchi disk transparency is inversely related to algal productivity, i.e., the more algae in the water, the less Secchi transparency will be; the less algae in the water, the greater Secchi transparency will be.

Light in lakes is important for several reasons, particularly for its role in open water photosynthesis and algal productivity. As light diminishes with depth, so does photosynthetic potential. Since photosynthesis decreases with depth, there is a depth where oxygen produced from algal photosynthesis is equal to the oxygen consumed by algal cellular respiration. That is referred to as the *Compensation Point* and is estimated by multiplying the Secchi disk transparency by 2.

In 2023, Secchi disk transparency was measured in the lake 57 times: 15 at NB, CL, and SB; and 12 times at PF. Of the total number, 35 measurements (61%) were <2 meters, while only 2 measurements (4%) were >3 meters. All others (35%) were between 2 and 3 meters. The season average for the lake was 1.90 meters (Fig. 6).

Of the total number of measurements, 31 were collected in the summer (July – September). Twenty-two of those (71%) were <2 meters. The summer months average was 1.80 meters. Both the season and summer month averages were characteristic of eutrophic algal productivity.

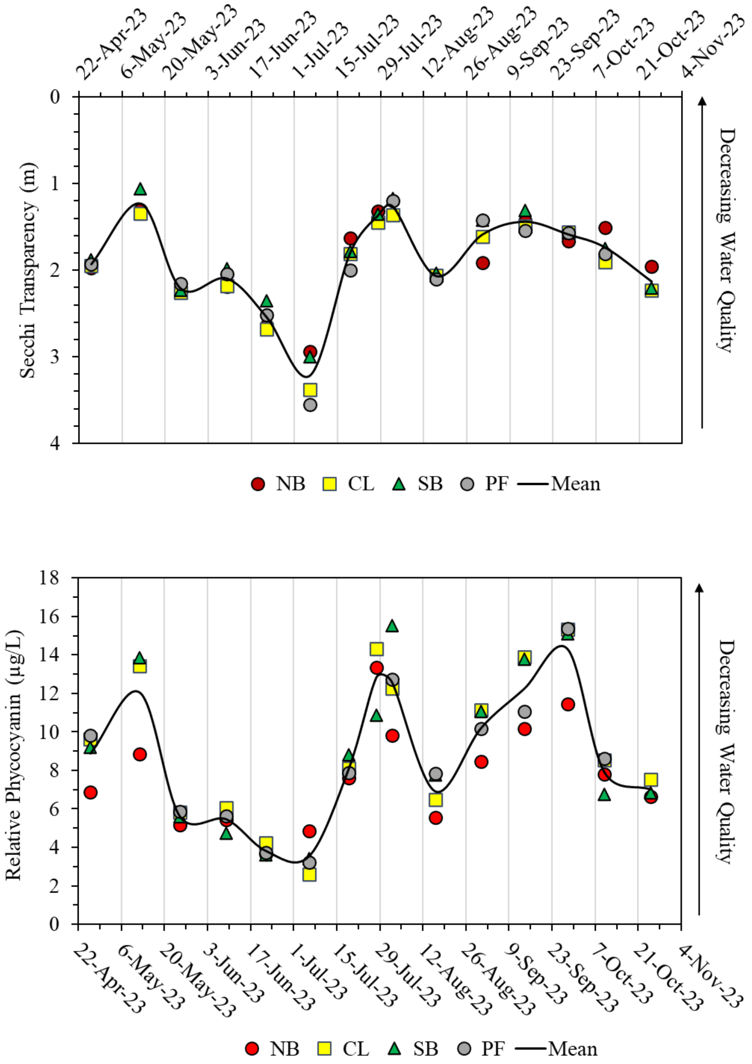

Figure 6. Secchi disk transparencies (top panel) and relative phycocyanin concentrations (bottom panel) at the four sampling sites on Bantam Lake in 2023.

Secchi transparencies were low in late April through early May. Transparency gradually increased through early July, but rapidly decreased through mid-July and early August. Most of the measurements after mid-August were <2 meters.

B. Relative Phycocyanin Concentrations

Measuring phycocyanin provides a means of assessing cyanobacteria (aka blue-green algae) biomass in the lake. Phycocyanin is an auxiliary photosynthetic pigment unique to the cyanobacteria and 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 principle that a particular substance fluoresces at a specific wavelength when light of another wavelength is directed on that substance. The fluorimeter in our 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.

Relative phycocyanin concentrations were recorded throughout the water column the same number of times that Secchi transparency was measured. Spatial and temporal distributions of cyanobacteria are reported later in this report (see *Algae and Cyanobacteria Dynamics*). Here, biweekly data for each site were the averages from the top three meters of the water column, i.e., average of measurement at 0.5, 1, 2, and 3 meters. Seasonal changes in relative phycocyanin concentrations were similar to changes in Secchi disk transparency but in an inverse fashion, especially in the first half of the season (Fig. 6). Higher relative levels in late April and early May decreased through early July, then rapidly increased by mid-July and early August. Mid-August levels were lower but afterwards increased through late September. October relative phycocyanin levels decreased disproportionately relative to the increases in Secchi disk transparencies.

C. Chlorophyll-a Concentrations

Unlike phycocyanin, chlorophyll-*a* is a photosynthetic pigment that is common to all freshwater algae and cyanobacteria and is a useful surrogate measurement for total algal biovolume in the water. Like relative phycocyanin concentrations reported above, results from chlorophyll analyses were reflective of the algal biomass in the top three meters of the water column where integrated samples were collected (see *Methods Section*).

Minimum concentrations of 3 to 5 µg/L were from the late April and mid-July samples collected at NB, CL, and SB (Fig. 7). Maximum concentrations were from the mid-September samples. The season average was 9.1 µg/L, while the summer season (July – September) average was 10.9 µg/L. The summer season average was indicative of late mesotrophic algal productivity (Table 2).

May, June and August averages for the lake were similar at 7.8, 7.7, and 8.4 µg/L. Concentrations increased exponentially from the July minimum levels to the September maximum concentrations. October levels decreased from September levels to 11.0 µg/L.

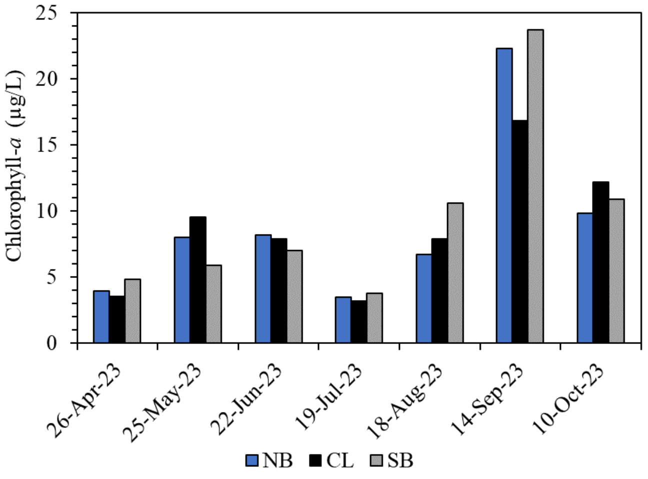

Figure 7. Chlorophyll-a concentrations measured at the North Bay (NB), Center Lake (CL), and South Bay (SB) sites of Bantam Lake in 2023.

D. Total Phosphorus

Algae and cyanobacteria require a range of micro- and macronutrients to maintain a population. In freshwater systems, phosphorus is the nutrient that most often limits algae growth (aka the *limiting nutrient).* Therefore, total phosphorus (the sum of particulate and dissolved forms of phosphorus) also serves as a measure of productivity in most lake studies. Samples were collected at 1 m of depth, at the thermocline, and at ½ meter from the bottom of the NB, CL, and SB water columns each month from May through October. Samples collected in May – July were analyzed by York Environmental Laboratory; those collected from August – October were analyzed by UCONN CESE Laboratory.

Several of the total phosphorus concentrations from May – July were reported as below minimum detection limit (MDL). York Environmental often used an MDL of 10 µg/L. In those instances, we have used 10 µg/L for the estimated concentration and in our analyses. The UCONN CESE Laboratory used an MDL of 2 µg/L and estimations were not necessary.

Epilimnetic concentrations ranged from 7 µg/L to 36 µg/L. Season epilimnetic averages for NB, CL, SB, and the lake were 21.7, 18.3, 21.7, and 19.9 µg/L, respectively. All averages were indicative of mesotrophic algal productivity (Table 2). Site averages were not significantly different from each other ($p>0.05$). The lake average epilimnetic concentration for April – July of 13.9 µg/L was significantly lower than the August – October average of 29.2 µg/L ($p<0.05$).

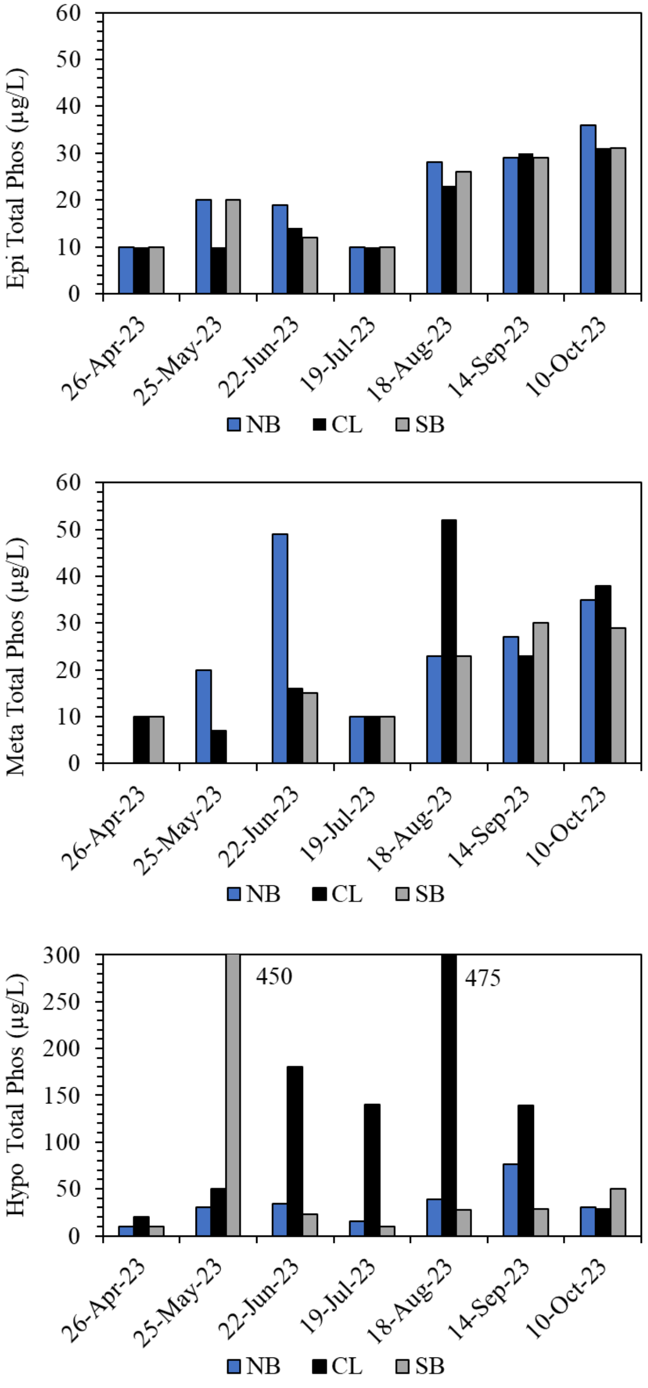

Figure 8. Total phosphorus concentrations in the epilimnion (Epi), metalimnion (Meta, aka near the thermocline), and hypolimnion (Hypo) at NB, CL, and SB sites on Bantam Lake in 2023.

With two exceptions, concentrations near the thermocline within the metalimnion were similar to corresponding concentrations in the epilimnion (Fig. 8). Those exceptions were the 49 µg/L at NB in late June, and the 52 µg/L at CL in mid-August. Season averages near the thermocline for NB, CL, SB, and the lake were 27.3, 22.3, 27.3, and 22.4 µg/L, respectively. Those averages were not significantly different from the corresponding epilimnetic averages ($p>0.05$).

Hypolimnetic total phosphorus concentrations spanned a range from the estimated 10 µg/L to ≥450 µg/L detected at SB in late May and at CL in mid-August. The NB and SB sites were similar in that most hypolimnetic concentrations were within the 10 to 50 µg/L range, while most of the CL concentrations were >130 µg/L.

Season hypolimnetic averages for NB, CL, SB, and the lake were 33.4, 147.6, 85.7, and 88.9 µg/L, respectively. The average hypolimnetic concentrations at CL and for the lake (all hypolimnetic data) were significantly higher than corresponding epilimnetic and metalimnetic (aka *near the thermocline*) concentrations ($p<0.05$). The same was not true for NB and SB.

E. Nitrogen

Nitrogen is typically the second most limiting nutrient for algae growth in freshwater systems and is also useful for understanding trophic conditions in a lake. 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. Here, we reported on total nitrogen and ammonia levels.

The two laboratories performing nitrogen-related analyses used different methods and different minimum detection limits. Analyses of samples collected from April through July by York Environmental measured TKN, nitrate, and nitrite, and used the sum of those for total nitrogen. Their minimum detection levels (MDL) for TKN and ammonia was 400 and 50 µg/L, respectively. In instances where results were reported as below detectable level, the MDL was used as the estimated concentration. The UCONN CESE laboratory was able to directly measure total nitrogen, as well as ammonia, with an MDL of 5 µg/L for both analytes in samples collected from August through October.

All but one epilimnetic of the total nitrogen concentrations were between the estimated 400 µg/L and 990 µg/L (Fig. 9). One outlier of 3,630 µg/ was reported from the late May sample from NB. Season averages for NB, CL, SB, and the lake were 1122, 689, 686, and 832 µg/L, respectively. Removal of the outlier results in NB and lake averages of 704 and 692 µg/L, respectively. Epilimnetic concentration >1,000 µg/L are considered highly eutrophic. Removal of the outlier from analysis resulted in all averages being within the eutrophic range.

All but one of the metalimnetic concentrations were between the estimated 400 µg/L and 990 µg/L. The one outlier of 1,370 µg/L was measured in the mid-July sample at SB. Season averages for NB, CL, SB, and the lake were 687, 630, 683, and 666 µg/L, respectively. Removal of the outlier did reduce the SB and lake season averages to 569 and 629 µg/L, respectively. All averages except for the SB average with the outlier removed were within eutrophic range.

Hypolimnetic total nitrogen concentrations also had an outlier of 7,920 µg/L in late June at NB. All other concentrations were between the estimated 400 µg/L and 2,380 µg/L. Removal of the outlier resulted in season averages at NB, CL, SB, and the lake of 749, 1,174, 799, and 915 µg/L, respectively. The highest season average at CL was due to concentrations measured in July through September during protracted period of anoxic conditions at the bottom of the CL water column.

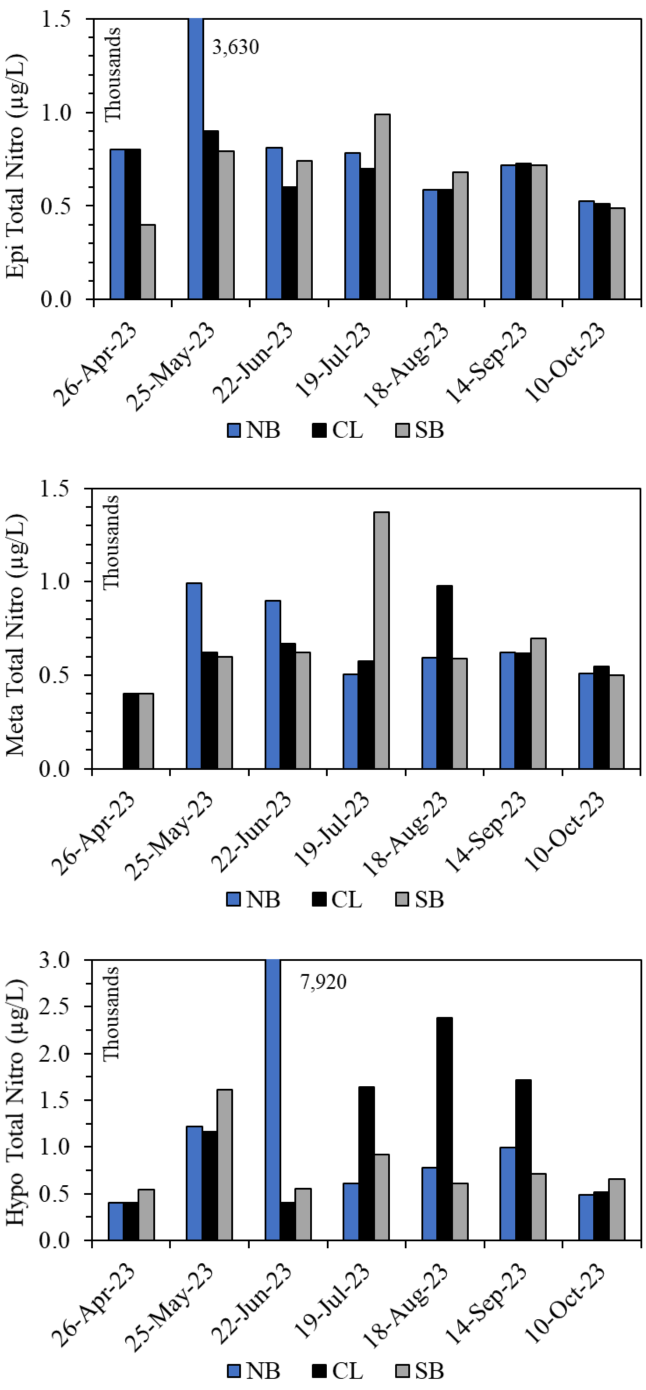

Figure 9. Total nitrogen concentrations in the epilimnion (Epi), metalimnion (Meta, aka near the thermocline), and hypolimnion (Hypo) at NB, CL, and SB sites on Bantam Lake in 2023.

Differences in season averages for the epilimnion, metalimnion, and hypolimnion at each site were not statistically significant ($p>0.05$). However, when concentrations were grouped for the lake by layer, the hypolimnetic average was significantly greater than the metalimnetic average ($p<0.05$).

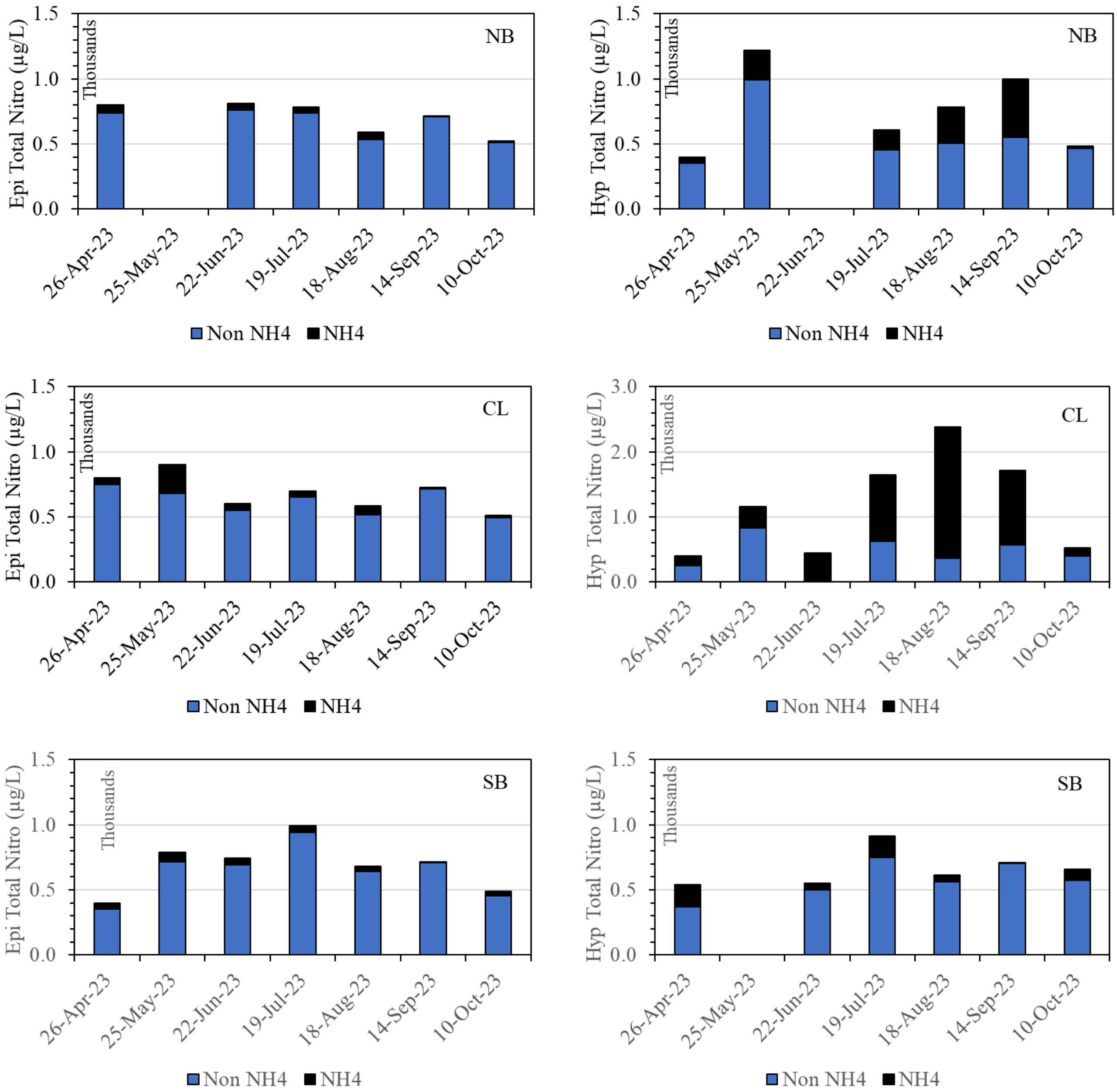

Figure 10. Total nitrogen (Nitro) in the epilimnion (Epi; left) and hypolimnion (Hyp; right) at North Bay (NB), Center Lake (CL), and South Bay (SB) sites at Bantam Lake. Total nitrogen is displayed in its ammonia (NH4) and non-ammonia constituents. Note the vertical axis for the Center Lake hypolimnion is twice that of all other vertical axes in the figure. Data from several site layers were removed due to total nitrogen or ammonia being outliers.

All be two of the 21 epilimnetic ammonia concentrations were on between 6 and 75 µg/L. One outlier of 220 µg/L was measured from a sample collected from CL; the other, 370 µg/L, was from NB; both were collected in late May. The epilimnetic average for the lake was 65.7 µg/L.

All but one of the metalimnetic concentrations were between 7 and 160 µg/L. The one outlier of 391 µg/L was from the mid-August sample from CL. The metalimnetic lake average was 80.3 µg/L. All be three hypolimnetic concentrations were between 10 and 446 µg/L. Outliers were 2,020 and 1,143 µg/L from CL collected in mid-August and mid-September, respectively; an outlier of 1,482 µg/L came from SB collected in late May. The lake hypolimnetic average was 402 µg/L. CL and lake hypolimnetic averages were significantly greater than averages from all other site or lake layers ($p<0.05$).

Ammonia was typically a small component of total nitrogen in the epilimnetic layer (Fig. 10). The same was true for the metalimnetic layer. Ammonia was a larger contributor to total nitrogen in the hypolimnion, particularly at the NB site and especially at the CL site. In July – September hypolimnetic samples from CL, ammonia far exceeded non-ammonia constituents of total nitrogen.

VI. Algae and Cyanobacteria Community Dynamics

Algae have been used in ecological assessments of lakes for over 100 years (Stevenson 2014). The composition, concentrations, and biomasses of assemblages of algae in the water column (i.e., phytoplankton) are reflective of environmental conditions in that lake. For example, a lake that is high in nutrients can often be dominated by Cyanophyta (aka cyanobacteria or blue-green algae) with high cell concentrations and biomass. High concentrations of cyanobacteria can form harmful algal blooms, which can present public health risks due to toxins that some cyanobacteria can produce (CT DPH & CT DEEP 2021). Algae communities that are more diverse include species from the Bacillariophyta (aka diatoms), Chrysophyta (aka golden algae), and Chlorophyta (aka green algae) and typically have lower cell concentrations and biomasses, reflect lower nutrient conditions, and are not toxigenic.

Much of the focus of the BLPA is the monitoring and management of the seasonal cyanobacteria growth and reporting those activities to the community (BLPA 2021). Unlike in most recent years, copper sulfate treatments did not occur in 2023 to manage cyanobacteria concentrations. Biweekly monitoring of the cyanobacteria in Bantam Lake started on April 23rd and concluded on October 23rd. Results were assessed using CT DEEP's Guidance to Municipalities (2023) and reported to the BLPA within 48 hours of sample collections. Cyanobacteria concentrations of 0 to 20,000 cells/mL were characterized as posing little to no public health risk; concentrations of 20,000 to 100,000 cells/mL were characterized as posing moderate risk; and concentrations of >100,000 were characterized as posing high risk.

A. Cyanobacteria Cell Concentrations and Relative Abundance

Cyanobacteria cell concentrations were very high in late April through mid- May, with most concentrations and the lake averages exceeding 250,000 cells/mL. By late May and through early June, concentrations had substantially decreased and were between 40,000 and 98,000 cells/mL (Fig. 11). Cyanobacteria cell concentrations decreased further and were between 4,000 and 9,000 cells/mL in late June. Levels increased modestly by early July with concentrations at all but one site and the average for the day below 20,000 cells/mL. The NB sample was found to have 21,228 cyanobacteria cells/mL.

Site and lake average concentrations increased by mid-July and then decreased through mid-August. Another modest increase was observed by late August, but none of the site or average concentrations exceeded 100,000 cells/mL since mid-May (Fig. 11). Late August through early October averages were between 72,000 and 86,000 cells/mL Concentrations in the last sample of the season were between 17,000 and 30,000 cells/mL and the average was 27,360 cells/mL.

Most of the cells counted in samples from NB, CL, and SB were cyanobacteria (Fig. 12). Photographs of most of the cyanobacteria genera observed in the plankton net samples or samples collected for counts are provided in Figure 13.

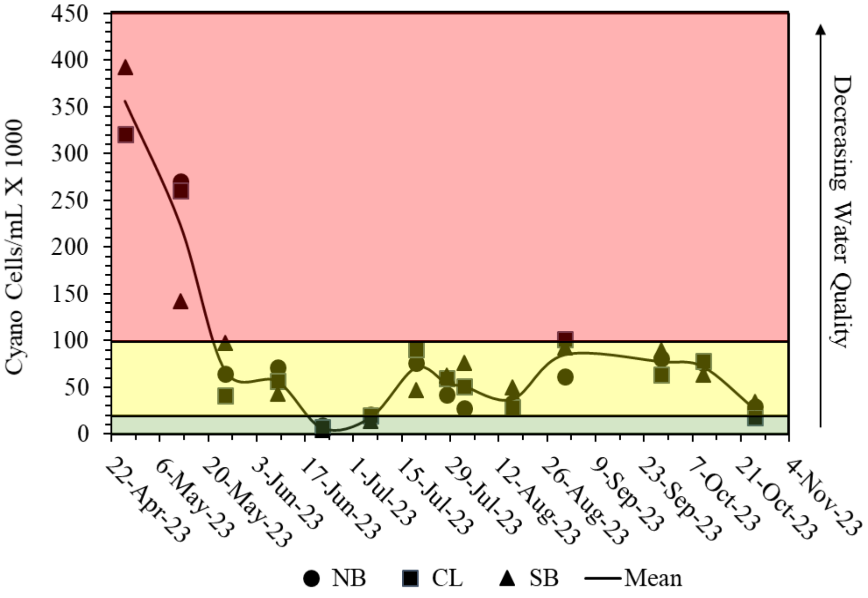

Figure 11. Cyanobacteria (aka blue-green algae) cell concentrations from April 26th to October 25th, 2023, at the North Bay (NB), Center Lake (CL) and South Bay (SB) sites in Bantam Lake.

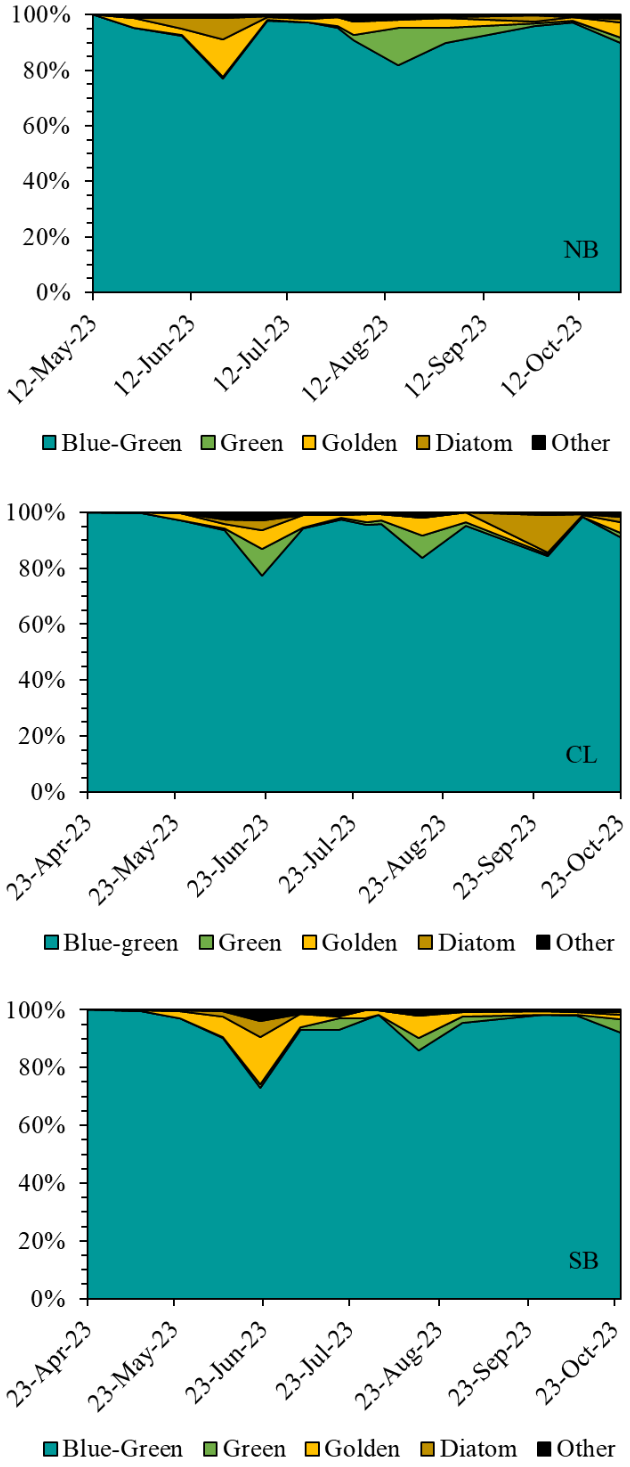

Figure 12. Relative abundance of major taxonomic algae groups in samples collected at North Bay (NB), Center Lake (CL), and South Bay (SB) at Bantam Lake in 2023.

Figure 13. Specimens of cyanobacteria genera observed and photographed in 2023. A) *Aphanizomenon spp*., B) *Pseudanabaena spp*., C) *Dolichospermum spp*., D) *Microcystis spp*., E) *Planktothrix spp*., F) *Gomphosphaeria spp*. Total magnification was 400x for all except for the first photograph of *Aphanizomenon spp*. which was 100x.

Table 3. Identified algal genera from the plankton net samples and whole water samples collected at North Bay (NB), Center Lake (CL), and South Bay (SB) samples at Bantam Lake in 2023.

Cyanobacteria	**Chlorophyta**	**Pyrrhophyta**
Aphanizomenon sp.	*Anikistrodesmus sp.*	*Ceratium sp.*
Aphanocapsa sp.	*Chlamydomonas sp.*	*Glenodinium sp.*
Aphanothece sp.	*Coelastrum sp.*	*Gymnodinium sp*
Chroococcus sp.	*Cosmarium sp.*	*Peridinium sp.*
Dolichospermum sp.	*Crucigenia sp.*	
Gomphosphaeria	*Dictyosphaerium sp.*	**Cryptophyta**
Microcystis sp.	*Elakatothrix sp.*	*Cryptomonas sp.*
Planktothrix sp.	*Eudorina sp.*	
Pseudanabaena sp.	*Gloeocystis sp.*	**Euglenophyta**
Snowella sp.	*Gonium sp.*	*Euglena sp.*
Woronichinia sp.	*Kirchneriella sp.*	*Phacus sp.*
	Micractinium sp.	*Trachelomonas sp.*
Bacillariophyta	*Mougeotia sp.*	
Asterionella sp.	*Nephrocytium sp.*	**Chrysophyta**
Aulocoseria sp.	*Oocystis sp.*	*Chrysosphaerella sp.*
Cyclotella sp.	*Pediastrum sp.*	*Dinobryon sp.*
Fragilaria sp.	*Quadrigula sp.*	*Mallomonas sp.*
Rhizosolenia sp.	*Scenedesmus sp.*	*Synura sp.*
Stephanodiscus sp.	*Selenastrum sp.*	*Uroglenopsis sp.*
Synedra sp.	*Sphaerocystis sp.*	
Tabellaria sp.	*Staurastrum sp.*	
	Tetraedron sp.	

VII. Lake Water Chemistry

A. Specific Conductance

Conductivity is a surrogate measurement for the sum of the ionized minerals, metals, and salts in the water and a measure of water’s ability to transmit an electrical current. Data collections included measures of both conductivity and specific conductance and were measured in microsiemens per cm (µS/cm). Specific conductance is conductivity standardized to a set water temperature of 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 plant and algal communities has been shown to be related, in part, to conductivity levels in lakes (e.g., Siver 1993, McMaster & Schindler 2005, June-Wells et.al. 2013).

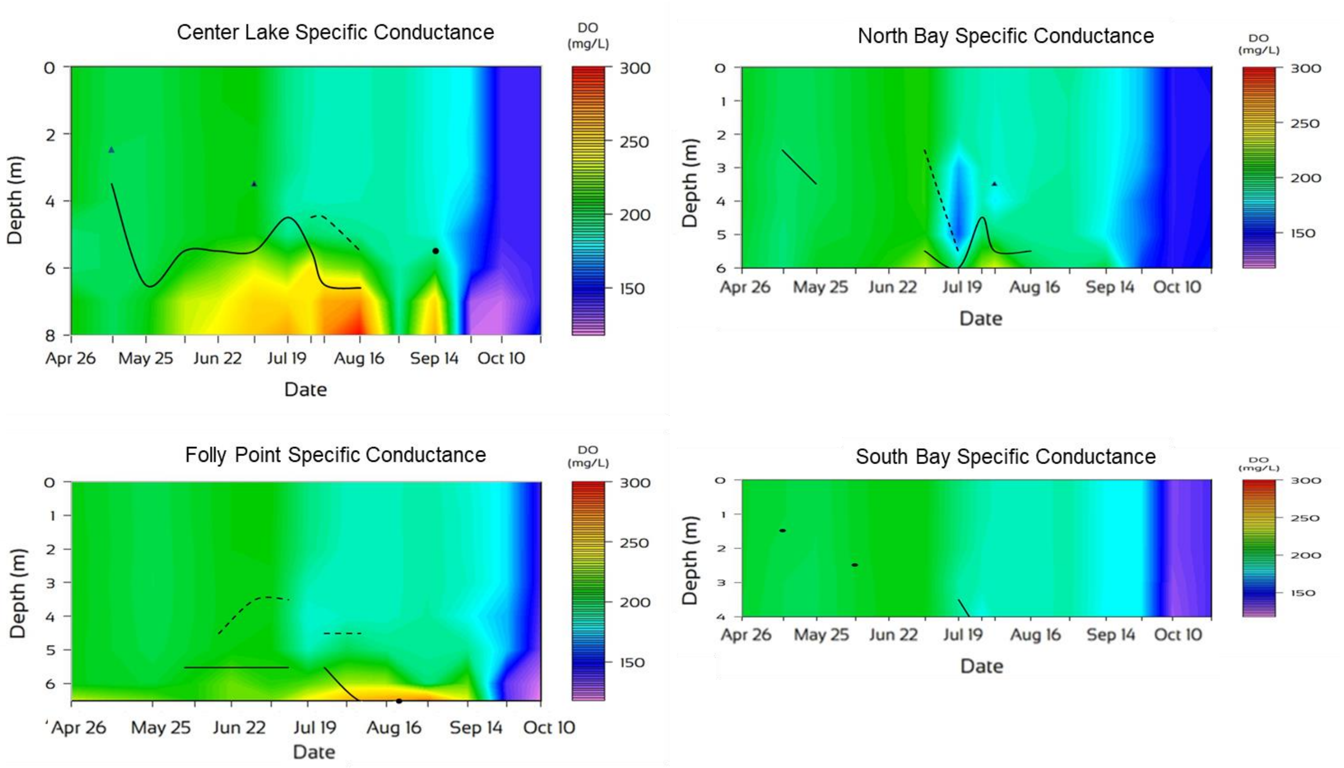

Figure 14. Isopleth plots of water column specific conductance at the Center Lake, North Bay, Folly Point, and South Bay sites of Bantam Lake in 2023. The dashed black lines and black triangles represent the position of the upper boundary of the metalimnion; the solid black lines and black circles represent the position of the thermocline.

Specific conductance in surface waters experienced notable decreases over the course of the season at all sites (Fig. 14). Late April through early July levels at 1 m of depth ranged between 199 to 211 µS/cm. Between early July and early August, specific conductance decreased to a lake average of 187 µS/cm. Specific conductance modestly increased by late August to 189-190 µS/cm. Another notable decrease occurred by late September, when the lake average was 176 µS/cm. Between late September and mid-October, the greatest decrease of nearly 40 µS/cm occurred resulting in a lake average of 140 µS/cm, which did not notably change by late October.

Specific conductance near the bottom of the CL and FP sites was highly variable. There, levels were like epilimnetic levels through late May. Afterwards, CL specific conductance below the thermocline increased and reached a maximum of 298 µS/cm at the bottom in mid-August (Fig. 14). At FP, levels at the bottom of the water column were always at least a little higher than epilimnetic levels but diverged from epilimnetic levels in by mid-July and reached maximum levels of 281 µS/cm by late August.

Specific conductance at the bottom of the SB site was not appreciably different from that near the surface throughout the season. At NB, notable differences in specific conductance between the bottom and top were intermittent and reached a maximum of 239 µS/cm in early August. There was also an unusual decrease in specific conductance between 2 and 5 m of depth on July 19th (Fig. 14). Levels in the top 2 m of the water column were 190-191 µS/cm. From 3 to 5 m of depth, levels decreased from 170 to 158 µS/cm before increasing to 193 µS/cm by 6 m.

B. Alkalinity and pH

Alkalinity is a measure of calcium carbonate and provides lake water and 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 anoxic cellular respiration in the lake sediments, and denitrification of nitrate to elemental nitrogen (Wetzel 2001).

Epilimnetic alkalinities were similar among the NB, CL, and SB sites except for the late May measurements at SB (Fig. 15). With those removed from our analyses, season average at the NB, CL, and SB sites and for the lake were 40.3, 39.3, 37.7, and 39.2 mg/L, respectively. Epilimnetic levels modestly increased from late April to season highs of 42-44 mg/L by late June before diminishing down to 30-37 mg/L by the end of the season.

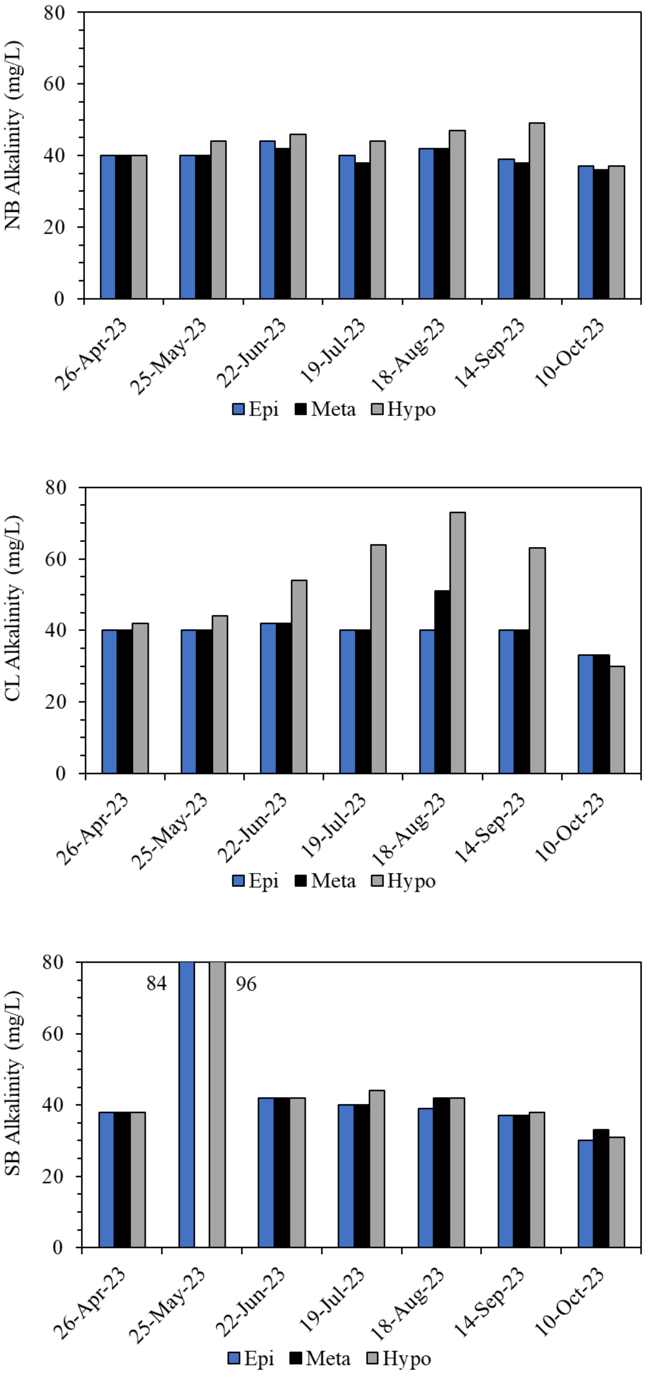

Figure 15. Epilimnetic (Epi), metalimnetic (Meta), and hypolimnetic (Hypo) alkalinity at North Bay (NB), Center Lake (CL), and South Bay (SB) sites in Bantam Lake in 2023.

Metalimnetic season averages at NB, CL, SB, and the lake were 39.4, 40.9, 38.7, and 39.7 mg/L, respectively. Metalimnetic alkalinities were very similar to epilimnetic alkalinities with the one exception of 51 mg/L at the CL site in mid-August. That metalimnetic measurement corresponded to the season hypolimnetic and lake high of 73 mg/L (Fig. 15). The hypolimnetic levels at CL began to deviate from epilimnetic and metalimnetic levels by late June and remained elevated through mid-September. Hypolimnetic averages for NB, CL, SB, and the lake were 43.9, 52.9, 39.2, and 45.6 mg/L. The late May hypolimnetic measurement at the SB site of 96 mg/L was deemed an outlier and omitted from those calculations.

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 since 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 pH near the top of the water column is often higher than the corresponding pH near the bottom, particularly during the peak of the growing season. That is often due to carbon being harvested by the algae community in waters near the surface, reducing the levels of carbonic acids capable of being formed.

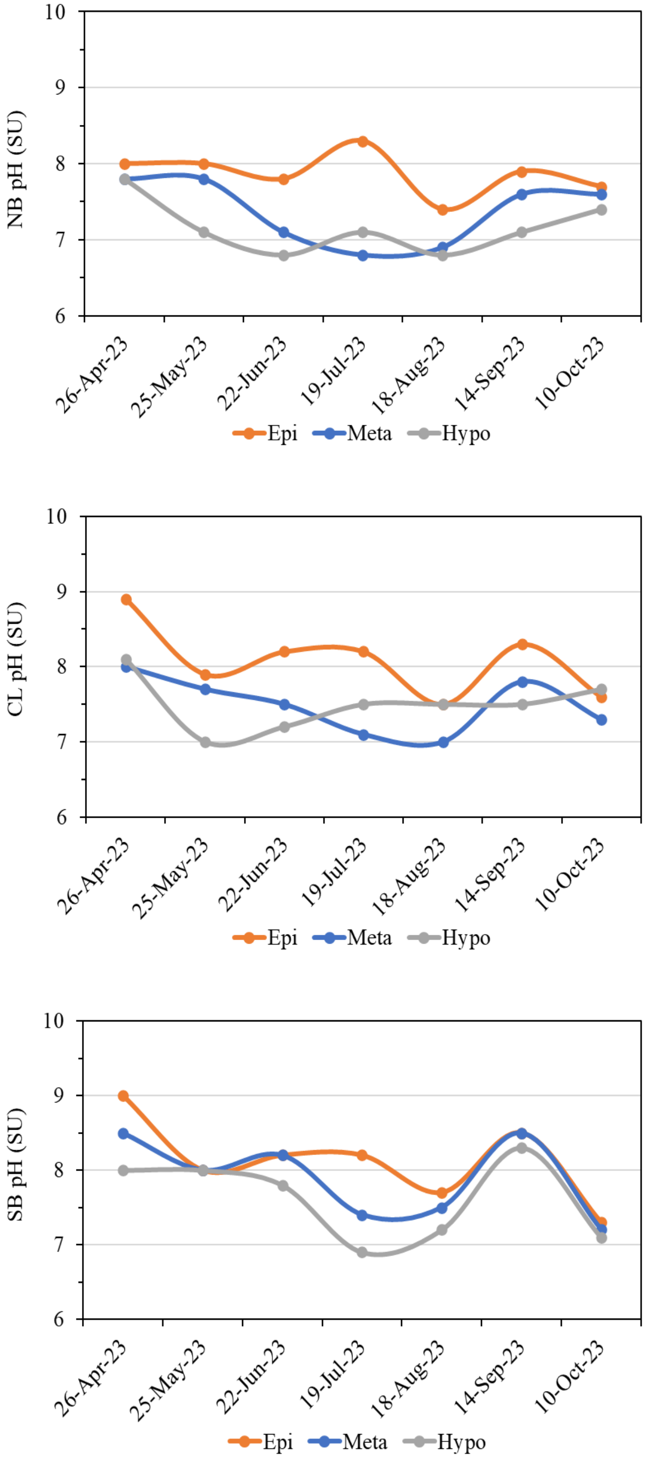

Figure 16. Epilimnetic (Epi), metalimnetic (Meta), and hypolimnetic (Hypo) pH at the North Bay (NB; top), Center Lake (CL; middle), and South Bay (SB; bottom) sites of Bantam Lake in 2023

Carbonic acid is a naturally occurring weak acid but can change the pH of water.

Season pH averages were highest in the epilimnion. The averages at NB, CL, SB, and the lake were 7.9, 8.0, 8.1, and 8.0, respectively. Metalimnetic and hypolimnetic averages were similar. At NB, those averages were 7.1 and 7.0, respectively; at CL, they were 7.3 and 7.5, respectively; and at SB, they were 7.8 and 7.5, respectively. The metalimnetic and hypolimnetic averages for the lake were 7.6, and 7.4, respectively.

The late April pH at CL and SB were the highest of the season (Fig. 16) and concurrent with the some of the highest cyanobacteria cell concentrations of the season. The mid-August decrease in pH at all three sites was suggestive of a mixing event. At SB, epilimnetic, metalimnetic, and hypolimnetic pH were similar much of the season, and indicative of the regular mixing of the water column at that site.

C. Cation & Anion Concentrations

Base cation and anion concentrations 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 create much of the conductivity levels in lake water. The ratios and other characteristics of those ions can be diagnostic when compared to other lakes, and when compared to levels in the same lake over time.

The laboratories which conducted the analyses reported results on a mass basis (mg/L). Here, we converted those and displayed them based on their electrochemical equivalents or milliequivalents (meq/L).[1] Those were calculated by dividing the measured mass of an ion by its equivalent weight. This provides a meaningful accounting for ionic charge (positive or negative). Accounting for electric charge can be preferable when comparing ion levels to other electrochemical characteristics of lake water, e.g., specific conductance.

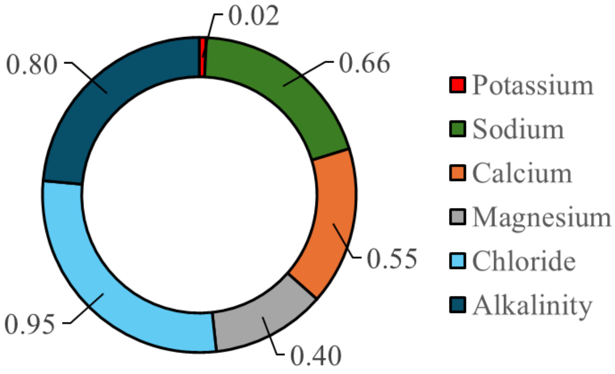

Figure 17. Bantam Lake average base cations (potassium, sodium, calcium, and magnesium) and anions (chloride and the alkalinity anions) concentrations for 2023 reported in meq/L.

Two sets of samples were analyzed from NB, CL, and SB. One set was collected in late April and the other in mid-August. One set was analyzed by each of the two labs receiving samples in 2023. Results from the two labs

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[1] See https://en.wikipedia.org/wiki/Equivalent_weight

were comparable except for chloride when the late April results were nearly twice the mid-August results (Table 4).

Lake water is charge balanced meaning the sum of the cations should equal the sum of the anions in meq/L. One anion not measured in these analyses that can contribute to the ion total is sulfate. In some studies, sulfate is determined by subtracting the sum of the anions from the sum of the cations. That difference is likely sulfate. That analysis has been performed in Table 4. In the late April samples, that calculation resulted in negative numbers. We surmise that the late April chloride results may be the reason.

Table 4. Results of analyses of the base cations potassium (K), sodium (Na), calcium (Ca), and magnesium (Mg), and the anions chloride (Cl) and the alkalinity anions (Alk) at the North Bay (NB), Center Lake (CL), and South Bay (SB) sites on Bantam Lake in 2023.

Site	Date	K	Na	Ca	Mg	Cl	Alk	Cations - Anions
		meq/L						
NB	26-Apr	0.01	0.72	0.52	0.39	1.22	0.80	-0.38
	16-Aug	0.04	0.61	0.62	0.42	0.69	0.84	0.16
	Average	0.02	0.66	0.57	0.40	0.95	0.82	-0.11
CL	26-Apr	0.01	0.71	0.50	0.38	1.22	0.80	-0.42
	16-Aug	0.03	0.58	0.59	0.40	0.66	0.80	0.14
	Average	0.02	0.64	0.54	0.39	0.94	0.80	-0.14
SB	26-Apr	0.01	0.72	0.50	0.38	1.23	0.76	-0.37
	16-Aug	0.04	0.63	0.57	0.42	0.70	0.78	0.17
	Average	0.02	0.68	0.54	0.40	0.96	0.77	-0.10
Lake	26-Apr	0.01	0.72	0.51	0.38	1.22	0.79	-0.39
	16-Aug	0.04	0.60	0.59	0.41	0.68	0.81	0.16
	Average	0.02	0.66	0.55	0.40	0.95	0.80	-0.12

On average, sodium was the most abundant cation on a meq/L basis, followed by calcium and magnesium. Potassium was a minor contributor to the sum of all ions in samples (Fig. 17). Concentrations of chloride and the alkalinity anions were on average similar. The mid-August results suggest that there was measurable sulfate. The fact that total anions exceeded total cations in late April suggested that the chloride results in those samples may have been erroneous.

VIII. Trends and Discussion

D. Historical Changes

As noted earlier, Bantam Lake has been included in several State-wide surveys of Connecticut Lake over the last 100 years. In Table 5, we have compiled Bantam Lake data from some of those historic studies, as well as corresponding season averages from 2019 – 2023. Comparison of trophic variables from the 1930s, 1970s, 1990s indicated that Bantam became more eutrophic over that time which was consistent with the paleolimnological reconstruction of trophic status (see Fig. 2). Comparison of 1990 averages to those from 2019 – 2023 suggested that conditions became less eutrophic in the last 30 years, i.e., average nutrient and chlorophyll-*a* concentrations decreased, and Secchi transparency has modestly increased. However, averages from 2019 through 2023 represent an entire season while those from the 1930s, 1970, and 1990s are based on fewer data points that likely targeted peak growing season conditions. In future analyses, we can target those specific months in data collected since 2019 to compare with historical data.

Unlike trophic data that tends to be more seasonally variable, chemical characteristics tend to be more conservative, i.e., less variable over the season. Based on data in Table 5, there have been increases since 1970s in specific conductance, alkalinity, sodium, and chloride, and to a lesser extent calcium and magnesium. Changes that may have occurred since 2018 using the trophic variables, specific conductance, and pH are discussed below. The base cations and chloride were not used in those analyses. While there is some variability in averages for base cations and chloride, they do not appear to be trending either up or down.

E. Change Since 2018

One of the goals of the annual water quality monitoring program was to develop a database from which to assess trends. A robust database provides the ability to detect statistically significant trends that may be occurring in the lake. Below, two statistical approaches were used to assess whether the lake and specific variables were trending, i.e., significantly increasing or decreasing, or not significantly changing since 2018 (Appendix A). The first approach pooled annual epilimnetic and hypolimnetic data into one dataset; the second approached leveraged the annual epilimnetic and hypolimnetic datasets independently. The result was three independent datasets.

Two statistical methods were applied to each of the three datasets. The first method, *Multiple Linear Regression* (MLR), was employed to determine if the epilimnion, hypolimnion, and/or the lake (pooled data) had changed significantly based on the collective multiple variables in each dataset. A p-value statistic was calculated to determine whether the epilimnion, hypolimnion, or whole lake was experiencing change or not with $p<0.05$ indicating a statistically significant change.

Table 5. Average water quality characteristics in the epilimnion of Bantam Lake from the 1930s (Deevey 1940), 1970s (Frink and Norvell 1984), early 1990s (Canavan & Siver 1994, 1995), 2019, 2020, 2021, 2022, and 2023.

Parameter	Units	Bantam Lake								
		1930s	1970s	1990s	2018	2019	2020	2021	2022	2023
Total Nitrogen	µg/L		774	714	550	276	469	459	---	693
Total Phosphorus	µg/L	18.0	33.2	42	25.7	22.7	22.8	23.6	13.1	19.9
Chlorophyll-*a*	µg/L	14.7	31.3	19.7	9.1	9.8	8.5	8.0	11.8	9.1
Secchi Disk	meters	2.3	2.1	1.7	2.63	2.66	2.10	2.27	2.37	1.90
pH	SU	---	---	7.8	7.8	8.0	8.4	8.0	8.0	8.0
Sp. Conductivity	µS/cm	---	96	122	192	176	187	192	194	188
Alkalinity	mg/L	28.5	25.0	30.5	40.7	39.4	39.7	42.6	41.3	41.3
Chloride	mg/L	---	10.0	10.3	35.6	27.9	28.5	27.4	33.2	32.9
Calcium	mg/L	---	9.0	8.2	11.9	10.5	11.6	11.7	11.0	11.0
Magnesium	mg/L	---	3.9	7.8	4.8	4.2	5.1	4.9	4.9	4.8
Sodium	mg/L	---	6.2	7.4	17.2	15.5	15.8	14.7	17. .0	15.2
Potassium	mg/L	---	1.2	1.2	1.9	1.5	1.2	ND	1.3	0.9

The second method, *Analysis of Variance* (ANOVA), was utilized to examine selected variables independently of others to determine whether a change had occurred in a statistically significant manner over time. The F-statistic was used to calculate the probability (i.e., p-value) that a dataset's variable pattern differed from a random distribution of values, i.e. exhibiting a statistically significant change.

The results for MLR analyses indicated that no significant change has occurred at Bantam Lake since 2018 in the epilimnion, hypolimnion, or in the lake based on the combined dataset ($p>0.05$). The p-values indicated that some changes may be occurring, but not in a statistically significant way. For the lake as a whole and the hypolimnion, the variable having the greatest influence on the MLR models was total nitrogen which did appear to be increasing (Fig. 19). It is worth noting that there was no total nitrogen data for 2022 due to laboratory problems. In the epilimnion, the variable having the most influence on that MLR model was Secchi disk transparency which has decreased on average since 2018 (Fig. 18).

Results from ANOVA indicated that total nitrogen was significantly increasing in the hypolimnetic and in the lake based on the combined data, but not in the epilimnion. In the epilimnion, chlorophyll-*a* was found to be increasing in a highly significant fashion ($p<0.01$). Although significant, the annual average increase was small (Fig. 18).

Linear regression was applied to selected data below and we have indicated the R^2 values (aka Coefficient of Determination). This statistic measures how well a statistical model, i.e., the regression line, predicts an outcome and how well the points fit around the regression line. Scores range from zero, i.e., not predictive, to 1 or highly predictive. Although ANOVA indicated a significant chlorophyll trend, the R^2 for that linear regression was zero.

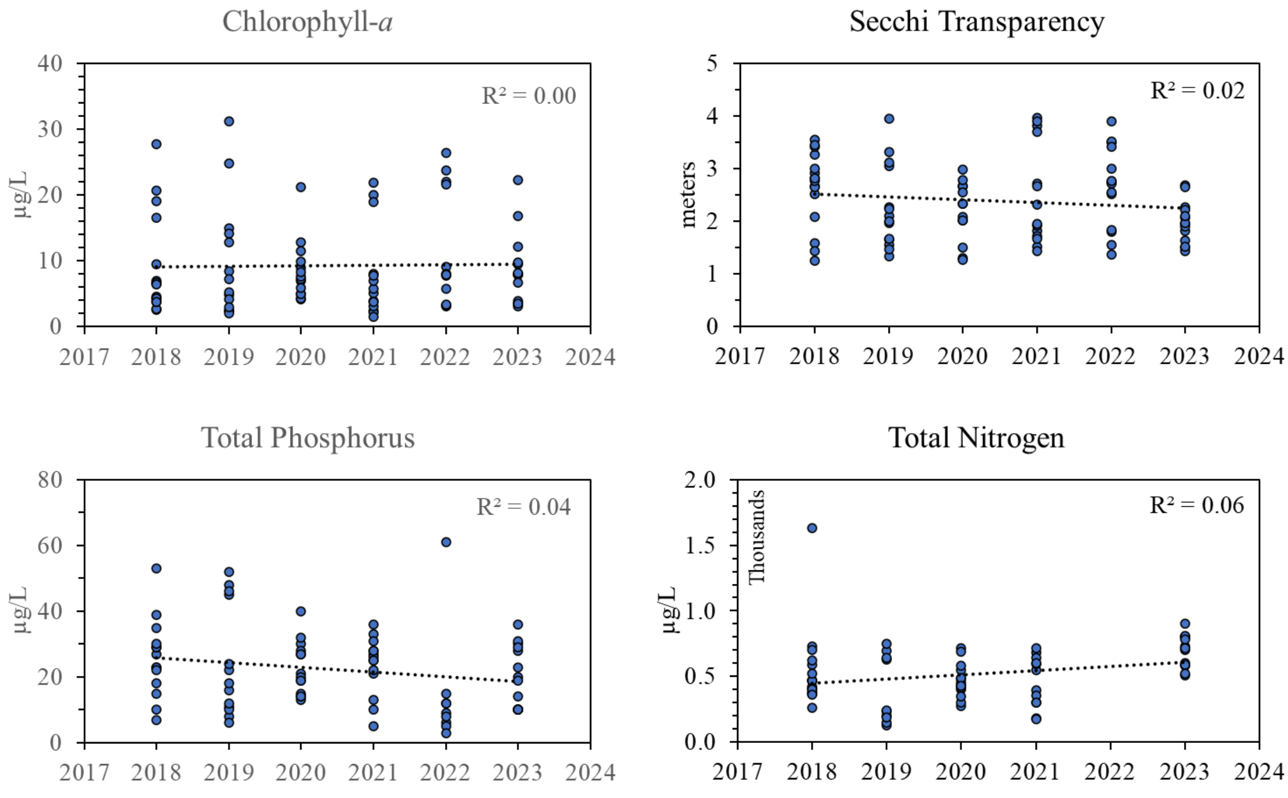

Figure 18. Linear regressions of epilimnetic trophic data: chlorophyll-a, Secchi disk transparency, total phosphorus, and total nitrogen collected annually from the North Bay and Center Lake sites from 2018 to 2023.

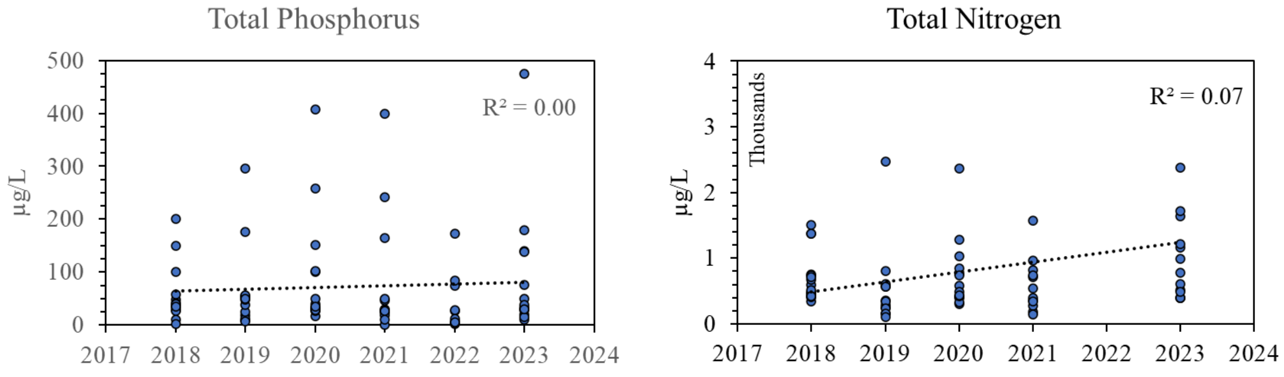

Figure 19. Linear regressions of hypolimnetic trophic data of total phosphorus and total nitrogen. Not displayed in the hypolimnetic total nitrogen data plot is the 7,920 µg/L measured in 2023.

F. Cyanobacteria Growth Rates

Annual reports submitted over the last several years have closely examined cyanobacteria growth rates with modified CyanoMonitoring protocols (CMC 2024), with particular focus on efficacy of copper sulfate treatments. CyanoMonitoring is an ongoing, nationwide program to collect data on cyanobacteria populations across the country to better understand the increases in bloom frequency and intensity. It utilizes lake scientists and lake managers, as well as citizen scientists, to collect samples and analyze them with fluorimetry (CMC 2021), similar to that discussed in earlier sections of this report.

CyanoMonitoring utilize the following formula to calculate cyanobacteria growth rates between two dates:

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

where $\mu\ d^{-1}$ is growth in micrograms phycocyanin per day; ln is the natural logarithm; F_2 is the fluorometrically measured mass of phycocyanin at day 2 (t_2); and F_1 is the fluorometrically measured mass of phycocyanin at day 1 (t_1). Whereas CyanoMonitoring utilizes in-lab fluorimetry to analyze phycocyanin in different cyanobacteria size factions in the same sample, (e.g., large bloom-former genera vs small picoplankton genera), we assessed relative phycocyanin growth utilizing in-lake fluorimetry in the top three meters of the water column at the four sites and plotted growth rates for each site along with phycocyanin levels (Fig. 20).

Relative phycocyanin levels began the season higher and decreased through late June to early July. During that period, most growth rate values were below or at zero. Phycocyanin levels and growth rates increased through late July to early August before decreasing through mid- to late August. Growth rates increased, as did relative phycocyanin levels through late September, before gradually decreasing to the end of the season levels.

In the 2022 report, we compared growth rates between sampling dates from the 2021 and 2022 seasons. The growth rates between two sampling dates were the average of the four sites and 95% confidence intervals were displayed to gauge variability among the four sites. Two copper sulfate treatments were implemented in each of those years. Those analyses were continued with the addition of data from 2023 data when no copper sulfate treatments occurred (Fig. 21).

The lake average growth rates during the 2023 season were comparable to those in the 2021 season and less comparable to those observed in the 2022 season when the July 19th copper sulfate treatment appeared to have resulted in a notable decrease in growth. Also of interest was the disparity in the 95% confidence intervals for each of the lake averages in all years. Some were very narrow indicating that the averages from the top three meters of the water column were very similar among the four sites. Larger 95% confidence intervals indicated that the site averages were more disparate, with the widest occurring in early August of 2023 (Fig. 21).

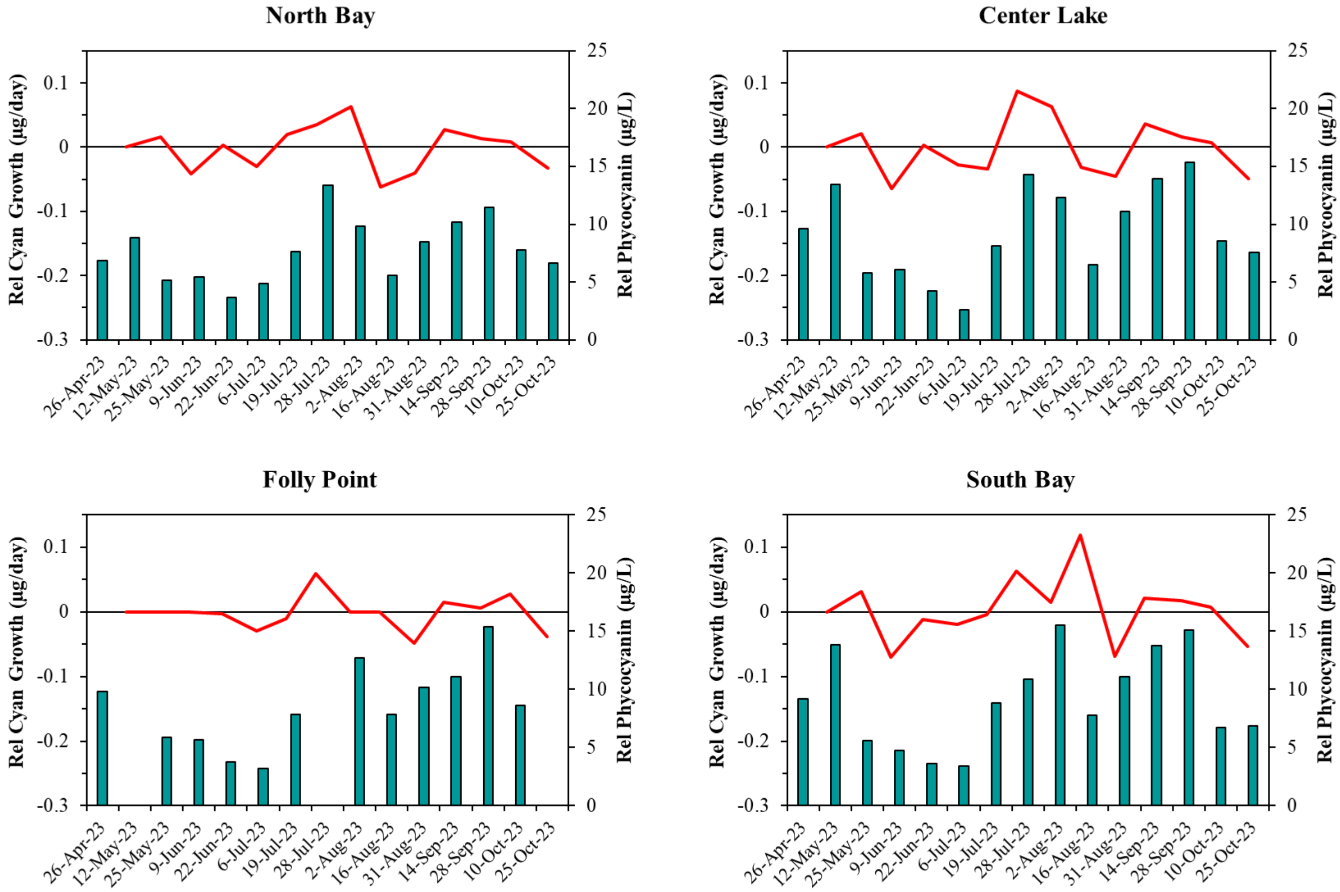

Figure 20. Biweekly relative phycocyanin concentrations and growth rates between sampling dates for the four sites in Bantam Lake during the 2023 season.

The large 95% confidence interval in early August of 2023 was reflective of the negative growth rates at NB and CL, and the positive growth rate at the SB site. No data was collected at the FP site on that sampling date. Most of the wider confidence intervals in 2023 occurred between early July and early August. In 2021 and 2022, those larger intervals generally occurred prior to early July. We surmise that larger differences between sites on a given sampling date may be related, in part, to weather conditions. For example, a light surface bloom prior to the early August 2023 sampling date may have been concentrated in the southern portion of the lake by light winds. Copper sulfate treatments could also create differences among sites if one area was the focus of the treatment while another area was not.

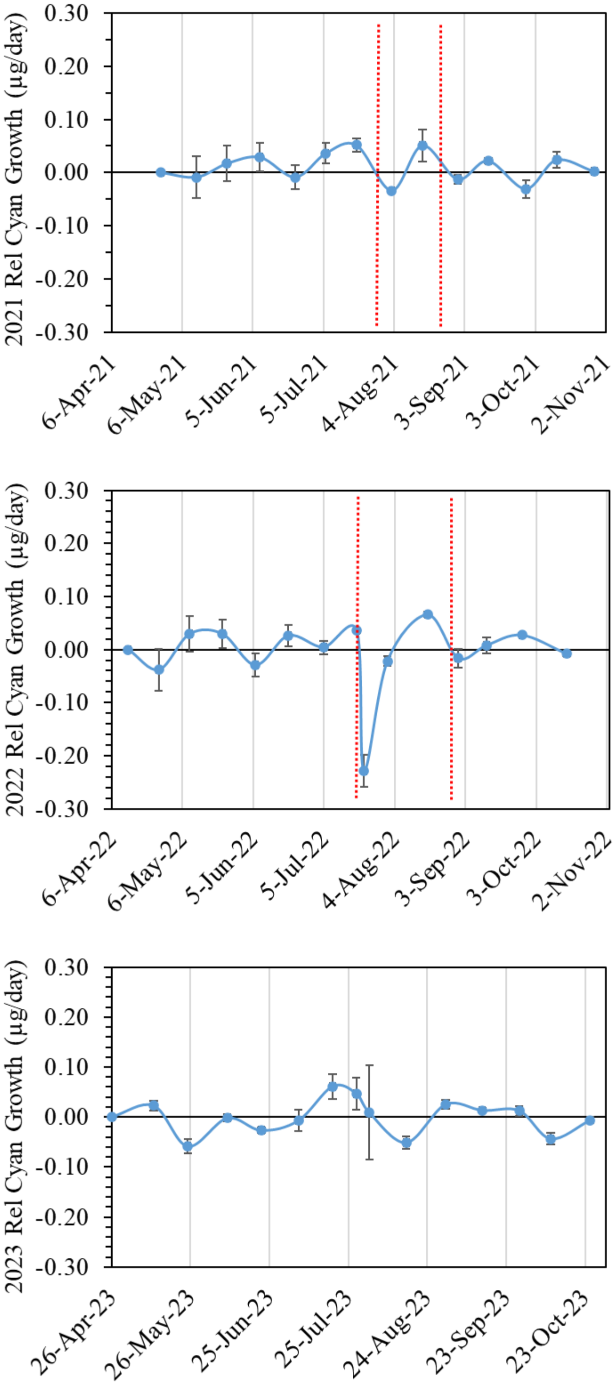

Figure 21. Changes in lake averaged cyanobacteria growth rates during the 2021 (top), 2022 (middle), and 2023 (bottom) seasons. The red vertical lines represent the dates of copper sulfate treatments: July 29 and August 24 in 2021; July 19 and August 30 in 2022. No treatments occurred in 2023. Error bars are 95% confidence intervals.

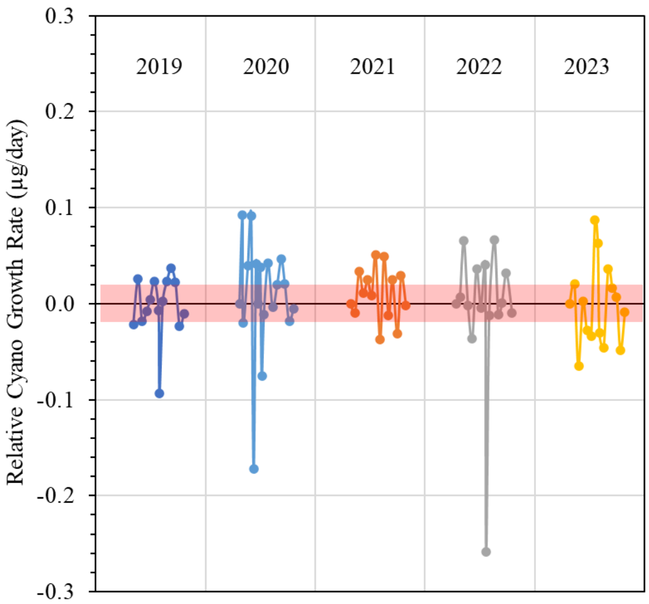

Figure 22. Growth rates at the Center Lake site in the 2019 through 2023 seasons. The red shaded area denotes ±0.02 µg/L/day change from no change (0 µg/L/day)

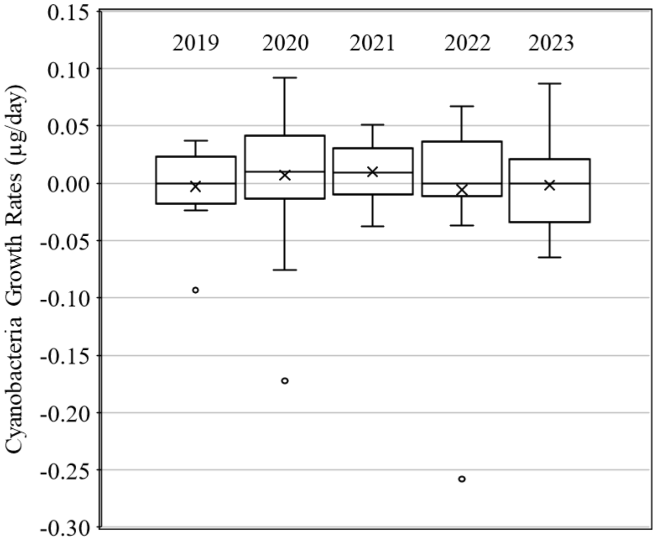

Figure 23. Box and whisker plots of growth rates at the Center Lake site in 2019 to 2023.

Seasonal cyanobacteria growth was also compared for the CL site over time from 2018 to 2023. Many of the points in that timeline were between 0.02 and -0.02 µg/day (shaded red in Fig. 22) and could represent natural variability. Points that are above 0.02 or below -0.02 could potentially represent a significant increase or decrease, respectively, in growth. In some, but not all instances, greatest decreases occurred after a copper sulfate treatment, e.g., early August of 2019 and late July of 2022. The notable decreases in growth at CL in early June and early July of 2020, however, did not occur after copper sulfate treatments which instead occurred in August of that season. This suggests that other variables are also influencing cyanobacteria biomass, e.g., efficacy of treatments, and/or how we assessed efficacy.

The same data displayed in Figure 22 was also displayed as "box and whisker" plots (aka box plots) in Figure 23. Box plots mathematically separate a dataset into quartiles with each quartile representing one-fourth of all points: the two inner boxes represent the second and third quartile and are separated by the *median* – the value in the middle of a dataset. The whiskers represent the first and fourth quartiles. In addition, a *mean* – aka the average – is also displayed by an X. *Outliers* are those points that occurred beyond the first and fourth mathematically determined quartiles. A box plot was created for each CL dataset from 2019 to 2023. Note that the mean and median each year were close to zero in all years. Outliers were all below the first quartile (negative growth).

Lastly, we examined all growth rate data from CL collectively from 2019 to 2023 in one box and whisker plot (Fig 24). The dataset was comprised of a total of 77 averages from the top three meters of the water column. The median and mean were zero or nearly zero, respectively. Nearly half of the points were between 0.03 and -0.01, i.e., in the second and third quartiles. All points except the outliers were between 0.092 and -0.075.

As noted earlier, the 2019 and 2022 outliers followed copper sulfate treatments, while the 2020 outlier did not. No outliers were observed in the 2021 and 2023 datasets. The fact that no treatments occurred in 2023 may explain why no outliers occurred that year. An important question to consider is why no outliers occurred in 2021 dataset even though there were copper sulfate treatments.

Our purpose of using different methods of displaying this data was to determine effective ways of assessing important changes. <u>This will become increasingly more important when different treatment methods are used, e.g. early season peroxide-based treatments.</u>

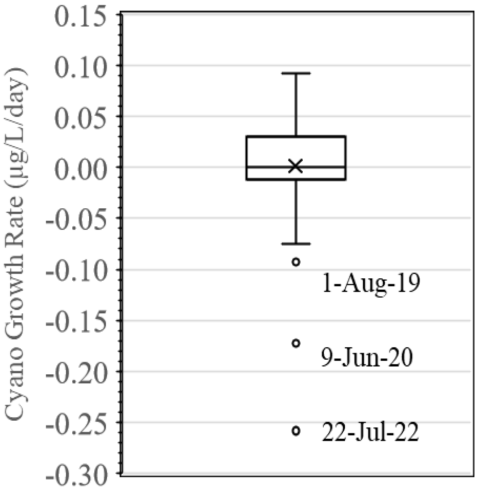

Figure 24. Box and whisker plot for all cyanobacteria growth rates at Center Lake from 2019 to 2023. Outliers are identified by the date the data was collected. A total of 77 points are represented in the plot.

G. Precipitation, Lake Levels, and Water Quality

Two notable characteristics of the 2023 season were 1) the high-water levels in the lake; and 2) the lack of cyanobacteria films or blooms at the surface of the lake. The two may be related.

The high-water levels in Bantam Lake were a result of record rainfall in 2023. The total for the year was the third highest on record for Connecticut with July reported as the wettest month of the year (Weiss 2024). Below, we examined the rainfall between April and October from 2019 to 2023, based on the Weather Station at the White Memorial Conservation Center (Weather Underground 2024; Fig. 25).

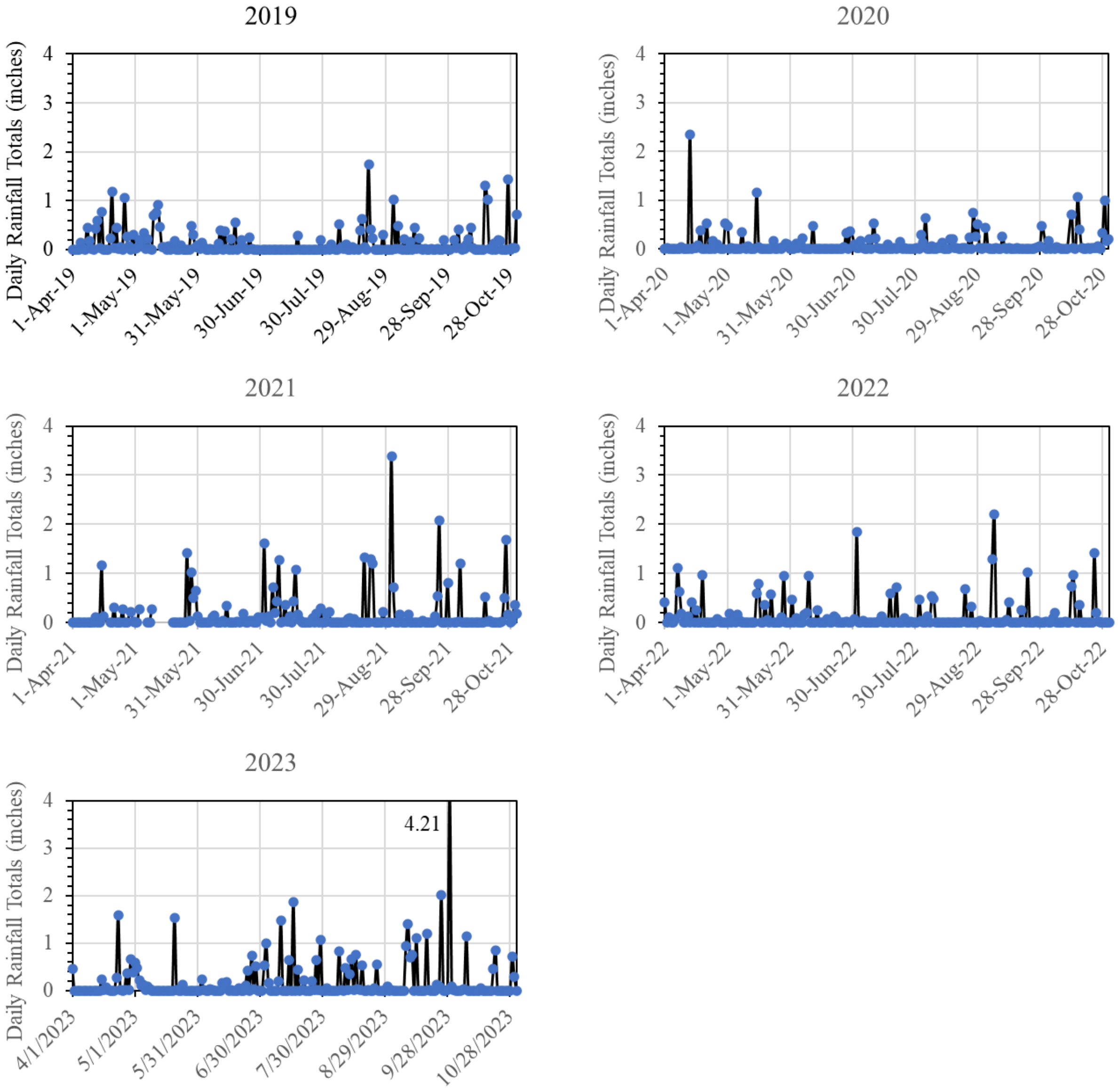

Figure 25. Daily rainfall totals from April through October in 2019, 2020, 2021, 2022, and 2023. Rainfall data was from the White Memorial Conservation Center Weather Station (Weather Underground 2024).

What sets apart the 2023 daily totals from those of the previous four years was the high number of events after late June that delivered 0.5 to 2 inches of rainfall. It was at that time when the 2023 seasonal cumulative total surpassed the cumulative totals in the past four years (Fig 26). There were also several events in September of 2023 when daily totals surpassed 1 inch, culminating with 4.2 inches of rain falling on September 29th. That event caused major flooding in New York City, Fairfield County, and other parts of Connecticut.

The amount of rain falling in a watershed will directly affect several related lake characteristics including residence or retention time, flushing rate, and annual hydraulic load. Canavan and Siver reported the retention time for Bantam Lake as 106 days meaning that a drop of water entering the lake will spend 106 days in the lake before leaving the lake. That data was likely based on average rainfall in the area at the time of determining retention time or before. By increasing the rainfall totals, retention time is decreased, and flushing rate and hydraulic load is increased.

The increased runoff to the lake can initially increase pollutants, like phosphorus, being exported from the watershed to the lake. Increased flushing or decreased retention time can also result in more of that phosphorus leaving or "being flushed" from the lake and watershed. In 2023, cyanobacteria growth rates increased starting in late June and decreased by late July. The lack of observed surface blooms may have been a result of the increased flushing rate and/or mixing of cyanobacteria throughout the water column by wind-driven mixing associated with storm events.

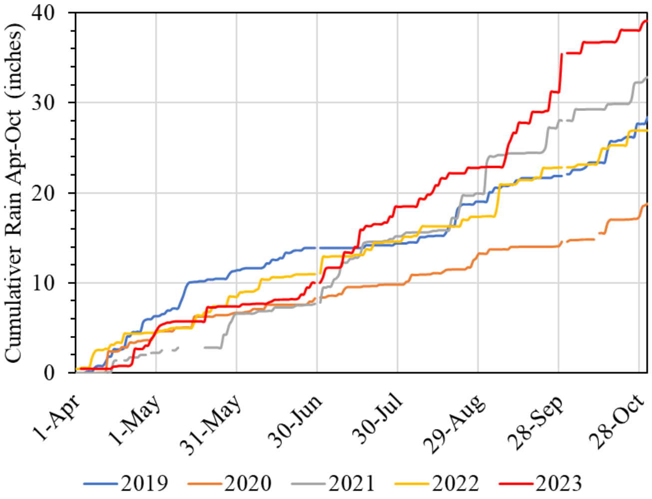

Figure 26. Cumulative rainfall totals from April 1st through October 31st in 2019 through 2023. Data from the White Memorial Conservation Center.

As noted earlier, seasonally decreasing specific conductance levels in epilimnetic waters was also likely a result of increased flushing at Bantam Lake. We also noted disparity between changes in late season relative phycocyanin and Secchi transparency, with the former decreasing disproportionally more than increasing Secchi disk transparency. Secchi transparency was likely affected by increased inorganic matter in the water, due to watershed runoff, rather than organic matter, i.e., algae and cyanobacteria.

Changing weather patterns are already having impacts on Connecticut lakes. These changes include decreased average spring and summer wind speeds which create earlier stratification, stronger resistance to mixing, and decreased bottom temperatures (Siver et al 2019), and earlier lake ice out dates and warmer spring temperatures which can expedite growth of cyanobacteria. Increased rainfall may also be a variable that will require more examination in the future, as the "new weather norms" become more apparent.

IV. Recommendations

The water quality issues confronting Bantam Lake have not changed in recent years: nutrient loading, high cyanobacteria concentrations and blooms, and increasing salt concentrations. Increasing salt concentrations does not appear to be as imminent since average specific conductance since 2018 does not appear to be increasing based on results from ANOVA. However, trends in trophic indicators, including increasing chlorophyll-*a* concentrations and decreasing Secchi disk transparency, are significant or nearly significant.

A. Cyanobacteria Management

Brawley Consulting Group has developed for the BLPA to manage cyanobacteria productivity in 2024 with an early season peroxide-based algicide. This approach was modeled after efforts of the US Army Corps of Engineers (Calomeni, 2023, Calomeni et al. 2022; Calomeni et al. 2023, USACE 2022). Locally, several public water supply companies have begun using this approach with success.

We continue to support this initiative. We would recommend budgeting for additional cyanobacteria monitoring so that samples can be collected just prior to and shortly after the spring treatment.

B. Sediment Phosphorus Sequestering - Alum

In 2023, Brawley Consulting Group submitted to BLPA a summary of planning efforts to sequester sediment phosphorus with Alum, thus eliminating a sizable portion of the lake's phosphorus budget. That document included dosing rates and cost estimates for the project which were $2.5 million over two years.

The project is currently considered prohibitively expensive. Notwithstanding cost, the project has the potential to be transformational with regards to water quality at Bantam Lake. We recommend that the BLPA develop a subcommittee to explore and develop sources of funding of this project in the future.

C. Statistical Analysis of Historical Water Quality Data

This year, Brawley Consulting Group applied statistical methods to assess possible water quality change between 2018 to 2023. Results did not indicate significant change over that period. The BLPA amassed a substantial water quality database prior to 2018 worthy of a rigorous statistical analysis to detect trends. These data could be compiled and analyzed with methods such as those used in this report and others to understand if and how the lake has changed within the timeframe of those data collections. If pursuing this is of interest, Brawley Consulting and BLPA should discuss the volume of data and develop a cost estimate for this type of project.

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Appendix A – Statistical Analysis

Multiple Linear Regression Whole Lake

	Estimate	Std. Error	t value	Pr (>|t|)	
Intercept	2.02E+03	3.17E+00	637.097	<2e-16	***
TP	2.87E-03	3.62E-03	0.793	0.429	
TN	5.77E-04	2.35E-04	2.472	0.015	*
SpCond	-1.11E-04	4.54E-03	-0.024	0.981	
Alk	-3.51E-02	3.63E-02	-0.969	0.335	
pH	3.85E-01	3.43E-01	1.121	0.265	
SE	1.82		p-value	0.1716	
R	0.07				
F	1.58				

Multiple Linear Regression EPI

	Estimate	Std. Error	t value	Pr (>|t|)	
Intercept	2.03E+03	5.59E+00	362.735	<2e-16	***
Secchi	-1.24E+00	4.49E-01	-2.755	0.00822	**
Chloro	-7.79E-02	4.72E-02	-1.651	0.10521	
TP	-3.54E-02	2.41E-02	-1.467	0.1489	
TN	1.18E-03	1.06E-03	1.109	0.27303	
SpCond	6.11E-03	1.72E-02	0.356	0.72361	
Alk	-7.67E-02	6.00E-02	-1.278	0.20719	
pH	-2.02E-01	5.86E-01	-0.344	0.73207	
SE	1.74		p-value	0.06052	
R	0.23				
F	2.11				

Multiple Linear Regression HYPO

	Estimate	Std. Error	t value	Pr (>|t|)	
Intercept	2.02E+03	7.36E+00	273.858	<2e-16	***
TP	3.08E-03	4.41E-03	0.697	0.4889	
TN	5.15E-04	2.49E-04	2.066	0.0436	*
SpCond	-1.38E-03	5.21E-03	-0.266	0.7915	
Alk	-3.27E-02	4.83E-02	-0.676	0.5021	
pH	7.44E-01	9.32E-01	0.798	0.4283	
SE	1.84		p-value	0.3561	
R	0.09				
F	1.13				

ANOVA Whole Lake

	Df	Sum Sq	Mean Sq	F value	Pr (>F)	
TP	1	1.61	1.61	0.4856	0.48734	
TN	1	15.87	15.87	4.7792	0.03091	*
SpCond	1	0.91	0.91	0.2743	0.60148	
Alk	1	3.66	3.66	1.1029	0.29592	
pH	1	4.17	4.17	1.2563	0.26476	

ANOVA Epi

	Df	Sum Sq	Mean Sq	F value	Pr (>F)	
Secchi	1	10.25	10.25	3.4019	0.07117	.
Chloro	1	16.5183	16.5183	5.4822	0.02332	*
TP	1	9.6245	9.6245	3.1942	0.08009	.
TN	1	2.7009	2.7009	0.8964	0.3484	
SpCond	1	0.1984	0.1984	0.0659	0.79854	
Alk	1	4.7438	4.7438	1.5744	0.21552	
pH	1	0.3573	0.3573	0.1186	0.73207	

ANOVA Hypo

	Df	Sum Sq	Mean Sq	F value	Pr (>F)	
TP	1	2.728	2.728	0.8026	0.37429	
TN	1	10.691	10.691	3.1455	0.08177	.
SpCond	1	0.819	0.819	0.241	0.62548	
Alk	1	2.79	2.79	0.8208	0.36898	
pH	1	2.165	2.165	0.637	0.42831	

Appendix B – Preparers' Qualifications

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RELEVANT EXPERIENCE

- Thirty years as a lake ecologist, manager, advocate, educator, and leader in Connecticut. Successful in the academic, public, and private sectors.
- Advanced the mission of the Candlewood Lake Authority from 1998 through 2017 with the last 14 of those as Executive Director. The board and staff of that agency served the five municipalities surrounding Candlewood Lake, the largest lake in the State and one of Connecticut's most important inland water resources.
- Developed meaningful relationships and worked with the general CT lake community, local and state environmental agency staff, academic researchers, elected leaders at all levels of government, and educators from middle school through college/university levels.
- Co-directed an interdistrict grant program that utilized Candlewood Lake as a living, learning laboratory. The program ran for 10+ years and engaged ~150 high school students and teachers each year.
- Have trained and supervised employees and/or students in Limnological and Paleolimnological field and laboratory methods.
- Founding member of the Connecticut Federation of Lakes, have, and served as a volunteer and an officer of Connecticut's lake advocacy, nonprofit organization until 2022.

PROFESSIONAL EXPERIENCE

- **Principal Limnologist – Brawley Consulting Group, LLC.** 2023 to present
- **Principal Partner – Aquatic Ecosystem Research, LLC.** July 2017 to 2022
- **Adjunct Faculty** – Western Connecticut State University, Biol. and Enviro. Science Dept. August 2011 to present.
- **Executive Director –** Candlewood Lake Authority, Sherman, CT 06784. April 2003 to July 2017
- **Lake Preservation Director –** Candlewood Lake Authority, Sherman, CT 06784. April 1998 to Oct. 2002
- **Academic Research Associate –** Connecticut College, New London, CT 06320. Sept. 1989 to Jan. 1998
- **Visiting Lecturer –** Connecticut College, New London, CT 06320. August 1997 to January 1998
- **Research Assistant** – Western Connecticut State University, Danbury, CT 06810. 1987 to 1989

CERTIFICATION, EDUCATION, AND TRAINING

- **Certified Lake Manager**, North American Lake Management Society, 2017
- **Professional Certification** in GIS, Pace University, 2014
- **Graduate Certification** in GIS Technology, University of New Haven 2001
- **M.A. in Botany**, Connecticut College 1993
- **B.A. in Biology**, Western Connecticut State University 1988

Awards

- **Excellence in Environmental Stewardship** from the **Connecticut Outdoor and Environmental Education Association** in 2018
- **Recognition of Service** in the **Congressional Record** by **US Rep. Elizabeth Esty** on June 14, 2017
- **Watershed Conservationist Award** from the **Housatonic Valley Association** in 2011
- **Conservation Professional of the Year** from the **Litchfield County Conservation District** in 2002
- **Honor Award**, **Southern New England Chapter of the Soil and Water Conservation Society** in 2000.
- **Green Circle Award** from the **Connecticut Department of Environmental Protection** in 1999.
- **Conservation Award** from **Housatonic Valley Association** for publication entitled *Candlewood Lake: Watershed Awareness and Lake Preservation* in 1998.

ORGANIZATIONS

- **Connecticut Federation of Lakes** – Founding member 1995; Treasurer from 1995 – 2001; Vice President from 2009 – 2011, 2018 - present; President from 2011 - 2015
- **Connecticut Forest and Park Association** – Board member from 1994 – 2002
- **North American Lakes Management Society** – Member since 1990

SELECTED PUBLICATIONS

PEER-REVIEWED SCIENTIFIC PAPERS

Siver, P.A., Sibley, J., Lott, AM., **Marsicano**, L.J. Temporal changes in diatom valve diameter indicate shifts in lake trophic status. J Paleolimnology 66, 127–140 (2021). https://doi.org/10.1007/s10933-021-00192-y

Siver, P., L. **Marsicano**, A. Lott, S. Wagener, N. Morris. 2018. Wind Induced Impacts on Hypolimnetic Temperature and Thermal Structure of Candlewood Lake (Connecticut, U.S.A.) from 1985-2015. Geo: Geography and the Environment. 5(2). https://doi.org/10.1002/geo2.56

Kohli, P., Siver, P.A., **Marsicano**, L.J., Hamer, J.S., and Coffin, A.M. 2017. Statistical Assessment of Long-term Trends for Management of Candlewood Lake, Connecticut, USA. Journal of Lake and Reservoir Management. 33:280-300

Lonergan, T., L. **Marsicano**, and M. Wagener. 2014. A laboratory examination of the effectiveness of winter seasonal drawdown to control invasive Eurasian watermilfoil (*Myriophyllum spicatum*). Journal of Lake and Reservoir Management. 30:381-392

Moore H.H., Niering W.A., **Marsicano** L.J, and Dowdell M. 1999. Vegetation change in created emergent wetlands (1988–1996) in Connecticut (USA). Wetland Ecology and Management. 7:177-191.

Siver, P.A. A. M. Lott, E. Cash, J. Moss, and L.J. **Marsicano**. 1999. Century changes in Connecticut, USA, lakes as inferred from siliceous algal remains and their relationship to land use changes. Limnology and Oceanography 44:1928-1935.

Siver, P.A. and L.J. **Marsicano**. 1996. Inferring trophic conditions using scaled chrysophytes. Beiheft zur Nova Hedwigia 114:233-246.

Siver, P.A., Canavan, R.W. IV, Field, C., **Marsicano**, L.J. and A.M. Lott. 1996. Historical changes in Connecticut lakes over a 55-year period. Journal of Environmental Quality 25: 334-345

Marsicano, L.J., J.L. Hartranft, P.A. Siver, and J.S. Hamer. 1995. An historical account of water quality changes in Candlewood Lake, Connecticut, over a sixty-year period using paleolimnology and ten years of water quality data. Journal of Lake and Reservoir Management 11:15-28.

Lott, A.M., Siver, P.A., **Marsicano**, L.J., Kodama, K.P. and R.E. Moeller. 1994. The paleolimnology of a small waterbody in the Pocono Mountains of Pennsylvania, USA: reconstructing 19th-20th century specific conductivity trends in relation to changing land use. Journal of Paleolimnology 12: 75-86.

Marsicano, L.J. and P.A. Siver. 1993. A paleolimnological assessment of lake acidification in five Connecticut lakes. Journal of Paleolimnology 9:202-221.

Siver, P.A. and L.J. **Marsicano**. 1993. *Mallomonas connensis* sp. nov., a new species of Synurophyceae from a small New England lake. Nordic Journal Botany. 13: 337-342

Siver, P.A. and L.J. **Marsicano**. 1991. Assessing acidification trends in Connecticut lakes using a paleolimnological approach. CT. Department of Environmental Protection Bulletin, 44 pp. + appendices

POLICY PAPERS AND SUBMITTALS

Marsicano, LJ. 2009. An Examination of Recreational Pressures on Candlewood Lake, CT. Candlewood Lake Authority. Sherman, CT. 68 pp.

Marsicano, L.J., et al. 2000 – 2017. Submittals of the Candlewood Lake Authority to the Federal Energy Regulatory Commission during license renewal and management plan processes for Housatonic Hydro, FERC Docket No. P-2576.

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hbrawley@gmail.com

PROFESSIONAL EXPERIENCE

Owner/Manager, Brawley Consulting Group LLC, Windsor, CT

(January 2008 to present).
Provides land conservation and management services to local land trusts and conservation organizations, including designing and implementing habitat restoration projects, grant writing, trail design and construction, crafting and monitoring conservation easement, boundary posting, Baseline Documentation Reports and developing property management plans. www.brawleycg.com

Land Manager, Naromi Land Trust, Sherman, CT

(March 2004 to present).
Manage all land trust properties and help acquire, monitor and enforce conservation easements. Responsibilities also include designing and building trails, securing funding for habitat restoration projects, and assisting with organizational and administrative tasks. Work cooperatively with the town and other conservation organizations to identify and prioritize lands for future acquisition. www.naromi.org

Land Manager, Kent Land Trust, Kent, CT

(September 2008 to August 2014).
Manage all land trust properties and help acquire, monitor and enforce conservation easements. Responsibilities also include securing funding for habitat restoration projects and preparing Baseline Documentation Reports (BDRs) and property management plans. Addressed backlog of stewardship items required for Kent Land Trust to become the second land trust in Connecticut accredited by the Land Trust Alliance.

Project Manager, Northeast Instream Habitat Program, Amherst MA.

(January 2004 to March 2005).
Coordinated all facets of two fisheries habitat assessment projects working with researcher at the University of Massachusetts, including project planning, data collection, hiring and overseeing seasonal staff, data analysis and report preparation. http://www.neihp.org/index.htm

Executive Director, Pomperaug River Watershed Coalition, Southbury, CT

(July 2001 to May 2003).
Managed all activities of non-profit watershed management organization dedicated to conserving regional water resources, including research, outreach, budgets, grant writing, website development, fundraising, and volunteer relations. www.pomperaug.org

Senior Project Manager, LabLite, LLC, New Milford, CT

(January 2000 to June 2001).
Product development, testing, sales, and customer service for a software company that provides Laboratory Information Management Software (LIMS) to environmental and other laboratories. www.lablite.com

Research Coordinator, The National Audubon Society, Southbury, CT

(March 1998 to January 2000).
Designed and implemented all research on birds and other wildlife at the 625-acre wildlife sanctuary. Conducted natural resources inventory, created checklists of wildlife and plants, established environmental education programs, and coordinated cooperative research projects with state agencies and regional conservation organizations.
http://ct.audubon.org/IBA_BOR.html

Environmental Analyst, Land-Tech Consultants, Inc., Southbury, CT

(November 1996 to February1998).
As Project Manager conducted environmental impact statements, wetland assessments, and wildlife surveys; prepared federal, state and local permit applications; designed pond and tidal wetland restoration projects; and conducted lake diagnostic studies. Worked with state agencies and local land use agencies to mitigate impacts of residential and commercial development projects. www.landtechconsult.com

Wetland Ecologist, The Deep River Land Trust, Deep River, CT.
(July to October 1995).
Worked in association with The Nature Conservancy Connecticut Chapter on a conservation project at two freshwater tidal marshes in the lower Connecticut River. Position entailed mapping dominant vegetation communities, identifying potential environmental impacts, researching information on appropriate buffer zones and recommending methods for long-term monitoring of the system.

Research Assistant, The Nature Conservancy CT Chapter, Weston, CT.
(May to July 1995).
Assisted with research on the productivity and survivorship of Worm-eating Warblers at the 1700-acre Devil's Den Preserve in Weston, CT. Responsibilities included mist-netting, bird banding, and locating and monitoring approximately 25 nest sites throughout the breeding season.
http://www.nature.org/wherewework/northamerica/states/connecticut/

Master's Thesis Research, Connecticut College, New London, CT.
(September 1993 to May 1995).
Conducted two-year study investigating relationships between bird populations and environmental conditions in tidal wetlands of Connecticut. Quantified bird use, vegetation, and selected environmental parameters in eight tidal marsh systems on the Long Island Sound to assess the use of birds as indicators of environmental quality.
http://www.conncoll.edu/departments/botany/index.htm

Research Associate, Connecticut College Arboretum, New London, CT.
(Sept. 1992 to January 1994).
Conducted a natural resources inventory of The Harriet C. Moore Foundation property in Westerly, RI, including producing lists of all plants and animals (flora and fauna), conducting a breeding bird census, and identifying and tagging over 100 ornamental trees. Developed a five-year plan for the management and use of this 35-acre public land preserve.
http://arboretum.conncoll.edu/

Principal Investigator, The Nature Conservancy CT Chapter, Middletown, CT
(Summer 1994).
Studied five marshes in the tidelands of the lower Connecticut River to assess the impacts of the spread of common reed (*Phragmites australis*) on bird populations. Designed project that included the systematic collection of data on bird use, vegetation sampling and an analysis of physical site characteristics.
http://www.nature.org/wherewework/northamerica/states/connecticut/

EDUCATION

Connecticut College, New London, CT. Master of Arts in Botany, 1995.

Connecticut College, New London, CT. Bachelor of Arts in American History, 1982.

The Loomis Chaffee School, Windsor, CT. Graduated 1978.

PUBLICATIONS

Brawley, A. H., Zitter, R. and L. Marsicano, Editors. 2005. Candlewood Lake Buffer Guidelines. Candlewood Lake News *Special Edition*, Vol 1:21.

Warren, R.S., P. E. Fell, R. Rozsa, A. H. Brawley, A. C. Orsted, E. T. Olson, V. Swamy and W. A. Niering. 2002. Salt Marsh Restoration in Connecticut: 20 years of Science and Management. *Restoration Ecology* 10 (3) 497-513.

Markow, J. and H. Brawley. 2001. Herpetofaunal and Avifaunal Surveys of Vaughn's Neck Peninsula, Candlewood Lake, Connecticut. Report to the Town of New Fairfield, CT. 32 p.

Brawley, A. H. 1998. A Vegetation Survey and Conservation Analysis of Vaughn's Neck Peninsula. Report to The Candlewood Lake Authority. The National Audubon Society. 11 p.

Brawley, A. H., R. S. Warren and R. A. Askins. 1998. Bird Use of Restoration and Reference Marshes Within the Barn Island Wildlife Management Area, Stonington, Connecticut, USA. *Environmental Management* 22(4): 625-633.

Marsicano, L. J. and A. H. Brawley. 1997. Land Use, Watersheds, and Aquatic Resources. *Connecticut Woodlands* 62(3): p. 21.

Niering, W. A., and A. H. Brawley. 1996. Functions and Values Assessment of Area A Downstream Wetlands and Watercourses. Naval Submarine Base New London, Groton, CT. Report to Brown & Root Environmental, The Environmental Protection Agency, and The United States Navy. 36 p.

Brawley, A.H. 1995. Pratt and Post Coves: A Vegetation Survey and Conservation Analysis. Report to the Deep River Land Trust, Deep River, CT. 62 p.

Brawley, A.H. 1995. Birds of Connecticut's Tidal Wetlands: Relating Patterns of Use to Environmental Conditions. Master's Thesis, Connecticut College, New London, CT. 87 p.

Brawley, A.H. 1994. Birds of the Connecticut River Estuary: Relating Patterns of Use to Environmental Conditions. Report to the Nature Conservancy Connecticut Chapter Conservation Biology Research Program, Middletown, CT. 23 p.

Brawley, A.H., G.D. Dreyer. 1994. Master Plan for the Future Management and Use of Moore Woods. Connecticut College Arboretum Publication. New London, CT. 65 p.

Brawley, A.H., G.D. Dreyer and W.A. Niering. 1993. Connecticut College Arboretum Phase One Report to the Harriet Chappell Moore Foundation. Connecticut College Arboretum Publication. New London, CT. 100 p.

ACTIVITIES

Forest and Trails Conservation Committee, Connecticut Forest & Park Association (CFPA)

Coverts Project Cooperator, UConn Cooperative Extension System