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April 2024

TO: Twin Lakes Association
ATTN: Russell Conklin
FROM: George Knoecklein, Owner, Principal Limnologist
Re: Twin Lakes 2023 water quality monitoring results.

Introduction

This summary letter presents our findings from monitoring the water quality of the Twin Lakes in 2023. For the purposes of this report, we identify the waterbodies as three separate lakes: East Twin, Middle Twin, and West Twin. East Twin Lake is the largest at 569 acres and deepest at 78 feet[1]. Middle Twin is much smaller at 177 acres and has a maximum depth of only 25 feet, and West Twin Lake is about 100 acres and is less than 8 feet deep throughout except for a small area of 8–10-foot water. East Twin is about 60% pelagic (too deep for aquatic plants), Middle Twin is only 17% pelagic, and West Twin is wholly littoral with no pelagic water. Water leaves the Twin Lakes system through a narrow channel at the extreme northwest corner of West Twin Lake (**Map 1**).

Map 1. Twin Lakes water quality monitoring stations and outlet.

[1] Initially deepest water was considered to be 21nmeters, but successively deeper water was found though the season, ending at 24 meters in October.

Monitoring Details

At each lake's monitoring station, water clarity was measured using a standard 8-inch Secchi disk and view scope. Water temperature, dissolved oxygen, conductivity, and pH readings were recorded at one-meter increments from the surface to the lake bottom. At East Twin and Middle Twin, water samples were collected at the top, middle, and bottom of the water column (East Twin – 1m, 12m, and 22m, Middle Twin – 1m, 3m, and 6m) for analysis of total phosphorus, total nitrogen, nitrate-nitrogen, and ammonia-nitrogen concentrations. At West Twin Lake, a single water sample was collected from the middle of the water column (approximately 1.5 meters) for analysis of the same four nutrients. Lastly, one water sample was collected each month from East Twin Lake for zooplankton and phytoplankton identification and enumeration.

Understanding Table 1 and the Relevance of Nutrient Values

The water quality data collected from the Twin Lakes is assessed using the CT DEEP categorization of lakes shown in **Table 1**, which is based on an extensive empirical study of 70 Connecticut lakes in the 1970s. Using somewhat arbitrary distinctions, CT DEEP was able to divide CT lakes into 6 categories using incremental increases in the amount of phosphorus in surface waters. The categories are determined using whole numbers of phosphorous concentration that appeared to define ranges of water clarities. Total nitrogen, although a powerful nutrient that is needed by all plants and animals, is seldom the sole driver of aquatic plant and algae growth. Rather, nitrogen increases as the system becomes more productive due to increased phosphorus concentration. The Secchi disk depth is an estimate of the clarity of the water, or how transparent the water is to light penetration. Phosphorus causes water clarity to decline in a nonlinear way due to the increased growth of phytoplankton, represented here by the concentration of the principal algae pigment, chlorophyll-*a*.

Table 1. Connecticut DEEP Trophic Categories and Ranges of Indicator Parameters.

	Category	T. Phosphorus (ppb)	T. Nitrogen (ppb)	Secchi Depth (m)	Chlorophyll-*a* (ppb)
1	Oligotrophic	0 -- 10	2 -- 200	6 +	0 -- 2
2	Oligo-mesotrophic	10 -- 15	200 -- 300	4 -- 6	2 -- 5
3	Mesotrophic	15 -- 25	300 -- 500	3 -- 4	5 -- 10
4	Meso-eutrophic	25 -- 30	500 -- 600	2 -- 3	10 -- 15
5	Eutrophic	30 -- 50	600 -- 1000	1 -- 2	15 -- 30
6	Highly Eutrophic	50 +	1000 +	0 -- 1	30 +

Lakes grouped in the top category, 'Oligotrophic', have little to no plants[2] and algae because the phosphorus concentration is very low (0 – 10 ppb[3]). Lakes grouped in the bottom category, 'Highly Eutrophic', have excessive amounts of plants and very green water resulting from high (50+ ppb) phosphorus concentration causing extensive cyanobacteria blooms.

The separation of lakes into the categories shown in **Table 1** is somewhat misleading because only Oligotrophic lakes can remain as such, due to lack of harm to the watershed and resulting in little to no loading. Lakes in all remaining categories are being impacted by development of the watershed and, subsequently, receiving more and more external phosphorus than can safely be aerobically utilized. Accumulated phosphorus leads to internal sediment release during periods of intense anoxia. Lakes with internal loading tend to develop cyanobacteria: a

[2] Aquatic plants are more difficult to fit into this scheme.
[3] ppb = parts per billion or 1 drop in 13 gallons

group of phytoplankton that are discernably different from all other phytoplankton in three fundamental ways. First, they are a photosynthetic bacterium as opposed to the eukaryotic life form of all other algae. Second, many are buoyant, so they float as opposed to sink like all other algae, and third, many can produce molecules that are toxic to eukaryotic life forms. Beginning in the Mesotrophic category, when the TP reaches 15-25ppb, cyanobacteria begin to be present in significant amounts. Cyanobacteria dominance forces lakes into the Eutrophic and then Highly Eutrophic categories with frequent blooms and shoreline scums.

2023 Twin Lake Water Quality Results

Water Clarity

Water clarity in East Twin Lake was excellent in 2023, remaining better than 6 meters in all months except July, when clarity was 5.3m (**Table 2**, **Figure 1**). The best observed water clarity of 8.2 meters occurred in June.

Middle Twin water clarity was also good, though not quite as good as East Twin. Clarity was good from April through September, ranging from ~5-5.5 meters. The water clarity declined in October to 3.3 meters despite East Twin clarity of 7.7 meters at that time. Middle Twin water clarity never exceeded the oligotrophic threshold of 6 meters during the 2023 season.

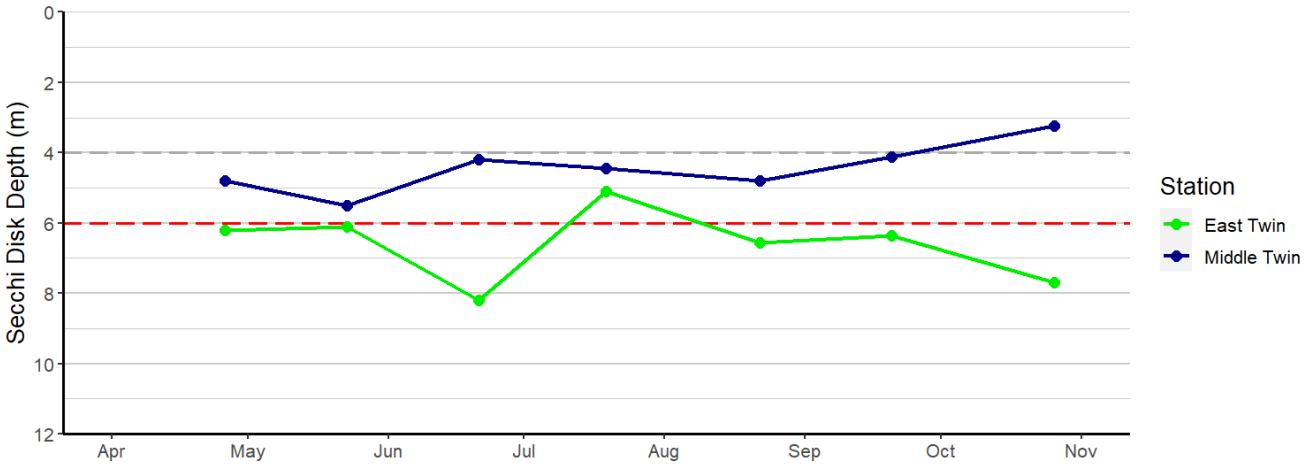
The West Twin basin is completely littoral with no pelagic water, that is, water too deep for plant growth. Data was collected from a small area, 20-30 feet in diameter, of deepest water, 3.6 meters. Because the lake is shallow, the Secchi disk was visible on the lake bottom during all monitoring events in 2023. Therefore, we cannot accurately gauge the water clarity in the lake. However, the water generally looked excellent, with the bottom visible throughout the lake where aquatic plants didn't block the view of the bottom.

Water clarity was always best in East Twin, averaging 6.6 meters, Middle Twin water clarity averaged 4.4 meters and appeared unaffected by clarity changes in East Twin. At West Twin, the Secchi disk was visible on the bottom for the entire season, so water clarity was at least, but likely more than 2.7 to 3.6 meters depending on water depth. It is likely that the Middle and West Twin water clarity was very similar.

Table 2. Secchi disk depths in Twin Lake during 2023. Underlined values are when Secchi was visible on the bottom.

Lake	26-Apr	23-May	21-Jun	19-Jul	22-Aug	20-Sep	26-Oct	Average
East	6.2	6.1	8.2	5.1	6.6	6.4	7.7	6.6
Middle	4.8	5.5	4.2	4.5	4.8	4.1	3.3	4.5
West	2.7	2.6	3.6	2.9	3.1	3	3.1	3.0
Average	***4.6***	***4.7***	***5.3***	***4.2***	***4.8***	***4.5***	***4.7***	**4.7**

Figure 1. East Twin and Middle Twin Secchi disk depths in 2023.



Water Temperature and Dissolved Oxygen

The water temperature of a lake is a function of solar radiation and the transparency of the water. Sunlight warms water that it can illuminate; water below the depth sunlight can penetrate remains dark and cold. As surface water is warmed by the sunlight, it becomes lighter and floats over the cold dark water below, thereby separating the lake into two layers. The upper water lit by sunlight will have uniformly warm water temperature and fully saturated dissolved oxygen concentration until late fall. The deeper layer will be dark, cold, and have dwindling dissolved oxygen supply.

East Twin Lake

East Twin Lakes was already stratified, with slightly reduced oxygen in the bottom water, during the first sampling event in late April (**Figure 2**). The lake developed an epilimnion in April that was roughly 5 meters deep (the epilimnion is the surface layer of the lake is equally warmed by the sun). The epilimnion persisted at roughly the same thickness, surface to about 4 or 5 meters, throughout the season. Water deeper than about 12 meters formed a stable hypolimnion, where the water temperature remained uniformly cold <8°C, and bottom temperature stayed constant at ~6-6.5°C for the entire season. Water between 4m and 12m formed the metalimnion (where the water temperature changes rapidly with depth). Changing water temperature causes large differences in density of the water, as water gets denser with colder temperatures. The structure of the water column is shown by the RTRM values shown in **Figure 3**. The length of the bars indicates the intensity of energy required to mix the two layers together. Values over 50 require a huge amount of energy to mix the two layers, so they are isolated from one another.

The lake experienced a Metalimnetic Oxygen Maximum (MOMax) from 6 to 10 meters for most of the season. This is indicative of increased phytoplankton activity at this depth. Several taxa of phytoplankton are capable of photosynthesizing (producing dissolved oxygen) at very low light levels and can take advantage of the higher density of deep water to maintain stable populations at one specific depth, which appears to be 9m during 2023.

Water deeper than 10 meters experienced dissolved oxygen loss. Dissolved oxygen loss was evident at the time of the first visit in April and progressed at an increasing rate during the season. Bottom waters became anoxic (water with less than 1 mg/L of oxygen) sometime in late July. The lake had fully anoxic water in August, September, and October, with water below 16 to 18m completely devoid of dissolved oxygen. This means there was a large volume of anoxic water in the lake for much of the season, allowing for the release of nutrients from the bottom water via internal loading.

Figure 2. Dissolved oxygen and water temperature profiles in East Twin Lake in 2023.

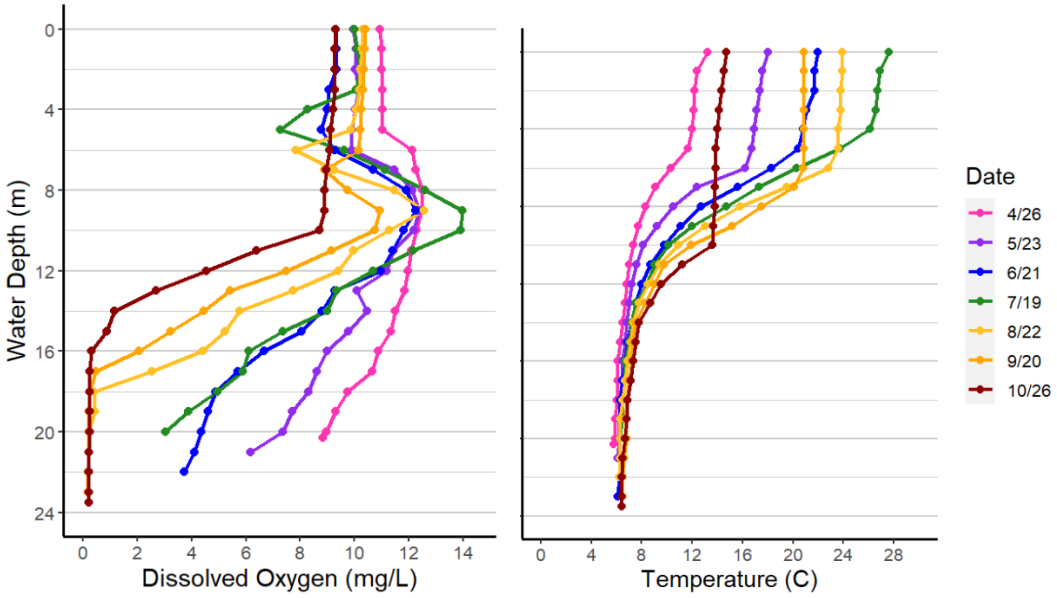
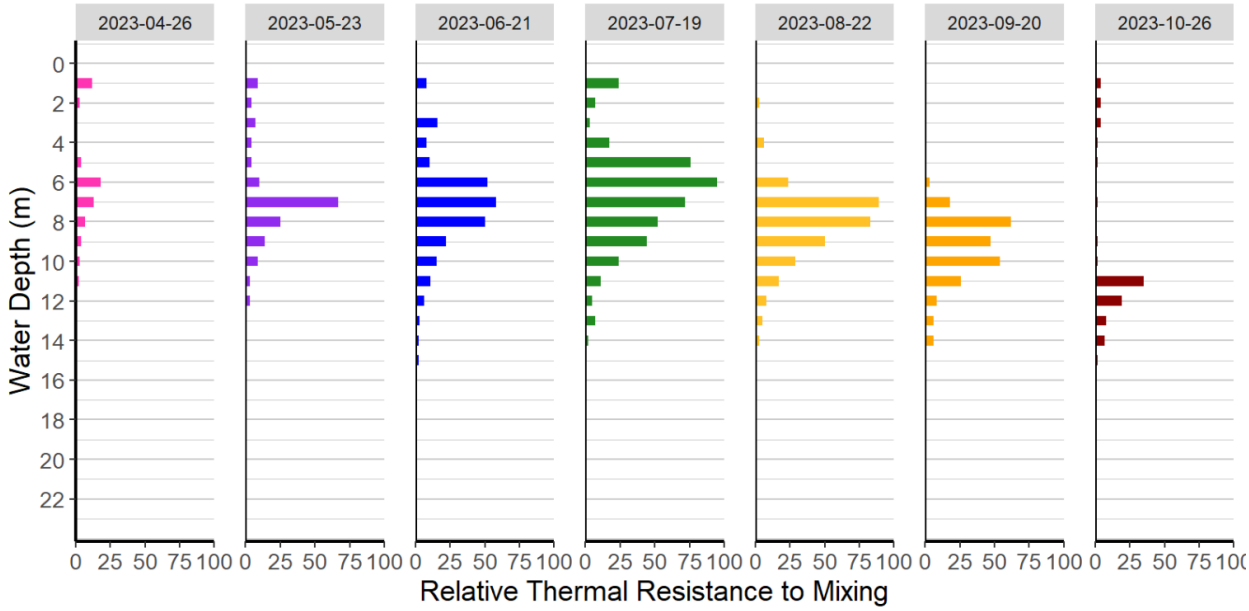


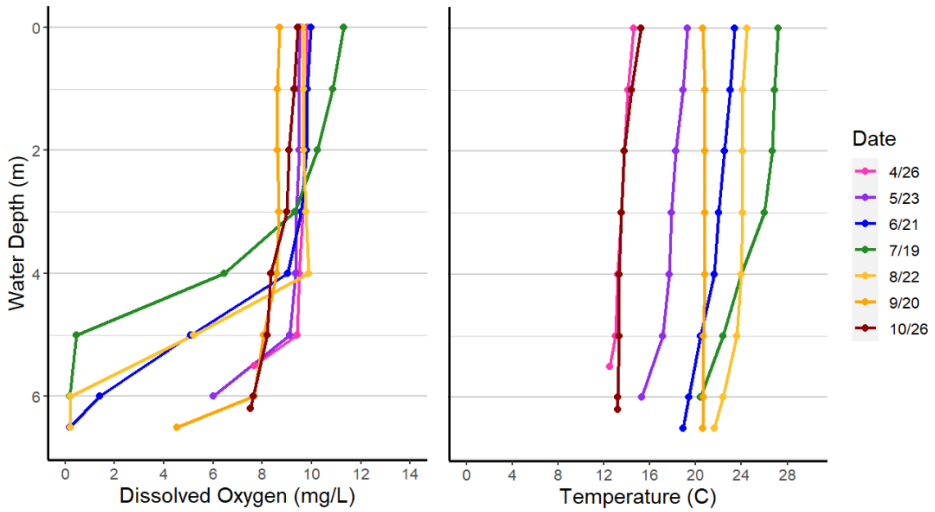
Figure 3. RTRM values for East Twin Lake during 2023.



Middle Twin Lake

In Middle Twin, the lake was mixed in April, with just slight dissolved oxygen loss in the bottom half meter of water (**Figure 4**). The water temperature remained fairly consistent throughout the water column for the entire season, with just slight stratification in July below 3 meters. The very bottom of the water column became anoxic in June. The anoxic boundary increased to a maximum height of ~1 meter from the lake bottom in July. After this point, the anoxic boundary began to decline, and oxic conditions returned by September. The water column was nearly fully mixed in October.

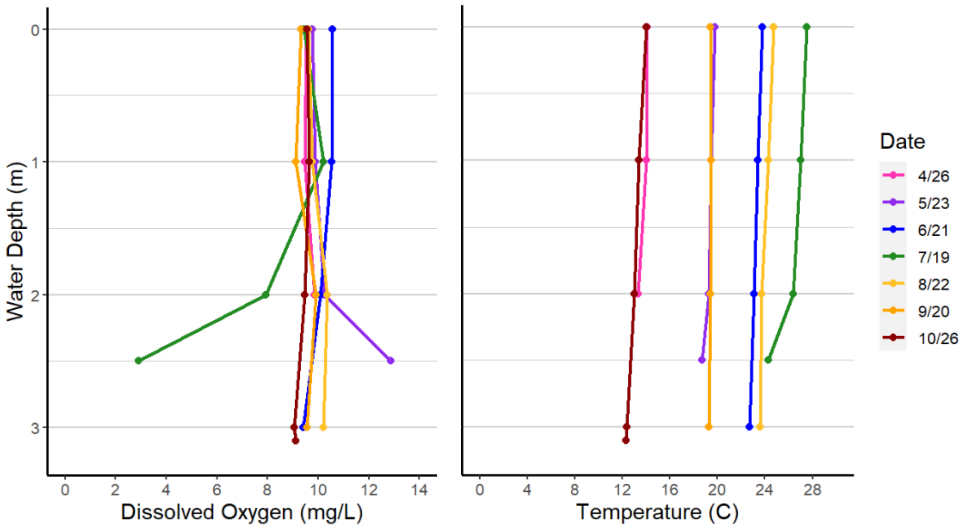
Figure 4. Dissolved oxygen and water temperature profiles in Middle Twin Lake in 2023.



West Twin Lake

West Twin Lake remained isothermal for the entire season (**Figure 5**). Dissolved oxygen concentrations were fairly consistent throughout the water column in most months, with the exception of a slight increase in DO in the bottom meter of water in May, and a decrease in DO between 1 meter and the bottom (2.5 meters) in July. In a lake as shallow as West Twin, there should not be any dissolved oxygen loss, even in the middle of the summer.

Figure 5. Dissolved oxygen and water temperature profiles in West Twin Lake in 2023.



Conductivity

The conductivity, or conductance, of lake water is the ability of the water to carry an electric current, reported as reciprocal of resistance micro-mhos (now reported as µS). The conductivity of the water is directly due to the concentration of dissolved solids in the water, primarily the salts of sodium, chloride, magnesium, potassium, calcium, and sulfate, which can be converted to total dissolved solids. Low conductance means the water is diluted, with low concentrations of ions. Higher conductivity indicates increasing saltiness of the water.

Conductivity of the Twin Lakes in 2023, shown below in **Figures 6-8**, ranged from a low of 202µS to a high of 351µS. Highest values occurred near the bottom during periods of anoxia. Generally, the lake water had a conductivity of ~250µS. East Twin Lake had lowest conductivity in April and May, 200-225µS. In the remaining months, June through October, the lake had conductivity of ~250µS. Middle Twin, however, had conductance of ~250µS in April and May, and lower values during the summer, somewhat opposite the pattern in East Twin. Comparison across all lakes (**Figure 9**) shows between-lake variability during April, May and June, followed by the three having nearly identical conductivity in July-October.

Figure 6. Conductivity profiles in East Twin Lake in 2023.

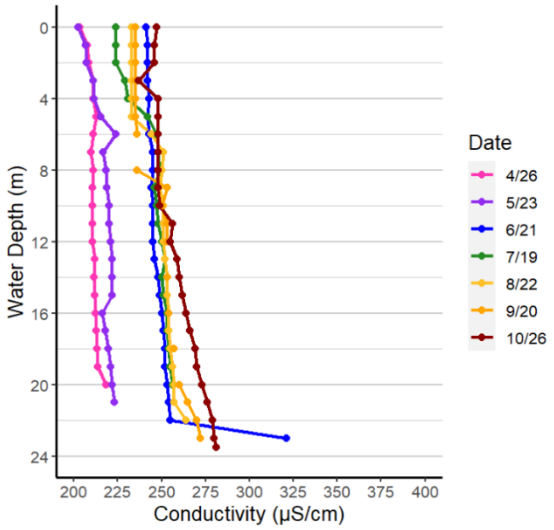


Figure 7. Conductivity profiles in Middle Twin Lake in 2023.

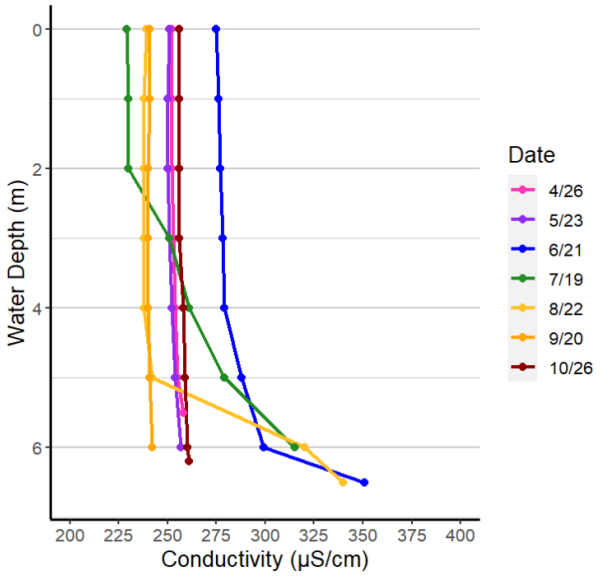


Figure 8. Conductivity profiles in West Twin Lake in 2023.

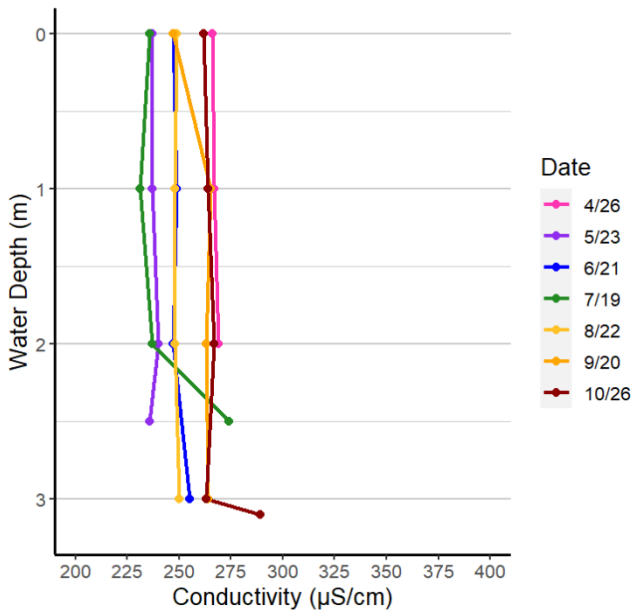
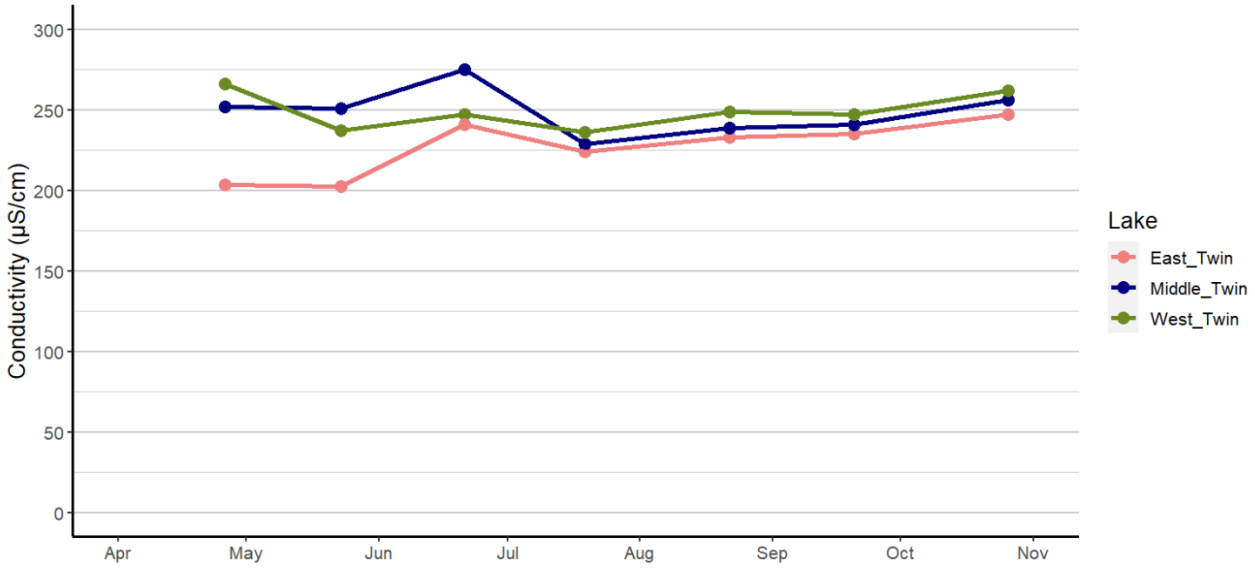


Figure 9. Conductivity at the surface of each lake in 2023.



pH

The pH of lake water is based on the complex interaction between water, calcium, and carbon dioxide. Because Twin Lakes has high calcium concentrations, the lake water can store a large quantity of bicarbonate and carbonate ions, giving the water a high buffering capacity. East Twin Lake water was always greater than 7.7pH, however values less than 8.0pH were rare (**Figures 10**). Epilimnion water tended to have a slightly higher pH between 8.4 and 8.7 units. Hypolimnion water tended to have lower pH between 7.8 and 8.2 units. Middle and West Twin maximum pH tended to occur in mid-depth water (**Figures 11 & 12**).

Figure 10. pH profiles in East Twin Lake in 2023.

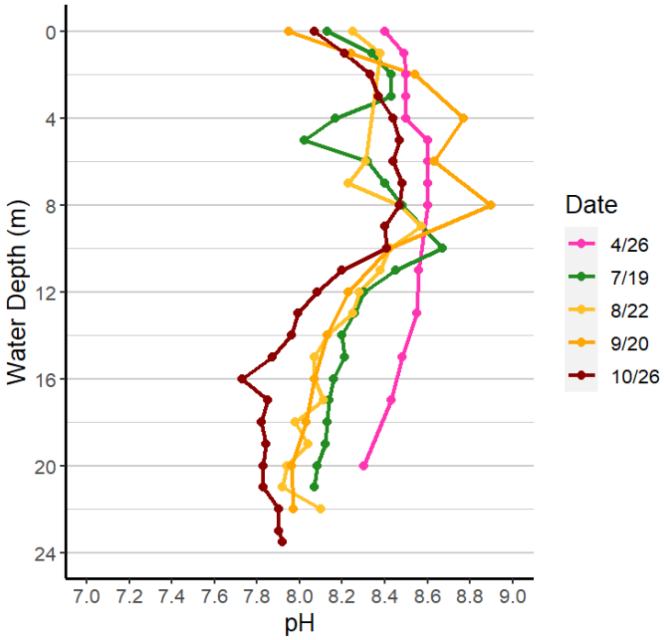


Figure 11. pH profiles in Middle Twin Lake in 2023.

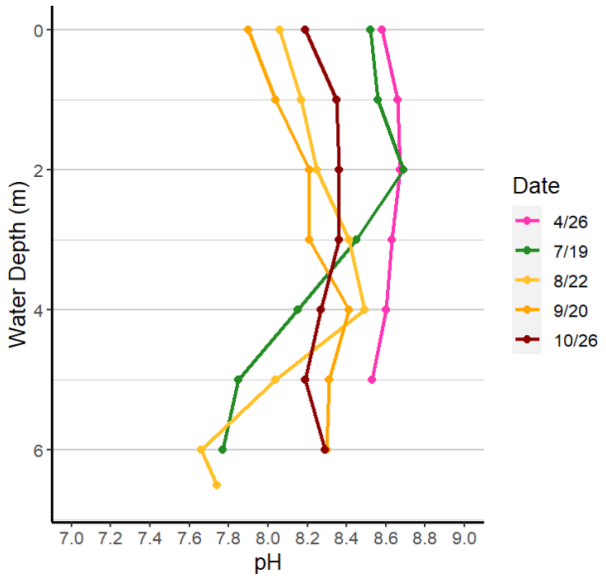
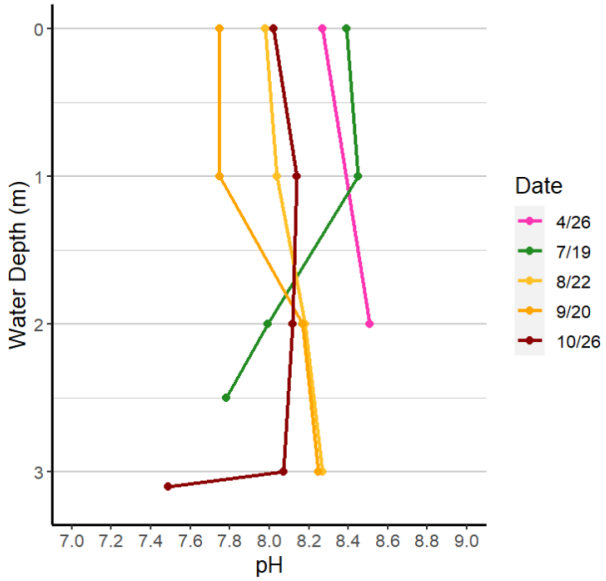


Figure 12. pH profiles in West Twin Lake in 2023.



Nutrients

Total Phosphorus

The goal for in-lake surface water is total phosphorus (TP) concentrations less than 10ppb. The upper acceptable threshold is 15ppb.

In East Twin, surface water TP remained under the 10ppb threshold in most months (**Table 3**, **Figure 13**). In August and October, TP was just over the threshold, at 11ppb and 12ppb respectively. Bottom water TP increased steadily between June and September. The October bottom water TP concentration was 156ppb, which is exceptionally high, leading us to question whether this sample was contaminated. Therefore, we have not included that data point in the figure.

In Middle Twin, TP was less than 10ppb in April, May, June, and September (**Table 4**, **Figure 14**). In July and August, TP was above 10ppb but under 15ppb. TP exceeded the 15ppb threshold of acceptability in October, but by just 1ppb.

Due to the shallow nature of West Twin, water samples were only collected at the middle of the water column, either 1.5 meters or 2 meters based on total water depth. TP concentration was good for middle water from April through June but was slightly elevated in September and October (**Figure 14, Table 5**).

Total phosphorus concentrations at 1m varied somewhat between lakes over the course of the season (**Figure 15**). East Twin had the lowest TP early in the season, while West Twin had the highest values. Later in the season, TP in the surface water of East Twin had little influence on the other lakes, but instead appears to react to similar forcing factors.

Table 3. East Twin 2023 total phosphorus concentrations (ppb).

Depth (m)	Apr-26	May-23	Jun-21	Jul-19	Aug-22	Sep-20	Oct-26
1	1	6	1	10	11	7	12
10	5	8	5	11	9	17	13
20	10	10	5	16	24	32	156

Figure 13. East Twin Lake 2023 total phosphorus concentrations.

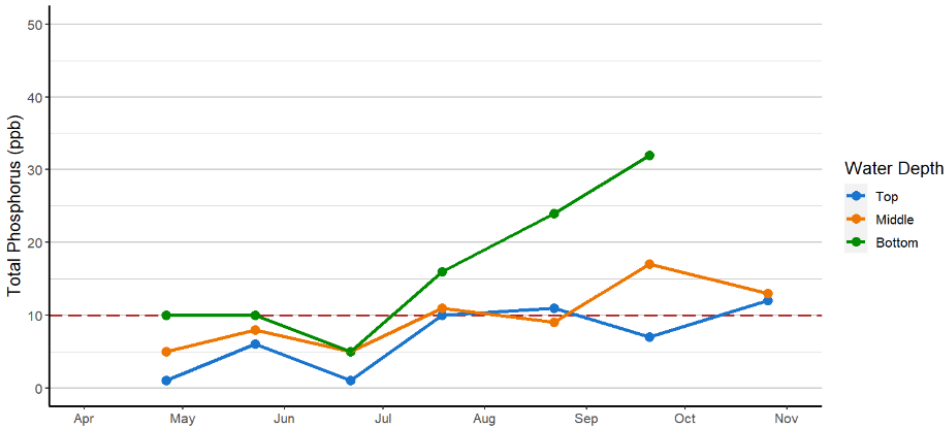


Table 4. Middle Twin 2023 total phosphorus concentrations (ppb).

Depth (m)	Apr-26	May-23	Jun-21	Jul-19	Aug-22	Sep-20	Oct-26
1	4	6	5	11	13	3	16
3	7	7	7	10	13	25	22
5	10	16	10	13	45	10	17

Figure 14. Middle and West Twin Lake 2023 total phosphorus concentrations.

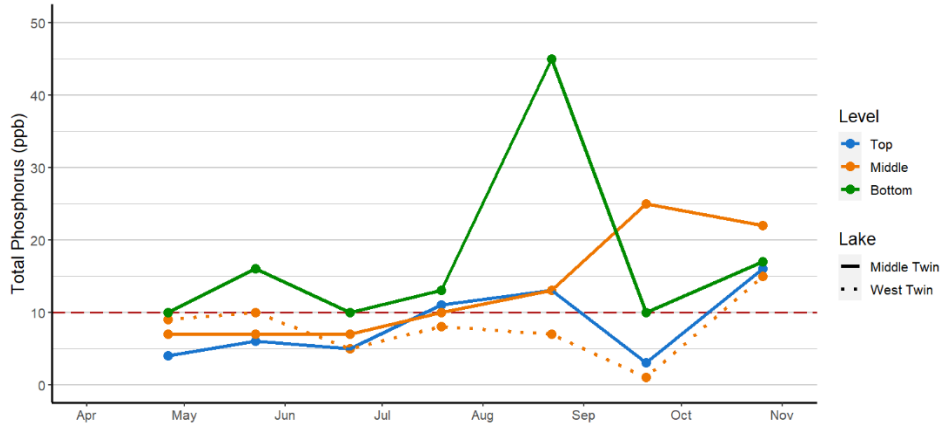
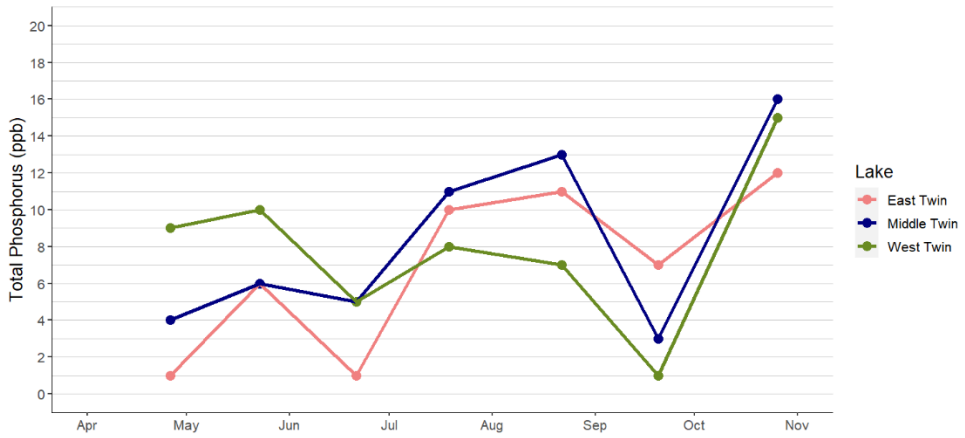


Table 5. West Twin 2023 total phosphorus concentrations (ppb).

Depth (m)	Apr-26	May-23	Jun-21	Jul-19	Aug-22	Sep-20	Oct-26
1.5	9	10	5	8	7	1	15

Figure 15. One-meter total phosphorus concentration in each lake during 2023.



Total Nitrogen

The goal for in-lake total nitrogen (TN) in the surface water is less than 200ppb and the upper acceptable threshold is 300ppb. Total nitrogen was elevated through the water column at all three lakes in 2023.

In East Twin, TN in the surface water exceeded 200ppb on all sampling dates and exceeded 300ppb in all months except for May (**Table 6**, **Figure 16**). TN in the middle of the water column was slightly lower than surface water concentrations on most sampling dates, suggesting organic nitrogen loading from the large contiguous wetlands and extensive littoral plant cover. In the bottom water, TN concentrations were similar to those in the middle and surface water samples from April through July but were elevated from August through October.

TN in the surface water of Middle Twin remained close to 300ppb in all months except for October, when the concentration dropped to just under 200ppb (**Table 7**, **Figure 17**). In the middle of the water column, TN values were very similar to those in the surface water from April through August. In September, middle water concentrations spiked as the lake began to undergo fall turnover. TN concentrations in the bottom water were slightly higher than surface and middle water concentrations from April through July, with a spike in August due to internal loading. Concentrations in the bottom water were lower in September and October due to fall turnover.

TN in the middle waters of West Twin were generally higher than middle-water samples collected from the other two lakes, possibly because of the fully littoral nature of this lake (**Figure 17, Table 8, Figure 18**). Most TN values were between approximately 300ppb and 400ppb, with a slight decline in concentration in September.

Table 6. East Twin 2023 total nitrogen concentrations (ppb).

Depth (m)	Apr-26	May-23	Jun-21	Jul-19	Aug-22	Sep-20	Oct-26
1	281	272	336	311	339	342	308
10	300	281	307	299	294	308	245
20	337	282	289	335	445	438	692

Figure 16. Total nitrogen concentrations at the top, middle, and bottom of East Twin Lake in 2023.

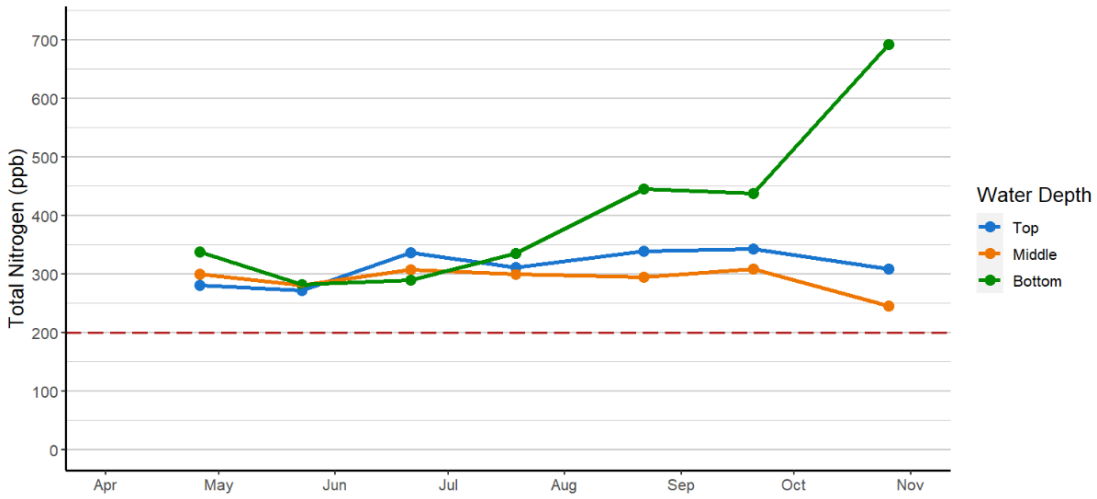


Table 7. Middle Twin 2023 total nitrogen concentrations (ppb).

Depth (m)	Apr-26	May-23	Jun-21	Jul-19	Aug-22	Sep-20	Oct-26
1	301	284	337	289	327	197	324
3	292	290	362	289	322	439	403
5	294	314	413	356	658	354	326

Figure 17. Total nitrogen concentrations in Middle Twin (top, middle, and bottom) and West Twin (middle) during 2023.

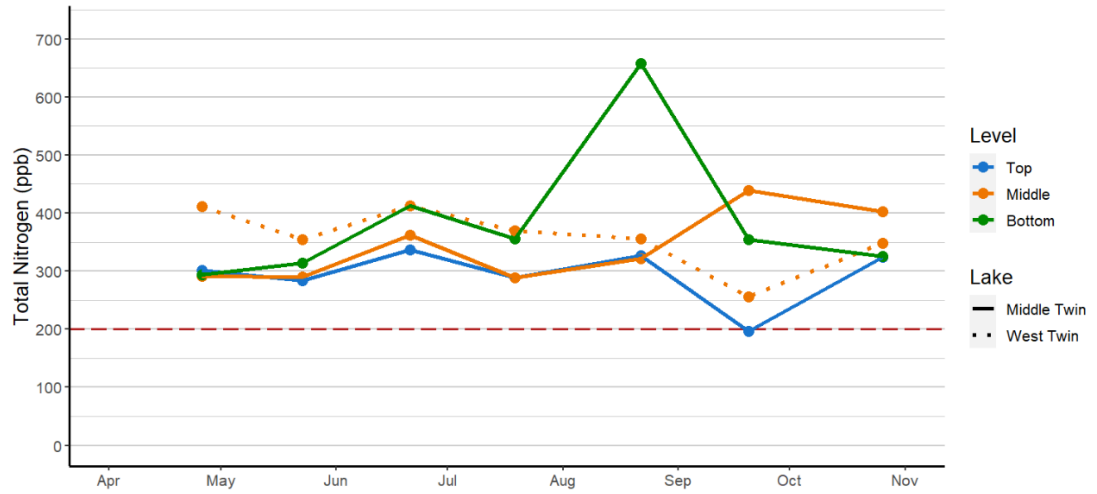
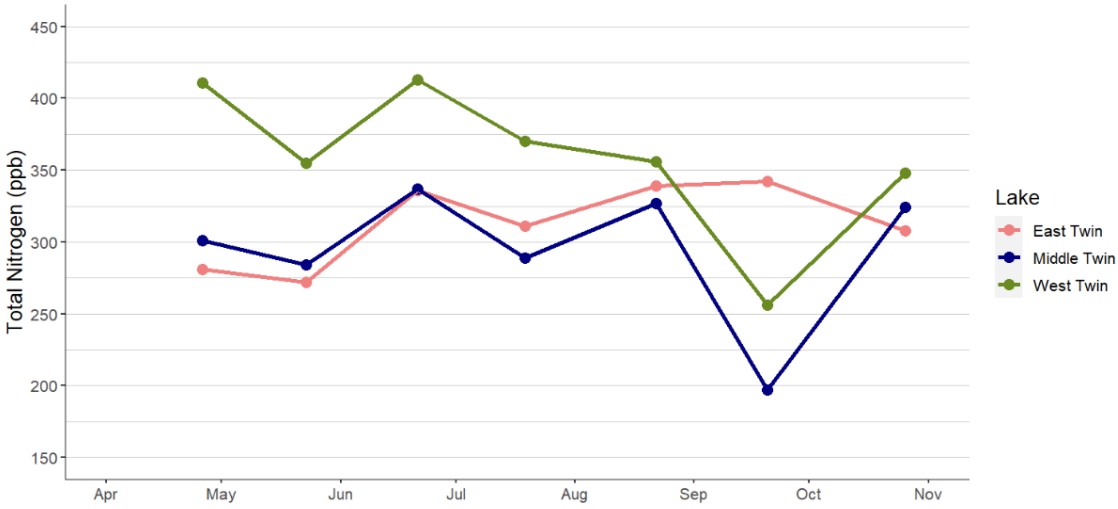


Table 8. West Twin 2023 total nitrogen concentrations (ppb).

Depth (m)	Apr-26	May-23	Jun-21	Jul-19	Aug-22	Sep-20	Oct-26
1.5	411	355	413	370	356	256	348

Figure 18. Total nitrogen concentrations at 1 meter at all lakes in 2023



Phytoplankton

Phytoplankton samples were collected from East Twin Lake during each monitoring event. Total phytoplankton numbers were low from April through August (**Figure 19**). In September, there was a spike in diatoms. In October, Chrysophytes were abundant.

Cyanobacteria, of which most genera are known toxin producers, were present in the April, August, September, and October samples. However, numbers never reached concerning levels. The World Health Organization provides guidance on the relative probability of health effects from cyanobacteria exposure based on cell counts (**Table 9**). Cyanobacteria density of less than 20,000 cells/mL is associated with low density of health effects. In East Twin Lake, cyanobacteria reached a maximum density of ~6,000 cells/mL in October.

Figure 19. East Twin Lake 2023 phytoplankton counts.

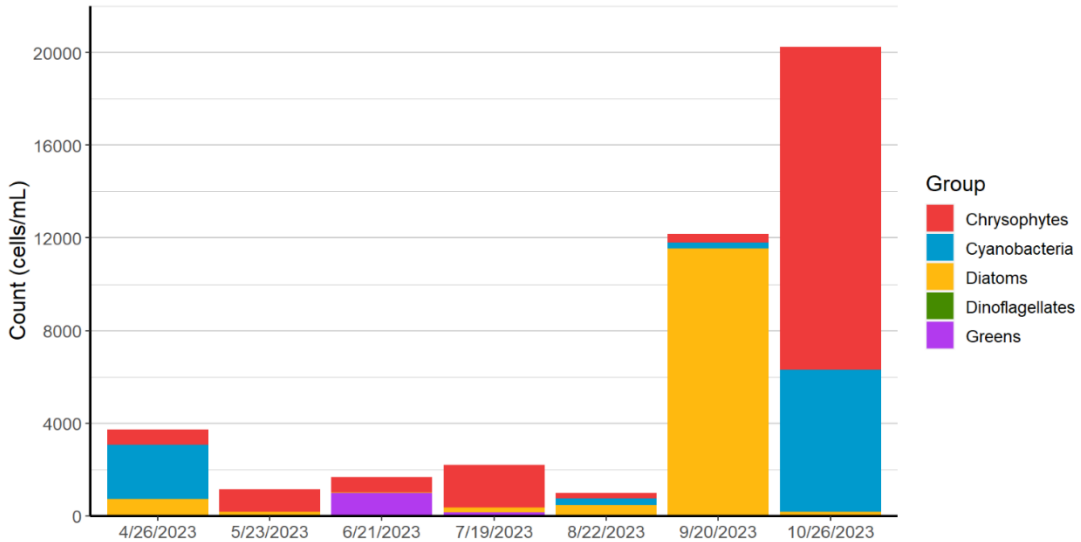


Table 9. WHO guidance values for the relative probability of health effects resulting from exposure to cyanobacteria.

Relative Probability of Acute Health Effects	Cyanobacteria Density (Cells/mL)
Low	< 20,000
Moderate	20,000-100,000
High	100,000-10,000,000
Very High	> 10,000,000

Zooplankton

The zooplankton community in East Twin Lake was primarily composed of rotifers and cyclopoids (**Figure 20**). Copepods were more abundant in April and May compared to later months. Cladocera were present at low density in most months. Calanoids were only present in the April sample. All zooplankton were small, roughly between 0.2 and 0.5 mm in length; very few zooplankton larger than 0.6mm were found (**Figure 21**). All the Daphnia Cladocerans were ~0.3-0.4 mm. This is the smallest size class for these organisms. The lack of larger-bodied organisms indicates heavy grazing by zoo-planktivorous fish. A lack of large-bodied Daphnia results in under-control of phytoplankton.

Figure 20. East Twin Lake 2023 zooplankton counts.

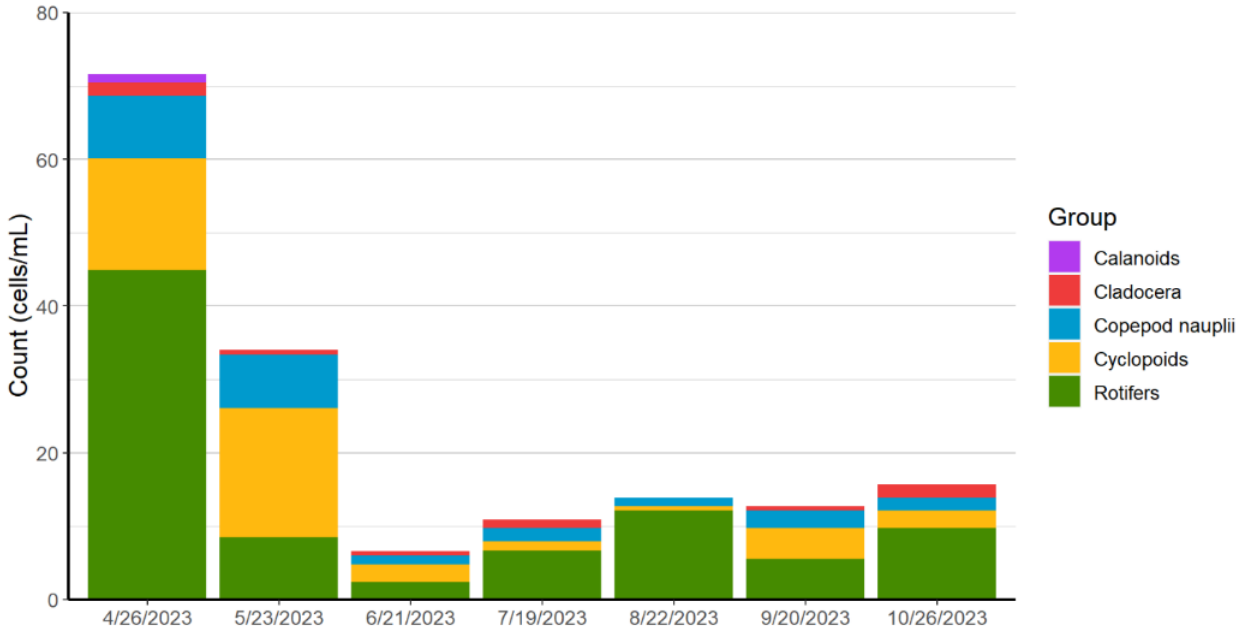
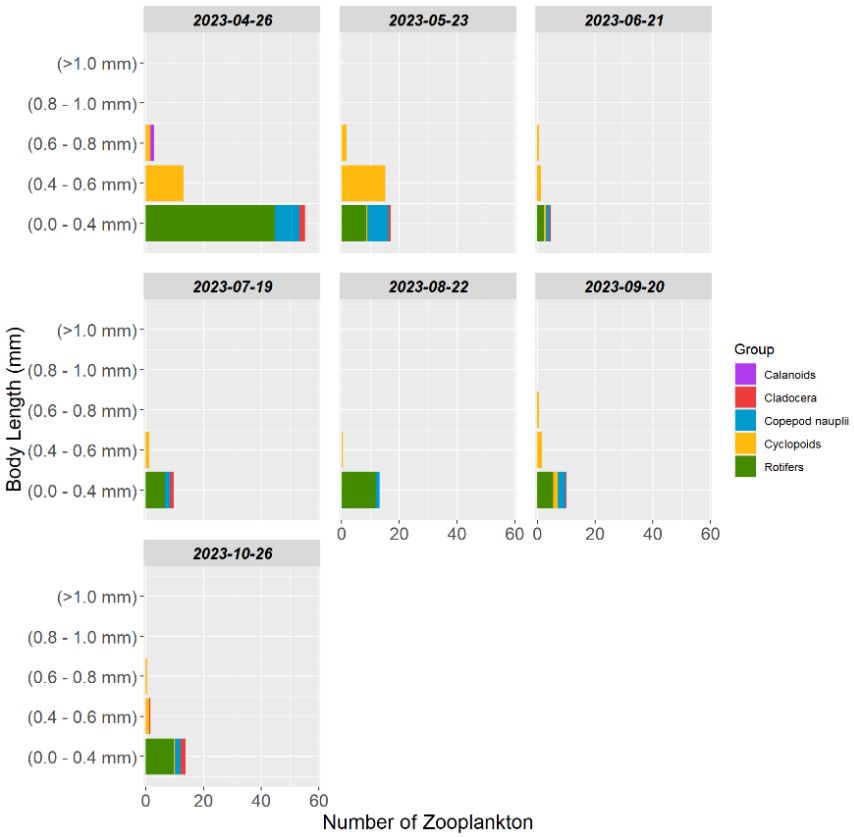


Figure 21. East Twin Lake 2023 zooplankton count by size class.



Conclusions & Recommendations

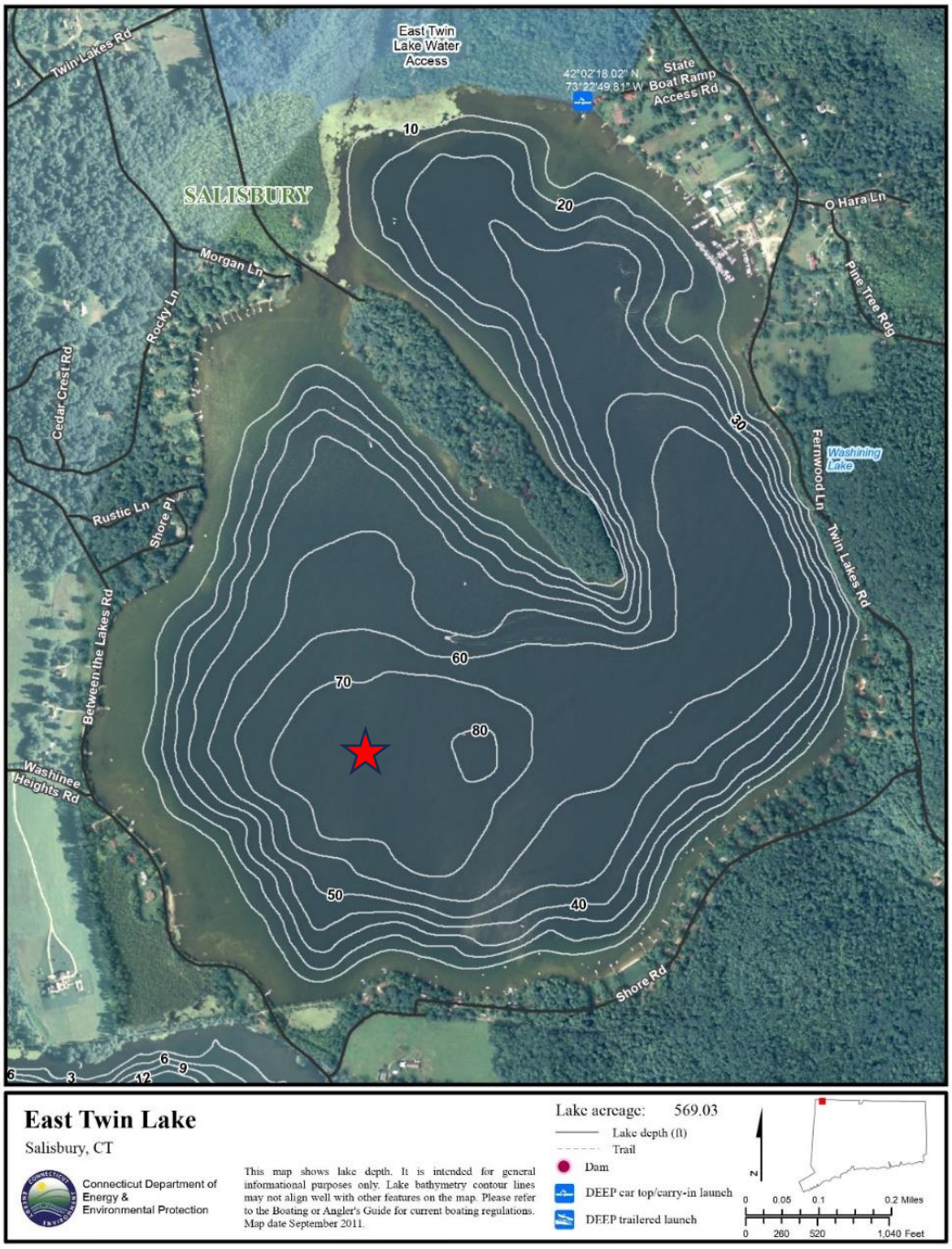
Water clarity was good at all three lakes in 2023. Phosphorus concentrations were acceptable overall, although East Twin and Middle Twin did exhibit moderate spikes later in the season due to internal loading. Total nitrogen was elevated above target concentrations in all three lakes.

In 2023, East Twin Lake was already stratified by the time of the first sampling in April, and remained heavily stratified, with a large volume of anoxic water, through the last sampling event of the season in late October. One of the goals of water quality monitoring is to capture lake condition during spring and fall mixing and to observe the total duration of anoxia in the bottom water. Therefore, in 2024, water quality monitoring should be conducted once per month from March through November. Though Middle Twin and East Twin are shallower, these lakes should be monitored in March and November as well, as there is not a significant cost increase for monitoring these lakes at the same time as East Twin.

Appendix

CT ECO. (n.d.). Bathymetry With Aerial - East Twin Lake [PDF]. Retrieved from http://cteco.uconn.edu/maps/lake/bathymetry/Bathymetry_With_Aerial_East_Twin_Lake.pdf

Bathymetric maps for East, Middle, and West Twin Lakes.



West Twin Lake

Salisbury, CT

Connecticut Department of Energy & Environmental Protection

This map shows lake depth. It is intended for general informational purposes only. Lake bathymetry contour lines may not align well with other features on the map. Please refer to the Boating or Angler's Guide for current boating regulations. Map date September 2011.

Lake acreage: 289.8

Lake depth (ft)

Trail

Dam

DEEP car top/carry-in launch

DEEP trailered launch

N

0 0.05 0.1 0.2 Miles

0 280 560 1,120 Feet