Lake Oscawana 2021 Water Quality & Aquatic Plant Monitoring Report

Prepared for the Lake Oscawana Management Advisory Commission,
Town of Putnam Valley, NY

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Executive Summary: Key Points from the 2021 Monitoring Report

- Secchi disk transparency was good from June through August 2021, but was moderately poor in September and October.
- Lake temperature data profiles demonstrated that thermal stratification was present prior to the April monitoring visit in 2021, due to a warm spring. Thermal stratification persisted at Station 1, in the deepest waters, beyond the final October 2021 sampling date. Temperature stratification had mostly eroded at Stations 2 and 3 by that time.
- There were no observable trends in the 2006-2021 lake thermal stratification (RTRM) analysis, despite regional research pointing towards impacts of climate change on lake mixing and stratification.
- The seasonal maximum ascent depth of the anoxic boundary was 5.77m below the surface, slightly higher in the water column than the 5.81m seasonal 2020 peak (slightly worse). This value is only marginally shallower than the target threshold of 6.0m.
- Dissolved oxygen loss and internal nutrient recycling does not control Oscawana water quality equally every year, watershed inputs are the major concern at this time. Aeration or oxygenation methods were considered and were determined to be not appropriate for Oscawana management at this time.
- The 2021 TP in surface waters across all three sampling stations was elevated from August through October (above the target <20ppb). Bottom water TP concentrations were elevated in late summer to fall at Stations 1 and 2, but not at Station 3.
- Surface TN concentrations followed a late-summer pattern, increasing as the ammonia nitrogen levels in the hypolimnion increased due to internal nutrient releases.
- At this time, no in-lake nutrient-binding strategies are permitted by NYDEC, thus products discussed are for informational purposes only, in case permit structure changes in future years.
- E. coli data collected from Inlet 4, and the culvert above Inlet 4, allowed the Putnam County Health Department to pursue potential upgrades to failed septic systems in the Inlet 4 sub-watershed. NEAR, LOMAC, and the Town building department continues to track septic pump-outs and regular communication with the County Health Department has been established regarding this issue.
- There were small to moderate cyanobacteria surface blooms documented in November 2021, but the summer cyanobacteria cell counts remained relatively low in open-water and no scums were observed in summer 2021.
- An additional 453 grass carp were stocked during the 2021 season in an effort to account for potential mortality since the initial 600 fish were stocked in 2016. This additional number of fish was estimated to bring the stocking rate back to approximately 7.9 fish per vegetated acre, and approximately 9.2 fish per acres of invasive Eurasian milfoil.
- No harvester tracker data was available for the mechanical harveseting performed in 2021.
- Aquatic plant survey results from 2019 to 2021 did not document major changes in range of dominant species.
- The mandatory septic system pump-out ordinance was expanded to the entire Oscawana watershed.
- Residents should refer to the 2020 Lake Oscawana Management Plan for a list of potential watershed improvement projects needed for continued nutrient reduction and improved lake water quality. LOMAC continues to work with the Town to improve stormwater and watershed management practices that affect Lake Oscawana.

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Northeast Aquatic Research

Description of Monitoring Parameters

All measurements should be taken at the deepest open-water location in a lake.
Large or irregularly shaped lakes often require more than one testing site.

Secchi Disk Clarity

Water clarity measurements use an 8-inch circular **Secchi disk** attached to a measuring tape. The disk should be lowered into the water on the shady side of the boat. Using a view scope to shade out light in one's peripheral vision, the Secchi disk is lowered until it disappears from view in the water column. The depth at which the Secchi disk disappears from view is considered the water clarity measurement. Secchi clarity is dependent on light penetration. Light penetration is affected by phytoplankton, suspended sediments, and microscopic organic matter in the water column. Clearer waterbodies have greater Secchi transparency values. Lakes and ponds experience fluctuations in Secchi clarity throughout the season, typically driven by increases or decreases in nutrients that stimulate phytoplankton growth. Ideally, water clarity should be tracked at least monthly from April to October.

Lake Profile Measurements

Temperature in lakes and ponds in the northeast follows a seasonal pattern of warming and cooling. Following ice-melt in early spring, lakes and ponds will be more or less uniform in temperature from top to bottom. Temperature measurements should be made at one-meter increments from the lake surface to the bottom on a monthly basis. Combined, measurements at all 1-meter depth increments are referred to as a lake profile. Profile measurements change as the sun's rays penetrate into the water column. Clearer water allows for greater sunlight penetration and deeper warming during the summer months. The depth and development of a **thermocline**, or the zone of rapid temperature change, is dependent on water depth, surface area of the lake, climatic conditions, and water clarity. A thermocline effectively isolates top and bottom waters during summer months because warm water at the surface is less dense than the cold water at the bottom of the lake. In the fall, the lake cools off as air temperatures drop, resulting in a weakening thermocline and eventually water "turn-over." Lake turnover simply means that the temperature becomes uniform from top to bottom and that there is no longer a thermocline. In lakes deeper than 20ft in the northeast, this turnover traditionally occurs in the spring and the fall. Shallower lakes are more dependent on weather and may experience multiple thermal mixing events in a season. Very large and deep lakes often have more complicated temperature dynamics that require multiple monitoring sites.

Dissolved oxygen in a lake is essential to aquatic organisms. At the surface of a lake, the water is in direct contact with the air, and atmospheric oxygen is dissolved into the water as a result of diffusion. Water mixing, driven by wind and temperature currents, circulates this oxygen throughout the water column during spring and fall mixing periods. Yet because lakes warm non-uniformly, the thermocline that develops in summer months will temporarily cut off the bottom waters from surface water circulation of oxygen. In lakes with very little decomposing plant material at the bottom, this is not usually a problem because there is enough oxygen to sustain the lake through the summer months. More nutrient-rich lakes, however, can be depleted of oxygen in the bottom waters below the thermocline. This phenomenon results in **anoxic** (<1mg/L) conditions in deeper waters of many lakes. An absence of oxygen changes the bottom chemistry for multiple months. It is critical to track oxygen loss beneath the thermocline and/or the level of the **anoxic boundary**. The anoxic boundary is defined as the depth of water at which dissolved oxygen is depleted in the summer. Anoxia worsens towards the end of summer, just before fall 'turn-over,' which will eventually replenish oxygen to the bottom, even in polluted lakes. Anoxia also tends to worsen over time, increasing incrementally for years and years. Organisms like fish and invertebrates that need oxygen to survive are not able to inhabit deeper waters in many lakes during the summer. Lakes and ponds with severe oxygen problems during summer months also experience increased nutrient levels at the lake bottom. This is the result of changing chemistry between the presence or absence of oxygen.

Lake Nutrients Samples

Water samples should be collected monthly from April to October in at least the deepest part of the lake. The most critical times for sampling are early spring, mid to late summer, and the fall. Sampling depths usually incorporate top, middle, and bottom depths. Deeper lakes may need more samples, and shallower lakes may only need top and bottom samples. Water samples are typically analyzed for total phosphorus, total nitrogen, ammonia nitrogen, and nitrate nitrogen. In baseline assessments, a number of additional parameters are also needed. ***Phosphorus*** and ***Nitrogen*** are the two principal plant nutrients that drive aquatic plant and algae growth. Due to lake temperature stratification, these nutrients are not usually present in the same quantities throughout the lake. Typically, the bottom of the lake has more phosphorus and nitrogen as the summer progresses because bottom-sediments release nutrients when oxygen is depleted. Just as anoxia increases over time, phosphorus and nitrogen also tend to increase over time as a waterbody becomes more eutrophic, or dominated by plants and algae.

Description of Monitoring Parameters Continued…

Calculated Values

Relative Thermal Resistance to Mixing (RTRM) is a unit-less ratio that describes the difference in water density between each meter. Higher numbers indicate stronger thermal **stratification**. Stratification is the result of density differences as warming surface waters become less dense than cold deeper water. The RTRM is a relative number that distinguishes the intensity and depth of the thermocline. RTRMs describe how the lake is or is not mixing with respect to layers of water at specific depths. RTRMs also show when the lake becomes de-stratified as the result of temperature changes or excessive wind energy that can overcome thermal density boundaries.

Percent Oxygen Saturation is the percentage of dissolved oxygen at a given depth, relative to the water's capacity to hold oxygen, which is based on its temperature. For instance, 50% O_2 saturation means that the water contains only half of the dissolved oxygen that it is able to hold at its current temperature. In essence, anything less than 100% means that the biological oxygen demand, or rate at which oxygen is used up, is depleting the water of oxygen at a rate faster than it can be replenished. A percentage greater than100% is frequently a result of excessive phytoplankton production of oxygen that causes the water to be supersaturated.

Additional Important Profile Measurements

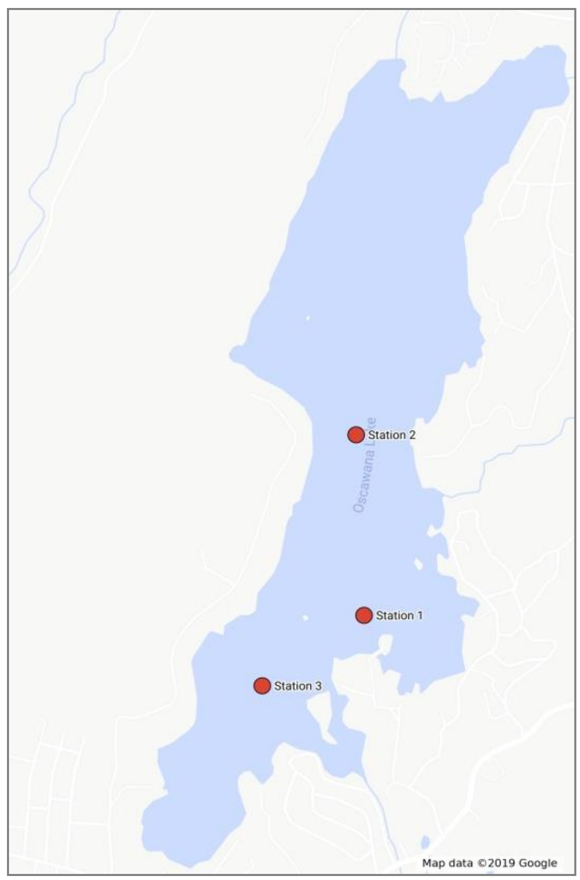
Specific Conductance, also referred to as conductivity, measures the quantity of dissolved ions in water that conduct electricity. Conductivity measurements can also be taken at one-meter increments from surface to lake bottom with calibrated probes. Alternatively only surface samples may also be collected and tested in the lab. Conductivity generally increases with dissolved salt content in the lake, which can be traced to either natural mineral sources or to human inputs from road salting and septic systems.

Station 1: The "Deep Hole" is approximately 35-ft deep and is the primary water quality monitoring site.
(41.39063, -73.84836)

Station 2: The northern monitoring station is located in approximately 27-ft of water.
(41.39553, -73.84824)

Station 3: The southern station is also located in roughly 27-ft of water and represents water quality near some of the most populated and disturbed areas of the lake.
(41.38817, -73.85275)

All water quality monitoring stations are too deep to support aquatic plant growth. All stations lose oxygen from late spring to late summer. The three sites differ substantially depending variable lake conditions.



Water Clarity

Water clarity is measured as Secchi disk transparency, using a view scope. The Lake Oscawana Management Plan set the minimum target water clarity value to be 2-meters, and identified that water clarity greater than 4-meters is particularly good based on the lake's historical data. These thresholds are shown as horizontal dashed lines in **Figure 1** below.

The 2021 water clarity was near average in April and May, and was good from June through mid-August. There were no exceptional (greater than 4m) clarity values recorded in 2021. By the September and October monitoring visits, water clarity had declined substantially and was either near to or less than the target 2-meters. The clarity in October was less than the minimum target of 2m, with the worst seasonal clarity recorded at Station 3 (1.65m) on that date. Reduced late-season water clarity is likely a combination of increased watershed inputs from heavier than normal summer rains, climate induced late-season water column stability, and increased 2021 internal nutrient loading and mixing of nutrients into the surface waters after fall water column turnover.

Figure 1. Water Clarity 2016-2021 Seasonal Pattern, St 1-3

Water Temperature

The 2021 temperature profiles measured at Station 1 are shown in **Figure 2,** profiles collected from Stations 2 and 3 are shown in **Figure 3**. Profiles show the lake had already begun to thermally stratify by the April 12th first visit of the season. Thermal stratification continued to strengthen through August forming a stable mixing layer between the surface and 4 to 6 meters between June and September. Stratification persisted into October with a remaining thermocline between 8 meters and the bottom on October 14th, the last visit of the season. The bottom water temperature showed no increase in October over September indicating the bottom water layers were still unmixed in October.

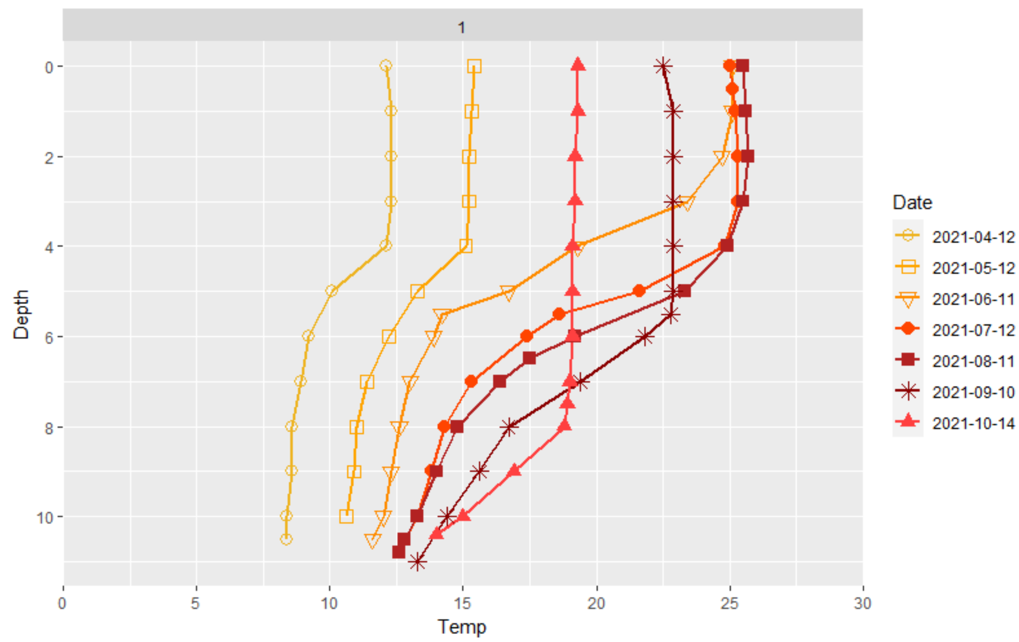


Figure 2. Station 1 Water Temperature (°C) 2021

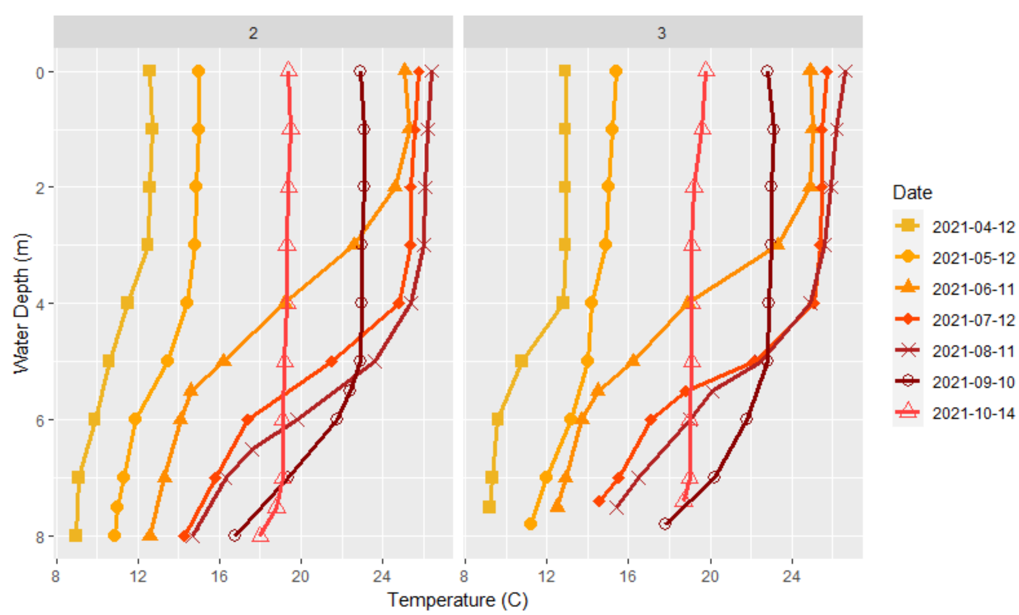


Figure 3. Station 2 & 3 Water Temperature (°C) 2021

The monthly temperature profile readings from April through October in 2016 through 2021 (Station 1) were compiled into a multi-season isopleth, **Figure 4** below. The figure uses color to represent different temperatures of the water in degrees Celsius, with blue representing cold and red representing very warm water. Warm, red and orange, water occurs at the surface and mid depths each summer while cold, blue water occurs in the winter and near the bottom. The mixing of the water column is represented by the yellow and green colored water getting deeper each fall, sometime reaching the bottom.

It is important to understand that an isopleth figure interpolates the water temperatures between sampling months, so if there were more frequent temperature profiles or any high-resolution logger data available, this figure may show slight partial mixing or extreme stratification events related to short weather changes. The increasing concern of climate change may bring longer and stronger thermal stratification. We believe it is prudent to install a string of continuous data loggers to better track the effects of climate on lake quality over time. The cost of a set of continuous loggers depends heavily on the parameters measured and the number of depths monitored. Options and potential costs will be discussed with the Town and LOMAC, but it would be likely be less than one thousand dollars to install several temperature-only loggers which will provide valuable seasonal data up to supplement the ongoing monitoring program. The monthly temperature monitoring would serve as quality assurance to validate the logger data across the season. The installation and maintenance could take place at regular monitoring visits.

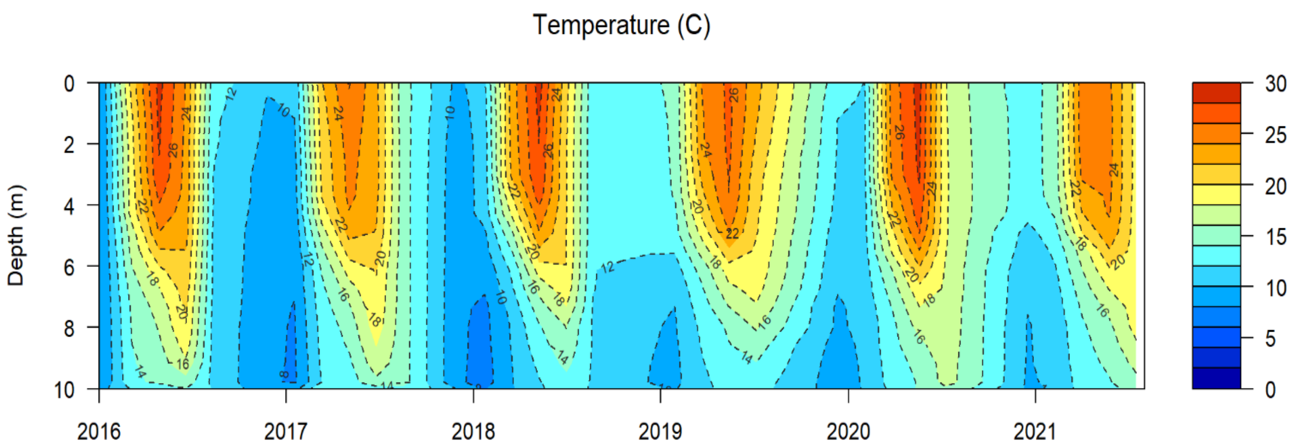


Figure 4. Long-term 2016-2021 Water Temperature Isopleth (Station 1)

The intensity of thermal stratification is quantified using Relative Thermal Resistance to Mixing (RTRM), a dimensionless value calculated using the density differences between 1-meter thick layers of water in the lake. The 2021 RTRM values from Station 1 are shown as horizontal bars in **Figure 5**. Tracking the change in RTRM each season allows understanding of duration and strength of thermal barriers in the lake, and it defines the location and thickness of the three lake layers during stratification (epilimnion, metalimnion, and hypolimnion).

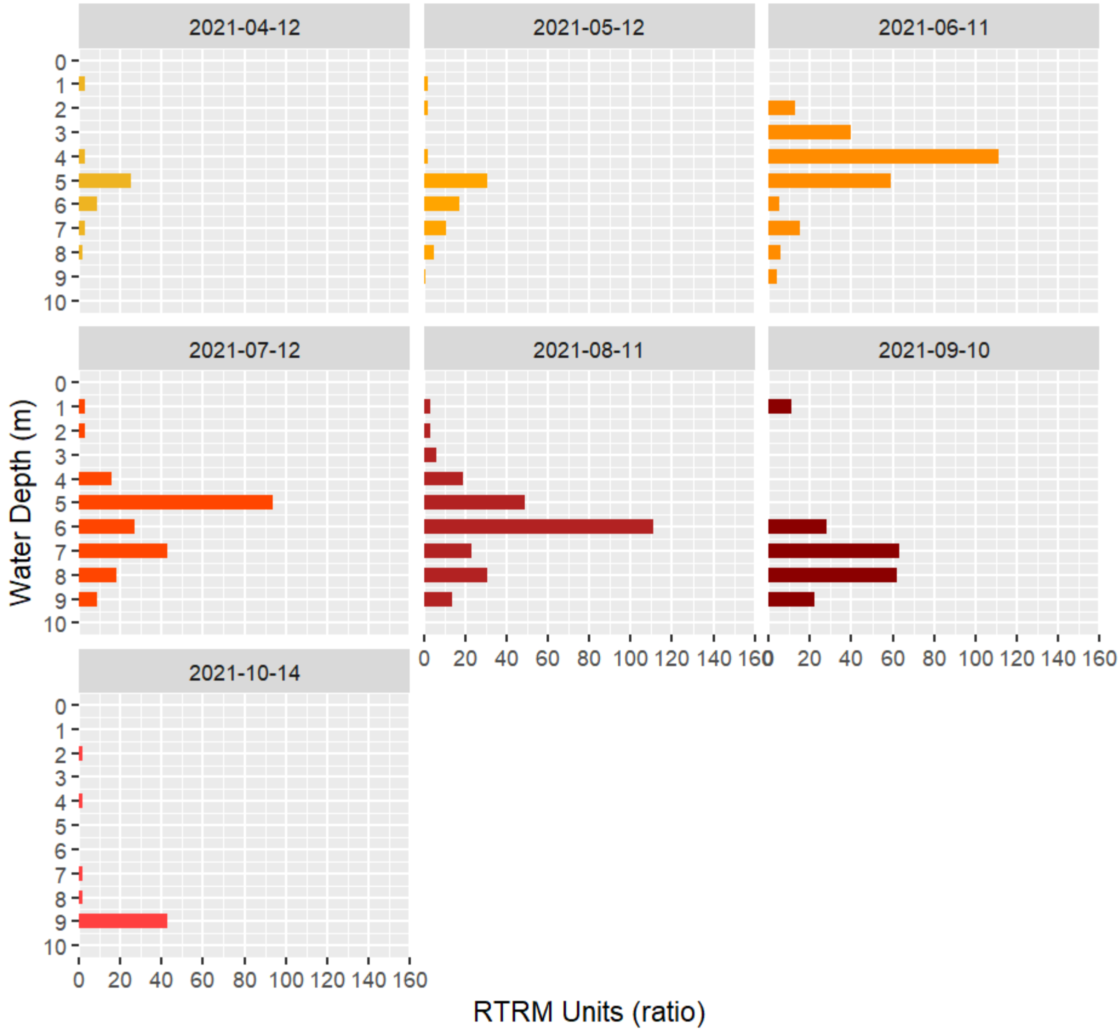


Figure 5. Relative Thermal Resistance to Mixing (RTRM) at Station 1 in Lake Oscawana during 2021.

The impact of warmer air temperatures differs from one lake to another, dependent on lake size, shape, and clarity of the water; tracking RTRM over time helps to quantify impacts of climate change on lake stratification and potential implications for bottom-water oxygen loss and internal recycling of nutrients that fuel algae blooms. As part of the 2020 data analysis, we revisited the historical 2006-2020 RTRM data, but no alarming trends were observed at that time. Little change in Lake Oscawana RTRM data may indicate that the lake is less impacted by warming air temperatures and climate change than some other northeast regional waterbodies. More frequent temperature data, using the suggested data loggers, would better track potential impacts of climate change on water quality. At present there is some natural variability in surface water temperatures over time due to the time of day that sampling has taken place over the last two decades.

Dissolved Oxygen

Dissolved oxygen profiles from Lake Oscawana in 2021 are shown for Station 1 in **Figure 6** and Stations 2 and 3 in **Figure 7**. Surface water dissolved oxygen concentration declined as the season progressed due to loss of saturation of the warmer water. Water deeper than the bottom of the epilimnion depth, 3-8 meters depending on the date, experienced severe dissolved oxygen loss. An anoxic boundary formed shortly after May 12th and persisted through to our last visit of the season on October 13th when water below 7.5m was anoxic. Raw profile data tables from 2021 are included at the end of this monitoring report.

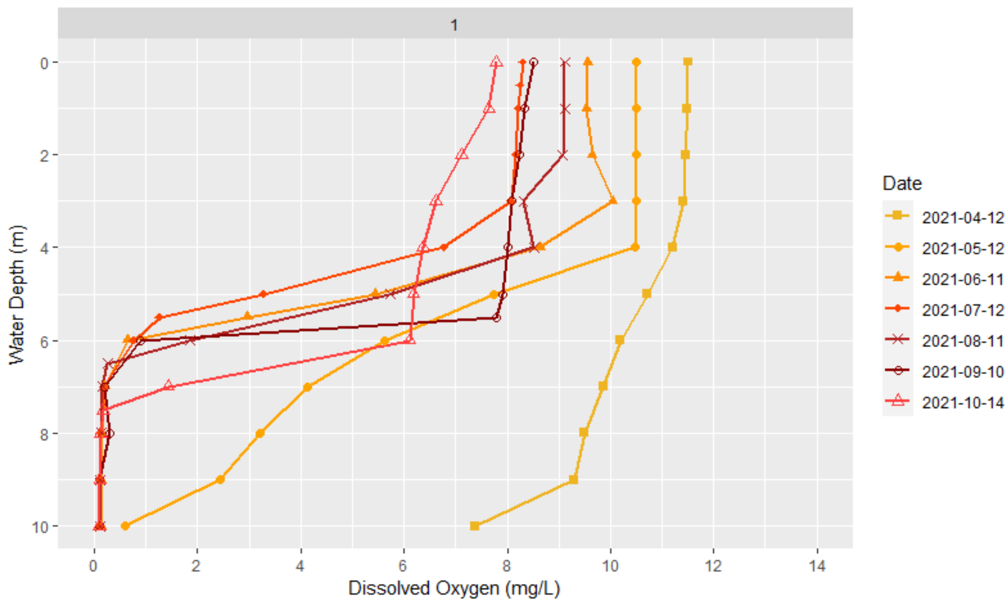


Figure 6. 2021 Dissolved Oxygen profiles from Station 1

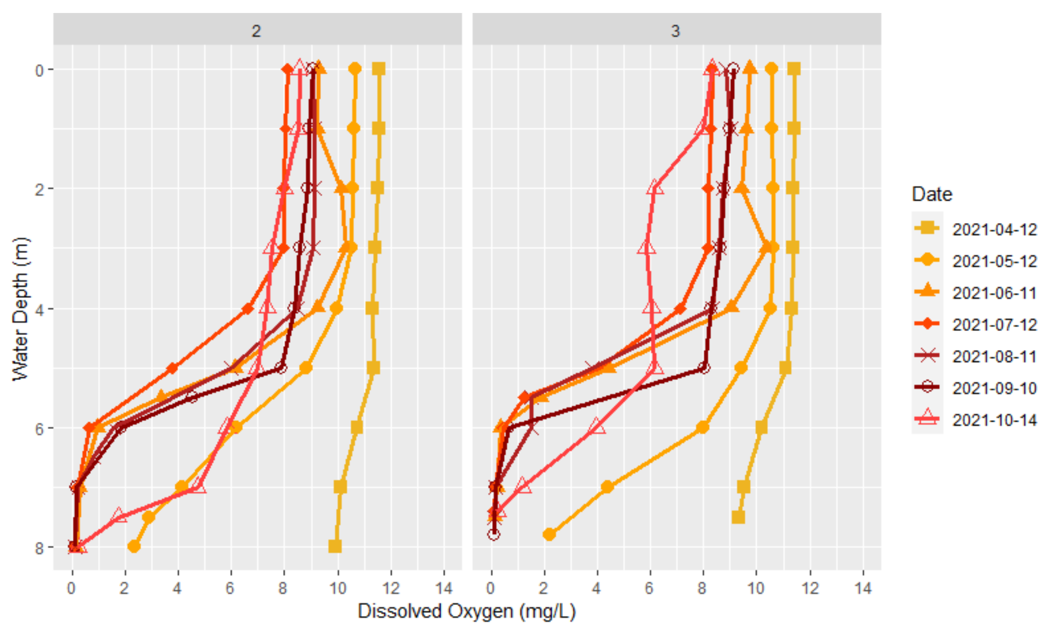


Figure 7. 2021 Dissolved Oxygen profiles from Station 2 & 3

The anoxic boundary followed the stratification of the lake in 2021 (**Figure 8**). Beginning in May when the first strong thermal boundary formed at 5 meters, water at that depth started losing dissolved oxygen. For the rest of the season the anoxic boundary was at or immediately below the depth of maximum RTRM value, until October when the anoxic boundary was 2 meters above the depth of maximum RTRM. The seasonal maximum ascent depth was 5.77m below the surface, slightly higher in the water column than the 5.81m seasonal 2020 peak. This value is only slightly above the target threshold of 6.0m. When the thermocline erodes in autumn, there is frequently a pulse of high nutrients brought from deep waters to the surface waters. This can stimulate fall algae and sometimes cyanobacteria blooms, as were seen in November 2021.

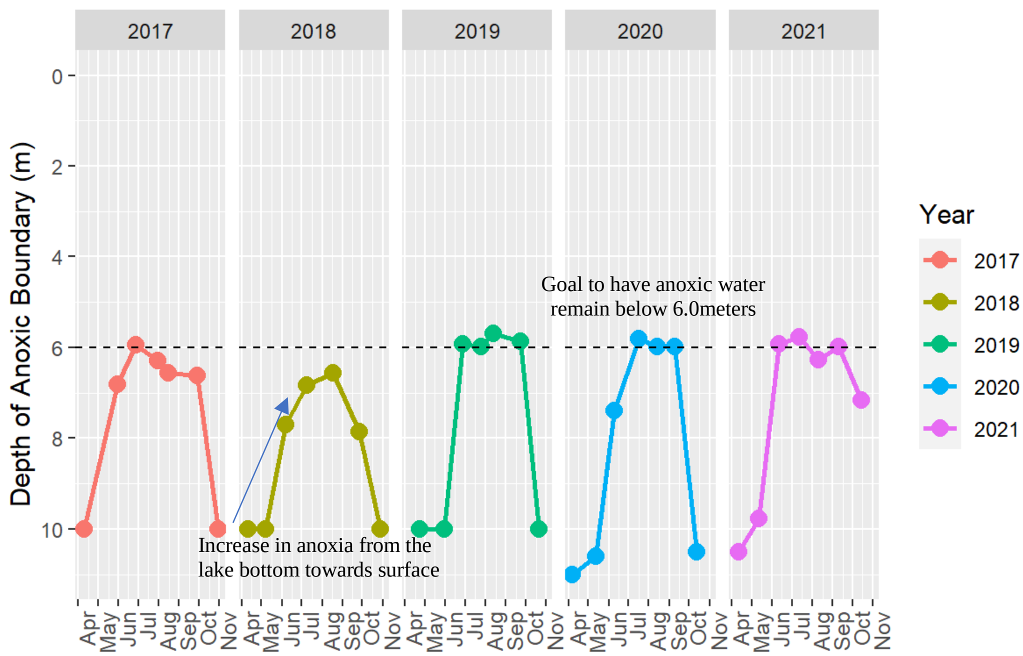


Figure 8. Seasonal Anoxic Boundary Pattern at Station 1 2017-2021

Dissolved oxygen isopleth interpolated values are shown in **Figure 9**, which also visualizes the ascent of the anoxic boundary (in red = 0 mg/L dissolved oxygen). The color scale from red to blue indicates the quantity of measured dissolved oxygen in the water column from 0-12mg/L across the various sampling depths and dates.

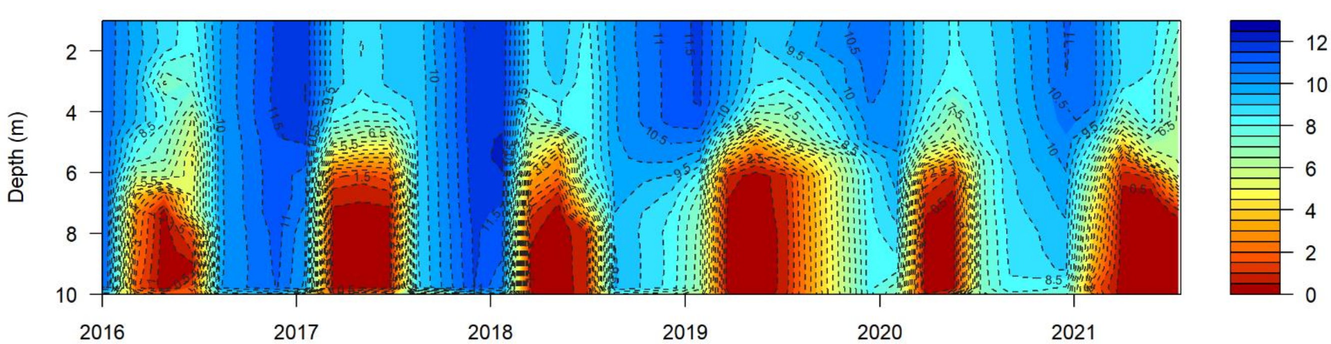
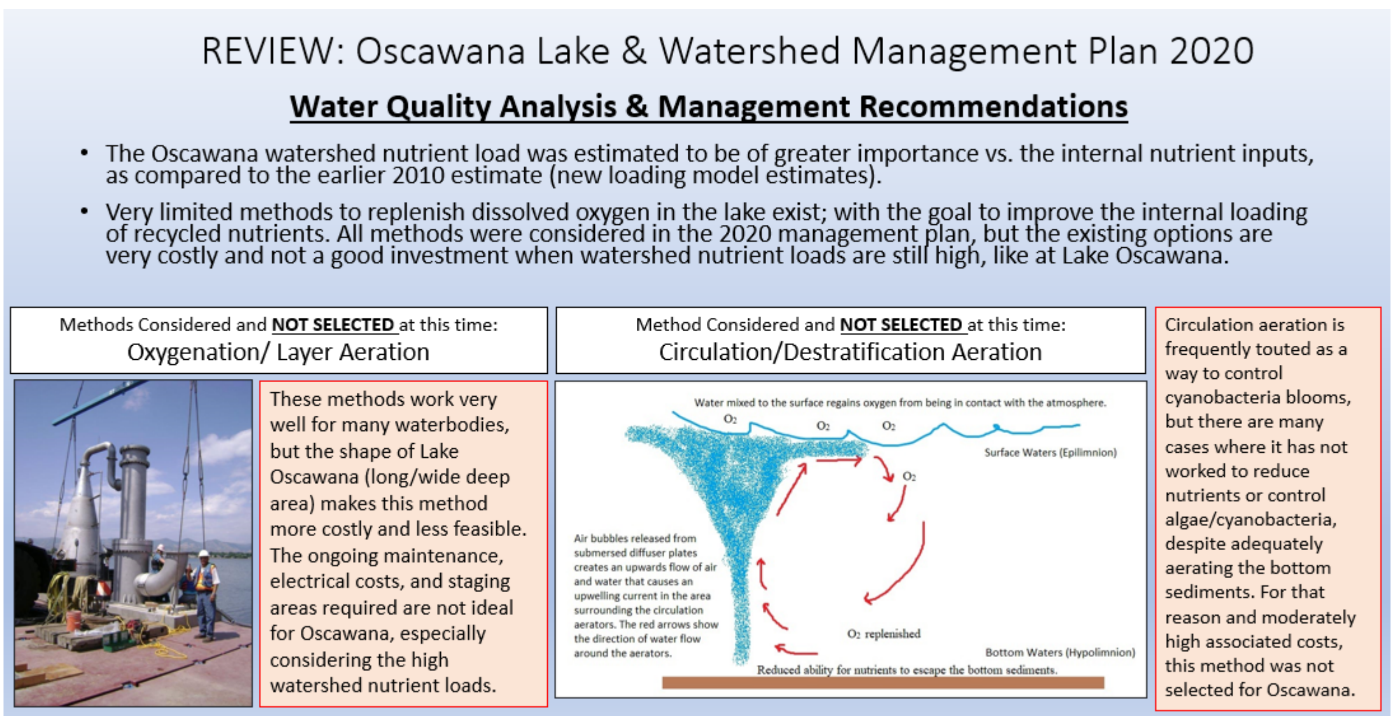


Figure 9. Historical Dissolved Oxygen (mg/L) Isopleth Model

As stated in the 2020 Lake Oscawana Management Plan, the data suggests that summer anoxia has not been the main driver of overall lake nutrients or water clarity in recent years, particularly in the summer months. For this reason, no recommendations were made to aerate or oxygenate the lake in the near future. Bottom-water oxygen loss is a natural process that occurs seasonally in temperate lakes. The level of oxygen loss at Oscawana has remained relatively consistent for over two decades and does not present a near-term threat to lake ecology. To reiterate, the long-term goal for anoxia at Oscawana is to maintain oxygen greater than 1.0mg/L at 6m for the entire season, with more than 6mg/L dissolved oxygen in water shallower than 6m. The long wind-fetch at Oscawana helps replenish dissolved oxygen naturally, through large lake mixing events in the surface waters.

Although the loss of dissolved oxygen in bottom waters does increase the amount of sediment-derived nutrients (internal loading of nutrients), an aeration system is not guaranteed to solve that problem and, in some cases, an upwelling type of aeration could even make the nutrient release issue worse. Please refer to the 2020 Lake Oscawana Management Plan and public presentation for more information about various options that were previously considered. Slide excerpts, modified from the 2021 public presentation, are included below as a review of which oxygenation and aeration methods were previously reviewed and deemed not suitable for Lake Oscawana at present (**Figure 10)**.

Figure 10. Recommendations & Reasoning Regarding Aeration & Oxygenation (Modified slide from 2021 Public Presentation)



Nutrients

Phosphorus

The Total Phosphorus (TP) concentration at Lake Oscawana should remain below 20 µg/L in the surface waters for the entire season in order to minimize the likelihood of harmful cyanobacteria (blue-green algae) blooms. The 2021 TP in surface waters across all three sampling stations was elevated from August through October. Earlier in the year, in June 2021, there was a considerable difference in surface TP across the three sampling stations; Station 3 in the south exhibited the highest value. We do not have a good explanation for the substantial difference between stations on this sampling date at this time, but increases in TP at this time of year are not related to internal sediment nutrient releases. Raw nutrient data values are included at the end of this report.

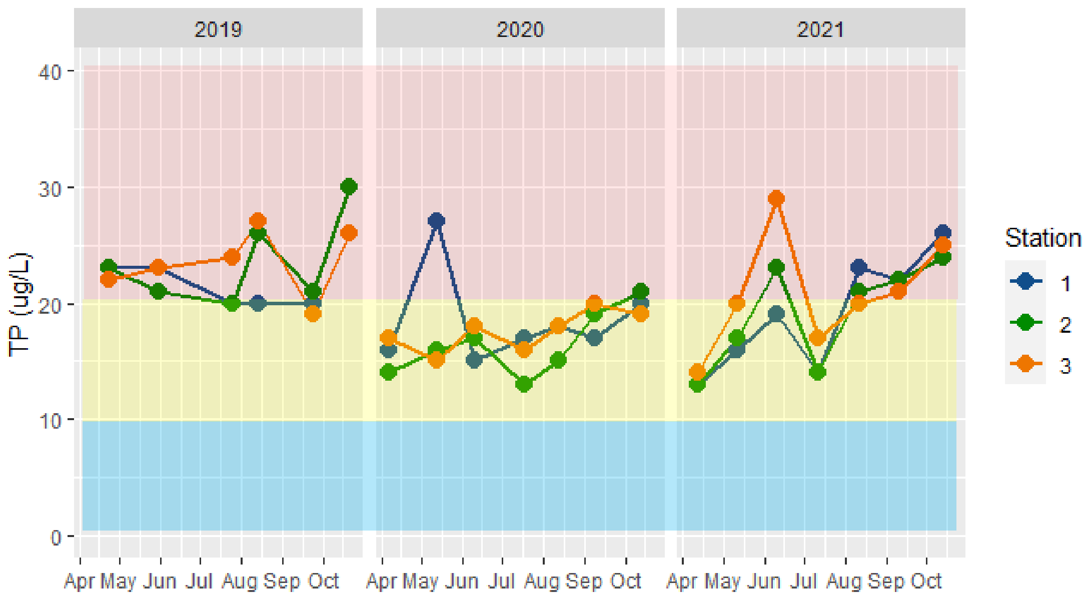


Figure 11. Surface (1m) Total Phosphorus 2019-2021 at all stations

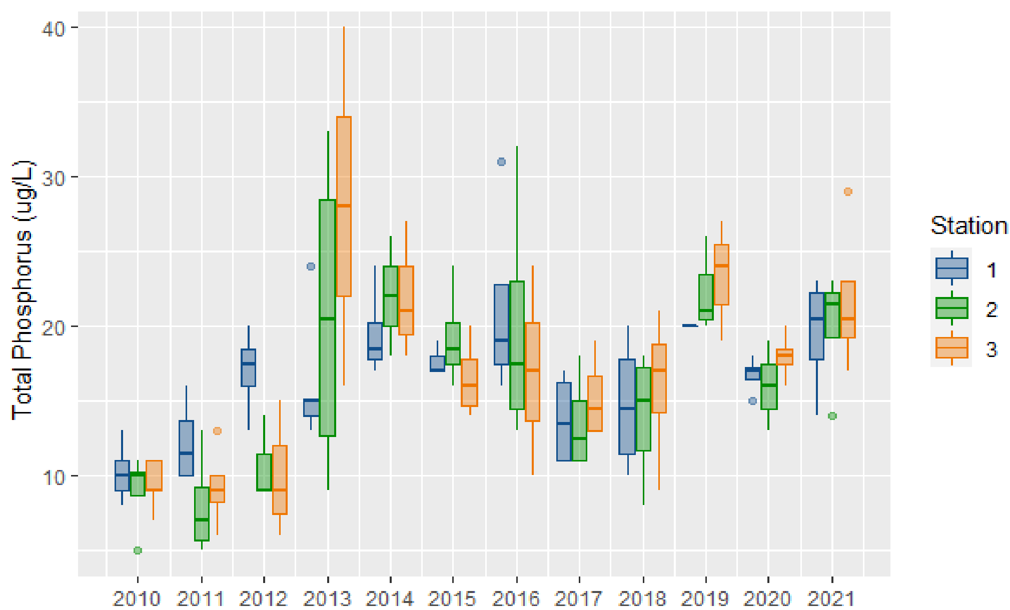


Figure 12. Long-Term Surface Water Total Phosphorus (St.1, 2, & 3)

In **Figure 13** below, the dotted line shows the monthly average bottom-water phosphorus concentrations between 2014 and 2019, from 9-meters at Station 1, and 7-meters at Stations 2 and 3. The 2020 concentrations, indicated by squares were consistent with the 2014-2019 averages each month. The 2021 values, marked as triangles, show significantly higher TP concentration in August and September at Station 1. The increase in bottom TP was also noted at Station 2 in September but not at Station 3. In fact, Station 3 showed lower than average TP in bottom water July and August. Recall that Station 1 values are normally much higher than bottom phosphorus at Stations 2 and 3 because the Station 1 sampling point is deeper (hence **Figures 13A** and **13B** use difference vertical axis scales). Oscawana was not sampled in November 2021.

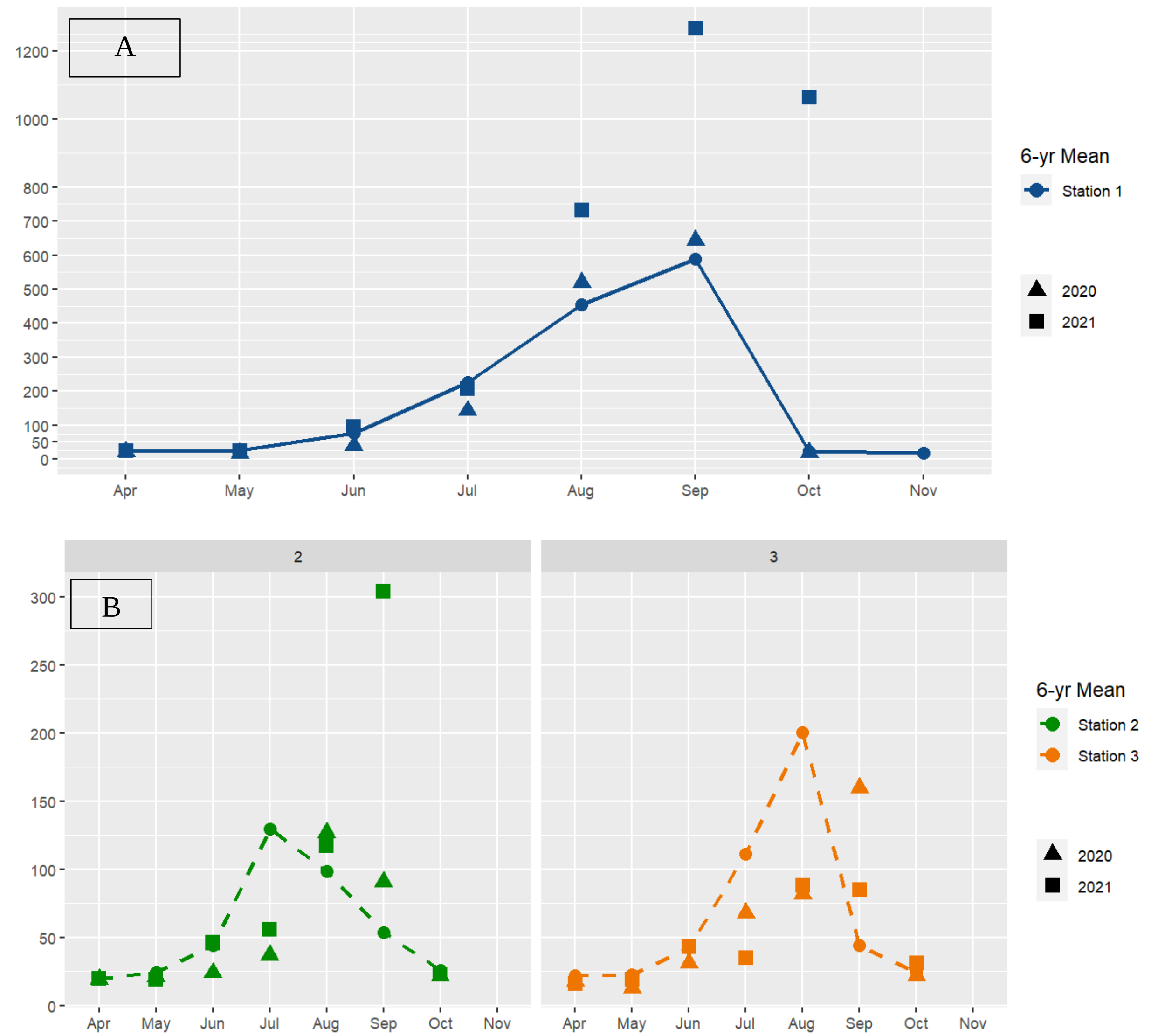


Figure 13. Station 1 (A) & Station 2 & 3 (B) Bottom Total Phosphorus (2014-2019 Mean vs. 2020 & 2021)

To reiterate key findings stated in the 2020 Lake Oscawana Management Plan: high levels of bottom phosphorus are related to internal loading during periods of anoxia. Yet, the lake's internal load does not appear to be the primary driver of water quality every year. For that reason, **management should focus on aquatic plants and watershed improvements before attempting to control the internal load**. If cyanobacteria blooms were to become more common in future years, it would be appropriate to revisit the methods available to mitigate internal loading or to bind water column phosphorus to temporarily restrict blooms. Various methods have been reviewed, in both the 2020 Lake Management Plan, and also in public presentations and discussions with LOMAC.

Nitrogen

Nitrogen is the secondary principal plant and algae nutrient in lakes. The average surface total nitrogen (TN) concentration in 2020 was similar at each of the three stations. The average of all surface samples from the three stations during 2020 was 269 µg/L, below a 300 µg/L target threshold for all but two Station 1 samples. The average of all surface samples from the three stations in 2021 was 300 µg/L. However, in 2021 TN concentration continued to increase during September and October to reach maximum seasonal concentration of ~400 µg/L in October. These moderately high concentrations were a result of the release of ammonia from anoxic sediments during the period of greatest anoxia. Overall, the 2021 surface water TN concentrations remained below the target water quality threshold until late summer to fall (**Figure 14**). Ammonia nitrogen, an inorganic available form of nitrogen, was measured in bottom-water only. Bottom nutrients are compared in **Figure 15** and demonstrate the cause of the simultaneous increase in surface total nitrogen.

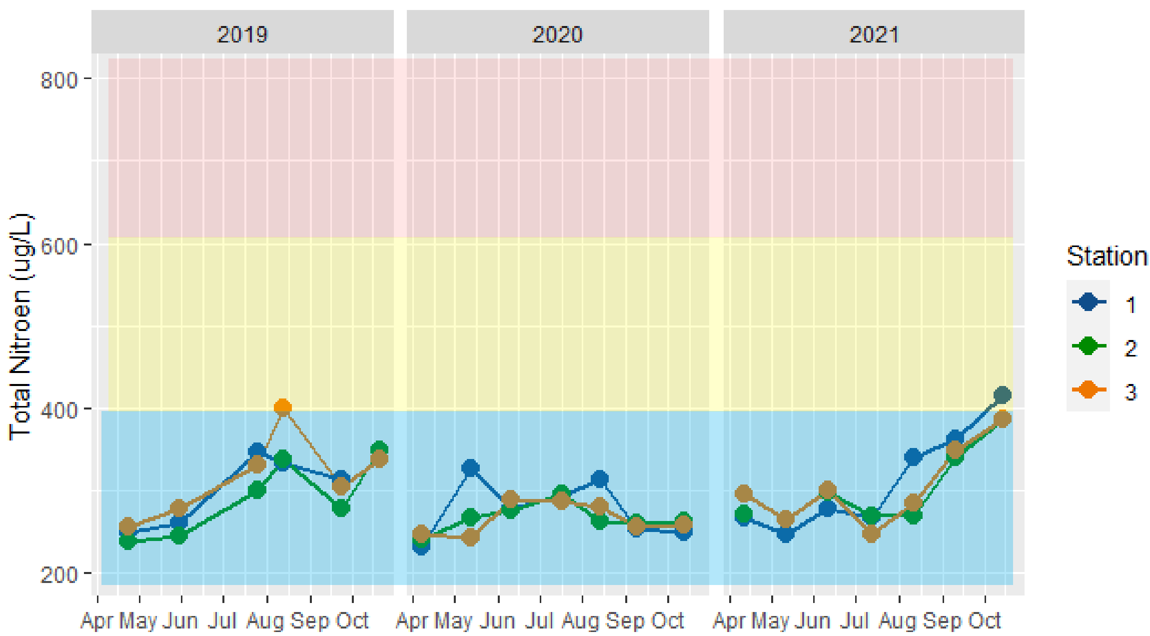


Figure 14. Surface total nitrogen 2019- 2021 at all stations

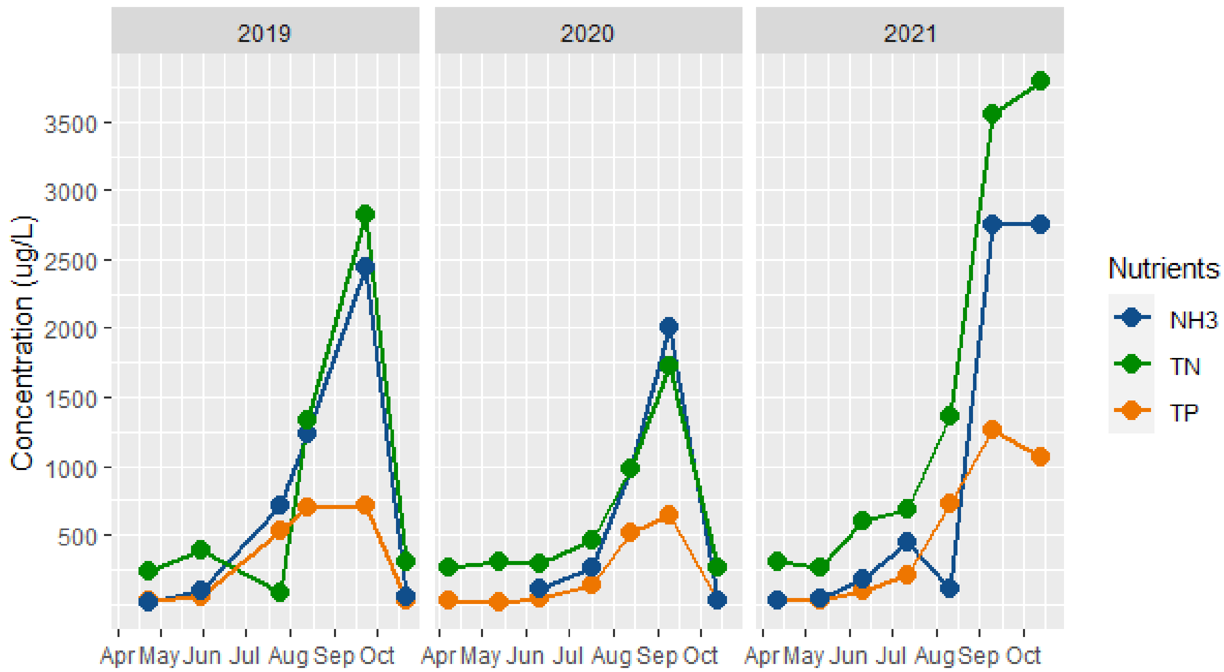


Figure 15. Station 1: 2019-2021 Bottom-water (~9-10m) Nutrients: Ammonia Nitrogen (NH_3), Total Nitrogen (TN), & Total Phosphorus (TP)

Inlet Nutrient & Bacteria Data

The 2021 seasonal inlet nutrient concentrations are displayed in **Tables 1 & 2,** which also displays the data results from 2020, for comparison. Blank cells indicate that no sample was collected. Inlet 6, on the west shore, is no longer accessible without crossing through developed property, and we would like written homeowner approval to cross through the two private residences to access this sampling location from now on. All other inlets were sampled in April, May, and June, which are typically the months with the highest volume of water flow in the watershed. The 2021 approved scope of work budgeted for just three months of all inlets monitoring, in order to allocate funds to other monitoring and consulting needs in 2021. Inlet 4, and a new monitoring site above the long-term Inlet 4 monitoring station (41.380628, -73.857156), were both sampled in August, September, and October. NEAR staff met with the Town of Putnam Valley building inspector to ensure adequate access off Sunset Hill Rd, between Cedar Ledges and Lee Ave (**Photo 1, Map 1**).

Nitrogen concentrations of >1000 μg/L are concerning, especially for stormwater events. Generally, the 2021 baseflow samplings for all inlets was moderate and within range of historical values. Baseflow TP concentrations above the 75th percentile of all historical measurements are highlighted in red (for both 2020 and 2021 data). The range of historical TP values is graphed in **Figure 16**. The same summary statistics are not valid for TN because nitrogen measurements only began in 2018 and there are not yet enough data points.

*Table 1. Inlet **total phosphorus (TP)** concentrations (μg/L) in 2021 (compared to 2020).*

Date	Weather	Inlet 1	Inlet 2	Inlet 3	Inlet 4	Upstream Inlet 4	Inlet 5	Inlet 6	Inlet 7
4/12/21	Baseflow	12	13	40	27		13	NA	20
5/12/21	Baseflow	16	22	16	78		20		19
6/11/21	Baseflow	19	44	38	97		21		37
8/12/21	Baseflow				173	955			
9/10/21	Baseflow				56	284			
10/14/21	Baseflow				68	961			
4/9/20	Baseflow	11	24	19	50		10	12	25
5/15/20	Baseflow	15	27	28	62		14		38
6/11/20	Moderate Rain			120	776				950

*Table 2 Inlets **total nitrogen (TN)** concentrations (μg/L) in 2021 (compared to 2020)*

	Weather	Inlet 1	Inlet 2	Inlet 3	Inlet 4	Upstream Inlet 4	Inlet 5	Inlet 6	Inlet 7
4/12/21	Baseflow	No samples tested for TN on this date (COC error)							
5/12/21	Baseflow	291	209	515	2275		99	NA	683
6/11/21	Baseflow	400	380	836	1745		137		618
8/12/21	Baseflow				1041	4685			
9/10/21	Baseflow				4130	4382			
10/14/21	Baseflow				2284	5333			
4/9/20	Dry/Baseflow	215	200	533	2587		105	32	851
5/15/20	Dry/Baseflow	251	203	433	2275		108		796
6/11/20	Moderate Rain			1121	2210				1247

NA = Not Accessible; we need written homeowner permission to access Inlet 6 from private property from now on.

The range of values across all sampling years is displayed in the boxplots below.

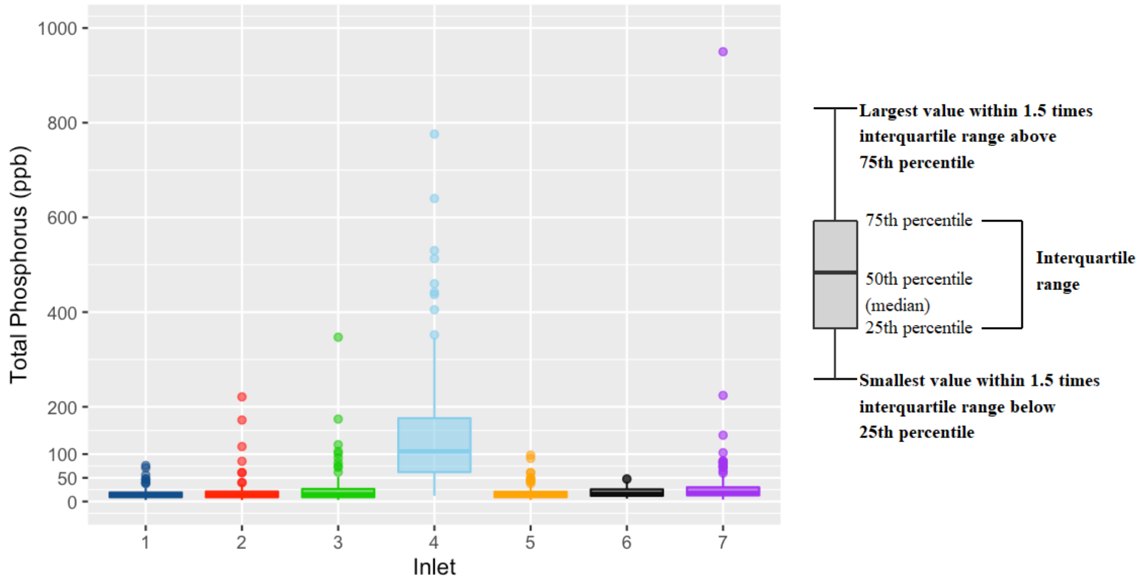
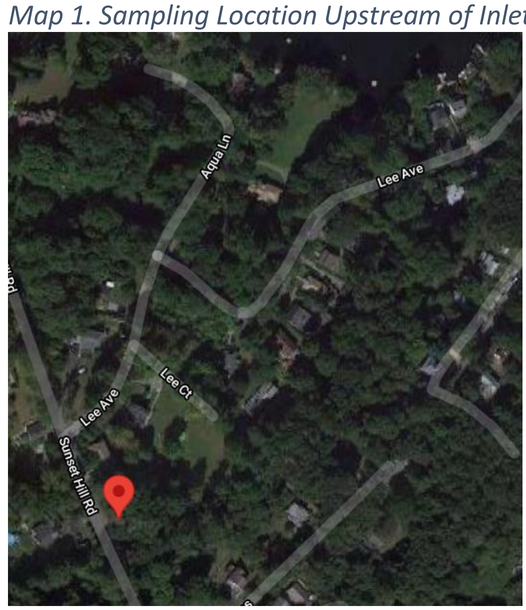


Figure 16. Historical range (1994-1997, 1999-2020) of inlet total phosphorus (µg/L) concentrations

Photo 1. Sampling Location Upstream of Inlet 4

Map 1. Sampling Location Upstream of Inlet 4



The water flow that feeds Inlet 4 is primarily from groundwater seepage. However, 2021 was the first year that water flowing from an under-road culvert was sampled, upstream of Inlet 4. It is not clear where the water in the culvert comes from and it may be illicit groundwater discharge, either directly or indirectly, to the Town Municipal Separate Storm Sewer System (MS4). The culvert likely picks up groundwater for road drainage purposes, or it may unintentionally pick up groundwater through catch basin leaks or faulty underground piping connections.

In addition to the nutrients sampling, Escherichia coli (E. coli) bacteria testing was done in August and October. Samples are collected in-situ by NEAR staff in sterile bottles (provided by the lab) and are delivered to EnviroTest Laboratories, Inc. NEAR reported the high results from the August and October Inlet 4 (upstream and downstream of the private pond) in a draft letter sent to LOMAC, addressed to the Putnam County Health Department on October 29, 2021. All E. coli bacteria test results are displayed in (Table 3) below.

The concentrations from the site upstream of Inlet 4 were consistently higher in both nutrients and E. coli. Both the very high Total Nitrogen (**Table 2**) and high E. coli (**Table 3**) from this pipe indicate that there is a wastewater contamination problem from higher up in the Oscawana watershed than was originally expected. It is still plausible that the Lee Ave homes contribute to elevated groundwater nutrients from onsite wastewater, but it appears that the Inlet 4 issue extends further than previously thought, to homes on and uphill of Sunset Hill Rd. The latitude and longitude coordinates of the bacteria sampling locations are included in the table below, to ensure adequate record keeping.

The Putnam County Department of Health has since initiated further inspections into the Inlet 4 upstream potential onsite wastewater contamination issue, and has used the E. coli data to formally track illegal septic leakage that is harming Lake Oscawana and public health.

Table 3. All 2021 E. coli samples (Colony Forming Units/100mL)

All baseflow samples	Inlet 3 (41.395986, -73.842008)	Inlet 3 Upstream (41.397151, -73.833317)	Inlet 4 (41.38173, -73.8564)	Inlet 4 Upstream (41.389485, -73.840989)	Inlet 7 (41.38962, -73.84326)	Inlet 7 Upstream (41.389485, -73.840989)
4/12/2021	11	Not sampled	16	Not sampled	66	
5/12/2021	4	Not sampled	96	Not sampled	38	< 1
6/11/2021	73	30	99	Not sampled	48	64
8/12/2021	Not sampled	Not sampled	330	>2419.6	Not sampled	Not sampled
9/10/2021	Not sampled	Not sampled	64	>2419.6	Not sampled	Not sampled
10/14/2021	Not sampled	Not sampled	7.4	>2419.6	Not sampled	Not sampled
4/22/2022	Not sampled	10	20	87000	20	Not sampled

All results were reported in spreadsheet format to Putnam County Department of Health

Table 4. Inlets Bacteria Test Results 2020

Date	Weather	Inlet #	Fecal Coliform	E.coli
4/8/20	Dry/Baseflow	7	120	250
4/8/20	Dry/Baseflow	4	170	260
4/9/20	Dry/Baseflow	7	240	340
4/9/20	Dry/Baseflow	4	140	96
4/9/20	Dry/Baseflow	3	<10	20
5/15/20	Dry/Baseflow	7	420	150
5/15/20	Dry/Baseflow	4	31	85
5/15/20	Dry/Baseflow	3	41	10
6/11/20	Moderate Rain	3	230	410
6/11/20	Moderate Rain	7	6,100	7,300
6/11/20	Moderate Rain	4	87,000	58,000
Units for Fecal Coliform are Most Probable Number of Viable Cells (MPN) per 100mL of sample water. Units for E. coli are Colony Forming Units (CFU) per 100mL sample water.				

Plankton

Zooplankton

Zooplankton are the tiny animals that live in open water. Phytoplankton are the microscopic plants that live in the water column. Together, plankton serve as the base of the food chain and are related to everything from water clarity to fisheries populations. Zooplankton are monitored at Lake Oscawana on a monthly basis from one location (Station 1, deep area). The 2019 monitoring program experimented with two monitoring stations, but it was determined that the information gleaned was relatively similar and that one station was appropriate for the purposes of Oscawana's management.

For many years, the zooplankton assemblage has been dominated by small Rotifers and lacked large-bodied Cladocerans, like *Daphnia*. *Daphnia* numbers are still low, but there does appear to be a small increase in Cladoceran and Copepod numbers compared to the last ten years. Copepod numbers were lower in 2021 than 2018-2020. **Figure 17** shows the animals per liter for each major group of zooplankton in 2019-2021. The Rotifer assemblage is known to have booms and busts in population, and the Oscawana monitoring program usually captures at least one peak and one low period. Maximum seasonal zooplankton counts from 2016-2021 are recorded in **Table 5**.

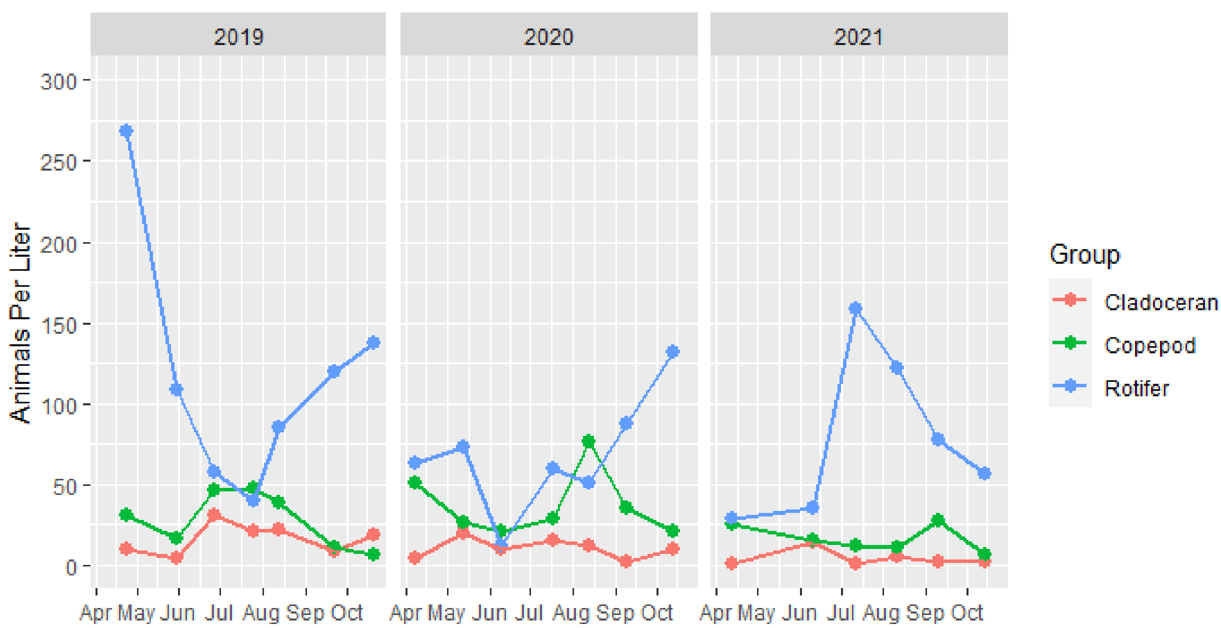


Figure 17. Station 1 Zooplankton densities in 2019-2021

Table 5. Annual Maximum Zooplankton Densities 2016-2021

Type	2016	2017	2018	2019	2020	2021
Cladoceran	16	24	8	31	20	14
Copepod	13	10	56	50	76	27
Rotifer	>500	120	170	270	87	158

The most dominant Cladocerans in 2020, and again in 2021, were small-bodied *Bosmina* and *Cerodaphnia,* there were few *Daphnia* over 0.6mm. Most zooplankton were less than 0.6mm across the 2020 and 2021 seasons. As in previous years, there were very few Calanoid Copepods in 2020 and 2021. There were overall fewer *Daphnia* observed throughout the 2021 season, and fewer Cladocerans in general. Monthly zooplankton samples from a single station are not a of high enough resolution to detect frequent population changes of the zooplankton assemblage of the lake. These samples are meant to pick up on dramatic zooplankton-related ecological problems, like the complete absence of *Daphnia* thoughout an entire season, or a zooplankton assemblage that is completely dominated with Rotifers, or simply if little to no zooplankton are even present. These types of results would prompt further investigation.

The Oscawana fishery was surveyed in 2019 and was deemed to be suitable. The bass population of Oscawana was good at that time, but walleye populations were low. This fisheries study, combined with the years of zooplankton data indicate that walleye stocking that begin circa 2001 has not worked to improve water quality through 'biomanipulation,' a technique once thought to be beneficial to water quality. Recent case studies in NY indicate that the level of walleye stocking needed to achieve biomaniupulation in Oscawana is not finanially feasible and that the technique is not best suited for lakes like Oscawana, which have a relatively large shallow-water littoral zone compared to vast deeper open-water area.

Please refer to the 2019 annual report for details regarding the Oscawana electro-shocking study and fisheries results. There is no plan to repeat the electroshocking survey in 2022.

Zooplankton size class data figures are included in the Appendix.

Phytoplankton

Phytoplankton are the plant-like microscopic organisms that are freely living in the water column and can make the water have a green or brown tint and obscure water clarity. Phytoplankton use sunlight for photosynthesis and serve as the base of the food chain and require constant supply of phosphorus and nitrogen for growth.

Total phytoplankton counts (cells/mL) by group for 2021 and 2020 are displayed in **Table 6**, below. Cyanobacteria, or blue-green algae, can form Harmful Algal Blooms (cyanoHABs) in the presence of high nutrients and calm water. Cyanobacteria prefer late summer and sometimes bloom in the fall, depending on lake temperatures and water density gradients. Oscawana does not have frequent and widespread cyanobacteria blooms every year, primarily because nutrient concentrations remain low enough to prevent dense blooms. Dense surface and shoreline accumulations are more generally common when total phosphorus exceeds 20 ppb (μg/L) in surface waters.

Table 6. A) Phytoplankton Algae Total Cells/mL by Group 2021, B) compared to 2020

A) 2021	**4/12/2021**	**4/28/2021**	**5/12/2021**	**6/11/2021**	**7/12/2021**	**8/11/2021**	**9/10/2021**	**10/14/2021**
Cyanobacteria	4,927	6,531	466	379	3,557	10,262	56,647	77,114
Green algae	0	933	146	321	175	0	87	0
Diatoms	4,344	379	4,315	1,720	583	525	525	2,478
Chrysophytes	641	3,061	233	321	0	0	0	0
Dinoflagellates	0	0	0	29	0	0	0	0
Euglenophytes	0	0	0	0	0	0	0	0

B) 2020	**4/7/20**	**5/13/20**	**6/10/20**	**7/17/20**	**8/13/20**	**9/9/20**	**10/13/20**
Cyanobacteria	8,455	612	0	6,560	2,187	136,565	40,408
Green algae	175	1,224	1,691	1,341	437	4,932	1,224
Diatoms	5,248	6,472	1,895	408	29	2,891	7,755
Chrysophytes	437	204	437	233	15	4,252	204
Dinoflagellates	0	0	0	58	0	0	0
Euglenophytes	0	0	0	0	0	340	0

The most abundant types of phytoplankton are consistently Cyanobacteria, Diatoms, Green algae in both 2020 and 2021. Green algae and Diatoms tend to be most abundant in spring and fall. Despite high cyanobacteria cell counts in September 2020, water clarity remained moderately good, and these high cell counts did not constitute "bloom" conditions based on visual observations. There were no shoreline scums observed in 2020.

In 2021, the cyanobacteria cell counts in open water during sampling months were highest in October, and counts appeared to continue increasing towards the end of the fall after lake thermal 'turn-over' occurred. The EPA generally recommends caution, when cyanobacteria cell counts begin to reach over 70,000 cells/mL in open water, but the chance of a shoreline cyanoHABs depends heavily on which type of cyanobacteria dominates.

In the northeast, it is more likely that larger-celled and larger colonies types in the *Dolichospermum* or *Microcystis* genus will form surface blooms and produce cyanotoxins. The NYDEC and EPA have considerable public information regarding HABs.

There were cyanobacteria surface blooms documented in November 2021. We do not normally sample open-water conditions during November, so we unfortunately did not have Station 1 phytoplankton cell counts or water quality data to pair with the shoreline cyanobacteria blooms that were noted. We did explain to LOMAC, however, that late-season cyanobacteria blooms are often caused by a combination of fall lake 'over-turn' brining bottom-water and sediment-derived nutrients to the surface. Prolonged periods of calm winds and warm late fall temperatures makes cyanobacteria blooms more likely.

Table 7. A) Cyanobacteria (Blue-green algae) by Genus Counts Per Month 2021 & B) 2020

A) 2021	4/12/2021	4/28/2021	5/12/2021	6/11/2021	7/12/2021	8/11/2021	9/10/2021	10/14/2021
Dolichospermum	0	117	0	0	1,953	1,749	1,020	0
Chrysosporum	262	3,499	350	0	1,458	0	36,968	43,294
Planktothrix	4,665	0	0	0	0	0	0	9,329
Planktolyngbya	0	2,915	0	0	0	7,464	18,659	24,490
Chroococcus	0	0	117	379	146	1,050	0	0
Totals	**4,927**	**6,531**	**466**	**379**	**3,557**	**10,262**	**56,647**	**77,114**

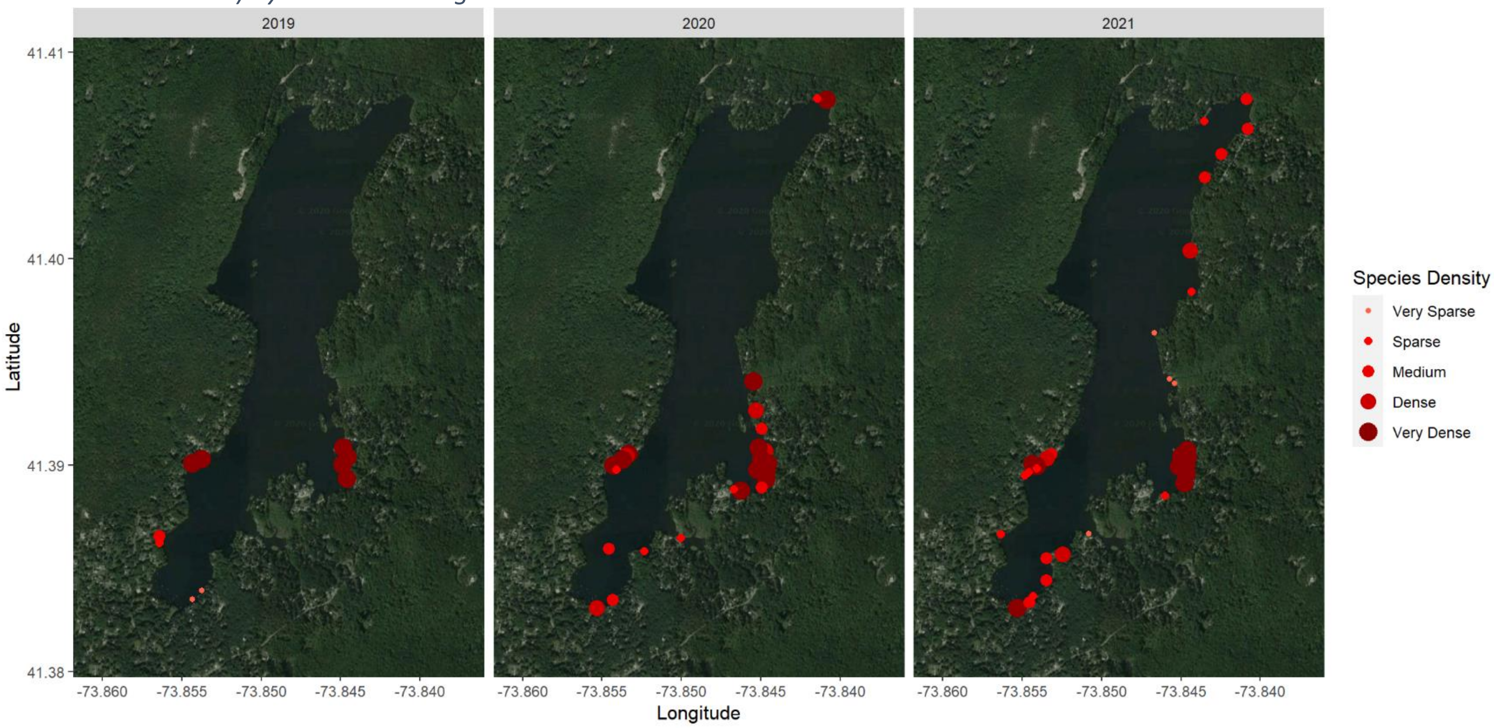
B) 2020	4/7/20	5/13/20	7/17/20	8/13/20	9/9/20	10/13/20
Dolichospermum	0	0	6,414	875	3,061	0
Chrysosporum	3,499	612	87	0	0	5,714
Planktothrix	3,790	0	0	0	133,503	22,449
Planktolyngbya	1,166	0	0	1,312	0	12,245
Chroococcus	0	0	58	0	0	0
Totals	**8,455**	**612**	**6,501**	**2,187**	**136,564**	**40,408**

Photo 2 November 2021 Cyanobacteria bloom near shore

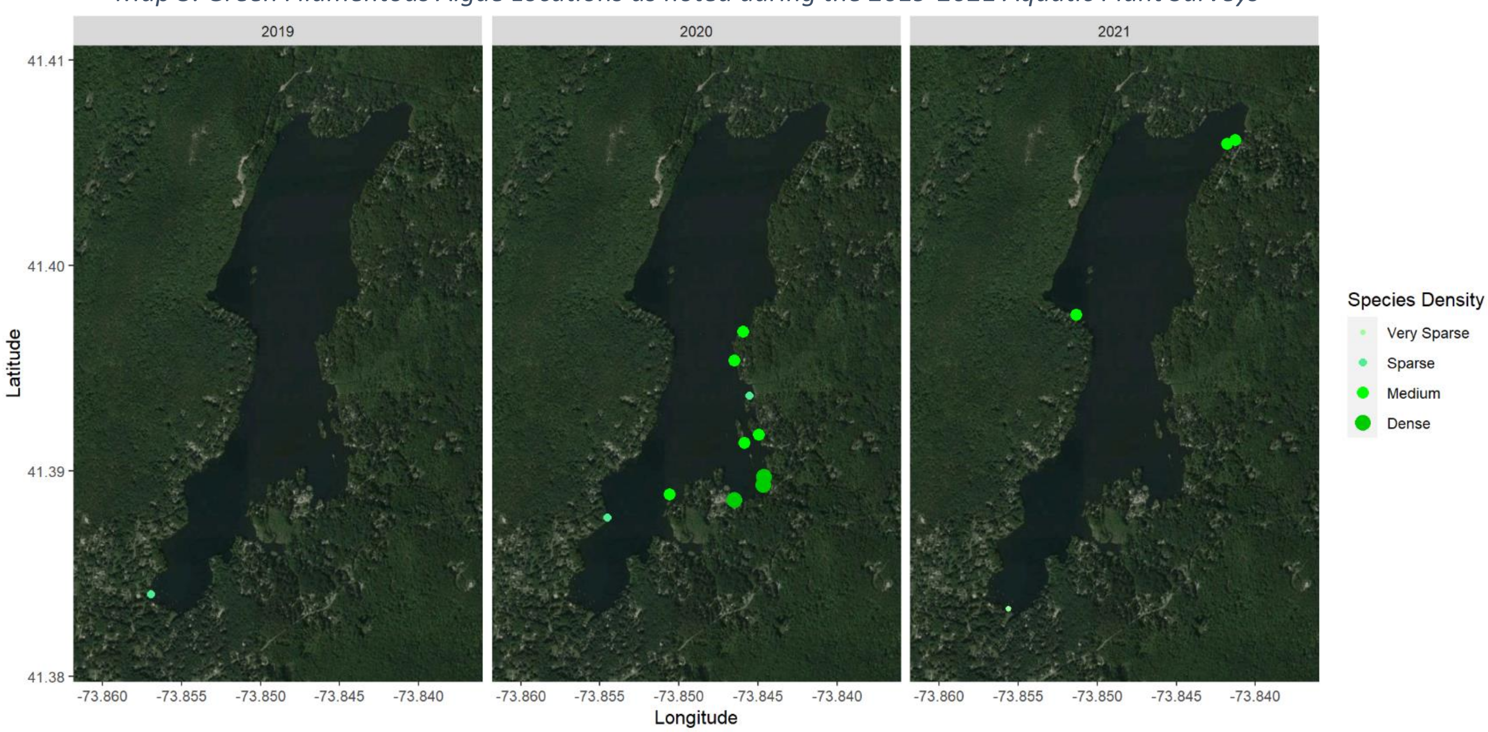
Lake Oscawana residents should be aware that cyanobacteria surface blooms are usually bright to dark green, but a shoreline scum may also appear blue or white. The blue and white coloring occurs as cells become sun-bleached and die. Toxins were not confirmed at the time of the photo, but may still be present in the water even if cells are visibly dead or dying. Residents and their pets should avoid contact with surface scums like in Photo 2. Please do not let your pet drink lake water, particularly if there are any

There are also non-phytoplankton types of algae in the lake. Filamentous green algae and filamentous cyanobacteria mats often grow in shoreline areas in Wildwood Cove, and to a lesser extent, in the northern coves and where Inlet 4 flows into the lake at the south end.

Map 2. 2019-2021 Comparison of Locations with Benthic (grows as a filamentous mat on top of the sediment) Cyanobacteria Algae

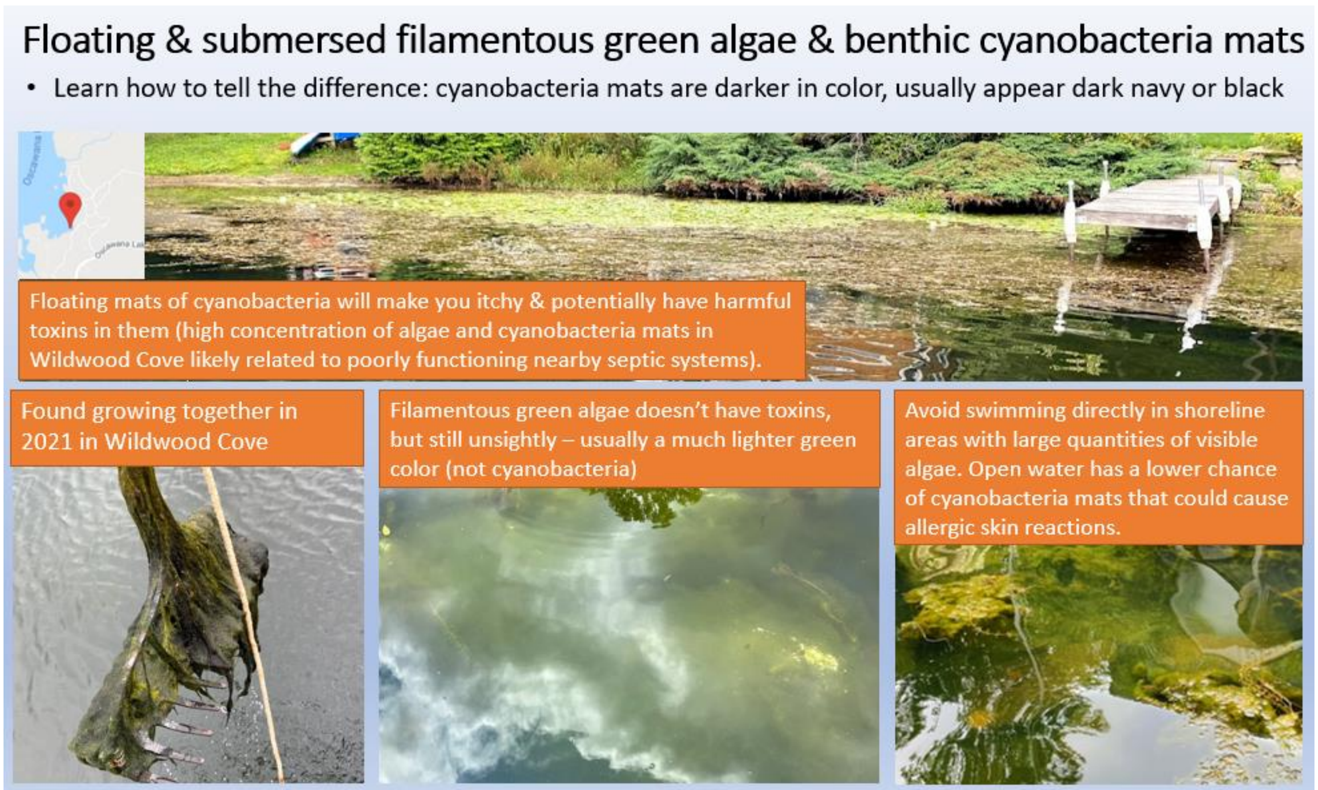


Map 3. Green Filamentous Algae Locations as noted during the 2019-2021 Aquatic Plant Surveys



During the 2021 public presentation, we discussed the importance of learning how to tell the difference between the lighter green filamentous algae blobs and the darker-colored filamentous cyanobacteria mats, which occasionally come to the surface as floating mats. Floating cyanobacteria mats have, to date, only been documented in Wildwood Cove. Cyanobacteria mats were most prevalent on the surface during the 2020 survey, presumably because the mechanical weed harvester also removes surface-growing filamentous cyanobacteria mats. Unfortunately, certain types of filamentous green algae are too slimy and slippery to be adequately removed by the mechanical harvester, but thankfully the light green slimy algae do not produce harmful toxins and are much less likely to cause skin rashes or other illness.

Figure 18. Filamentous Cyanobacteria Mats vs. Filamentous Green Algae (modified slide from presentation)



Aquatic Plant Management

Lake Oscawana was survyed for aquatic plants on August 9, 2021. Eurasian milfoil has continued to increase in frequency throughout the years, but was overall less dense in 2021 than in 2020, presumably a result of the active harvesting done in 2021.

As mentioned in the 2019 report, the 2016 conservative stocking of Grass carp had not affected the native Large-leaf pondweed *(Potamogeton amplifolius)* populations at that time. Large-leaf pondweed has consistently been the second most dominant plant in Oscawana since the early 2000s. The 2021 survey data, however, shows a slight decrease in the overall frequency of this native pondweed species. It is too early to tell if this decrease is notable or not.

The frequency and density of Robbin's pondweed (*Potamogeton robbinsii*) and Tapegrass *(Vallisneria americana*) had not changed considerably over the past eight years, but Robbin's pondweed was notably less frequent in 2020 and 2021. Coontail (*Ceratophyllum demersum*) was more frequent in 2021 than compared to the last few years. Coontail increases following grass-carp grazing are commonly noted. Tapegrass also appears to be more frequent in 2021 than in 2020, but that may also be attributed to the 2021 survey being performed several weeks later in the season in 2021. The 2020 aquatic plant survey was conducted on July 16th and 17th. Frequency and average density values for all species in 2019, 2020, and 2021 are compared in **Table 8**. Please note that the frequency data displayed in the 2020 annual report table was not correct. While the species relative dominance was correct, the percentages were inaccurately low. Somehow an error was made in the frequency calculations and the error was not caught prior to finalizing the 2020 report. We assure LOMAC that the values displayed below are accurate and have been tripple-checked. The frequencies were calculated using 306, 281, and 278 total waypoints from 2019, 2020, and 2021, respectively. The core 278 waypoints were the same each year, with several waypoints not revisited during the 2020 and 2021 surveys because they were too close to other points. The average density percentages in the 2020 table was correct and is redisplayed in **Table 8**, for all three years.

Table 8 Comparison of 2019, 2020, 2021 Plant Survey Data

2019				
Scientific Name	**Common Name**	**Year**	**Frequency %**	**Avg. Density %**
Myriophyllum spicatum	Eurasian Watermilfoil	2019	65	33
Potamogeton amplifolius	Largeleaf pondweed	2019	57	61
Nymphaea odorata	White Water Lily	2019	23	55
Vallisneria americana	Eel grass / Tapegrass	2019	18	52
Ceratophyllum demersum	Coontail	2019	11	33
Potamogeton robbinsii	Robbins Pondweed	2019	11	27
Lyngbya sp.	Cyanobacteria mats	2019	4	67
Sagittaria sp.	Grassy Arrowhead	2019	1	15
Spirogyra sp.	*Filamentous algae*	2019	<1	30
Brasenia schreberi	Watershield	2019	<1	15
Lemna sp.	Duckweed	2019	<1	NA

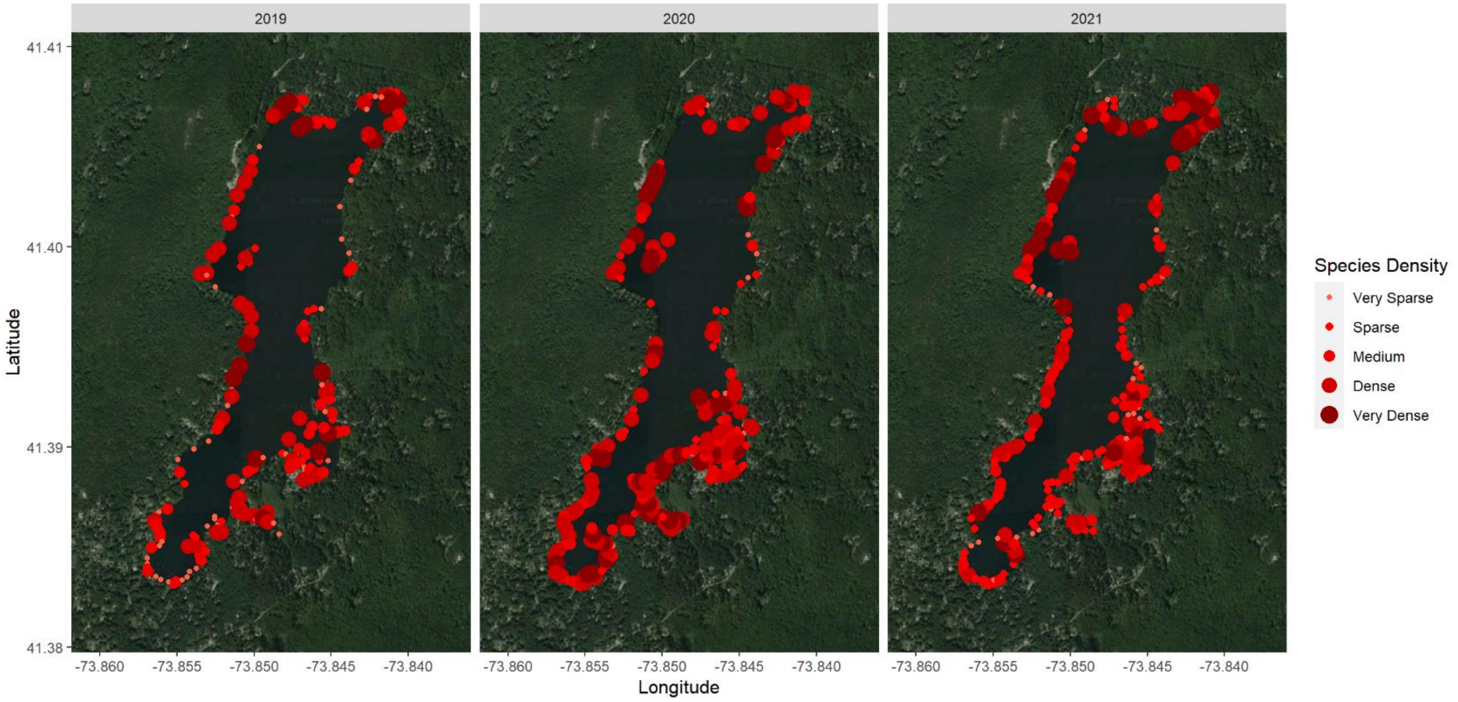
2020				
Scientific Name	**Common Name**	**Year**	**Frequency %**	**Avg. Density %**
Myriophyllum spicatum	Eurasian Watermilfoil	2020	75	51
Potamogeton amplifolius	Largeleaf Pondweed	2020	57	62
Nymphaea odorata	White Water Lily	2020	24	64
Vallisneria americana	Eel grass/ Tapegrass	2020	19	53
Ceratophyllum demersum	Coontail	2020	10	39
Lyngbya sp.	Cyanobacteria mats	2020	9	66
Spirogyra sp.	*Filamentous algae*	2020	4	42
Potamogeton robbinsii	Robbins Pondweed	2020	3	26
Brasenia schreberi	Watershield	2020	1	73
Nuphar variegata	Yellow Water Lily	2020	1	12
Potamogeton crispus	Curly Leaf Pondweed	2020	1	50
Sagittaria graminea	Grassy Arrowhead	2020	1	10
Najas minor	Brittle Naiad	2020	<1	10

2021				
Scientific Name	**Common Name**	**Year**	**Frequency %**	**Avg. Density %**
Myriophyllum spicatum	Eurasian Watermilfoil	2021	81	38
Potamogeton amplifolius	Large-leaf Pondweed	2021	49	48
Ceratophyllum demersum	Coontail	2021	28	29
Vallisneria americana	Eel grass / Tapegrass	2021	28	43
Nymphaea odorata	White Water Lily	2021	23	41
Lyngbya sp.	Cyanobacteria mats	2021	12	48
Brasenia schreberi	Watershield	2021	2	16
Sagittaria graminea	Grassy Arrowhead	2021	2	21
Spirogyra	*Filamentous Green algae*	2021	1	26
Najas flexilis	Common Naiad	2021	1	8
Nuphar variegata	Yellow Water Lily	2021	1	13
Potamogeton robbinsii	Robbins Pondweed	2021	1	5
Najas minor	Brittle Naiad	2021	<1	10
Potamogeton crispus	Curly Leaf Pondweed	2021	<1	60
Utricularia gibba	Small Floating Bladderwort	2021	<1	5

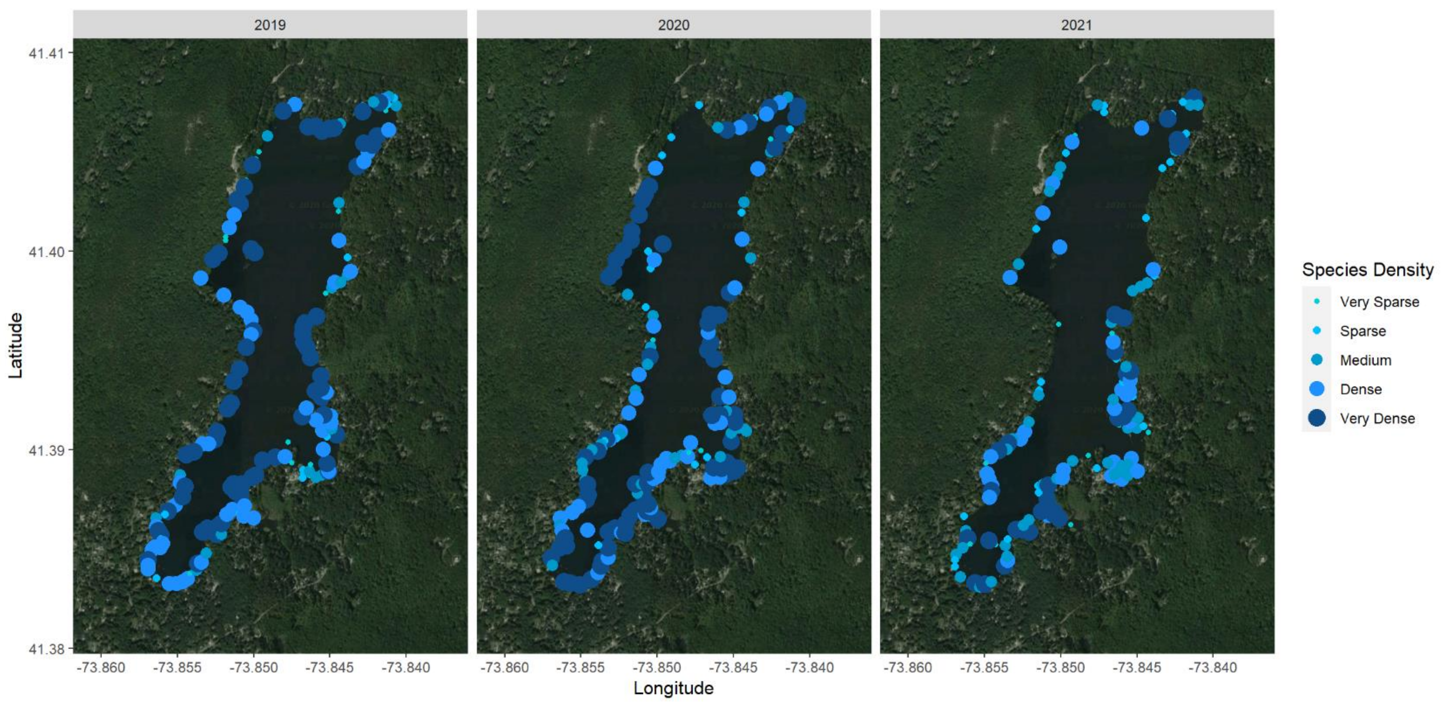
The DEC granted a permit for the additional stocking of 600 grass carp in spring 2021. Survey results from 2022 will document further pressure of grass carp on particular species.

The Eurasian milfoil density was notably higher in 2020 in Wildwood Cove and Abele Cove than in 2021 (**Map 4**) because there was no active mechanical harvesting in 2020, but harvesting resumed in 2021 with a considerably larger machine.

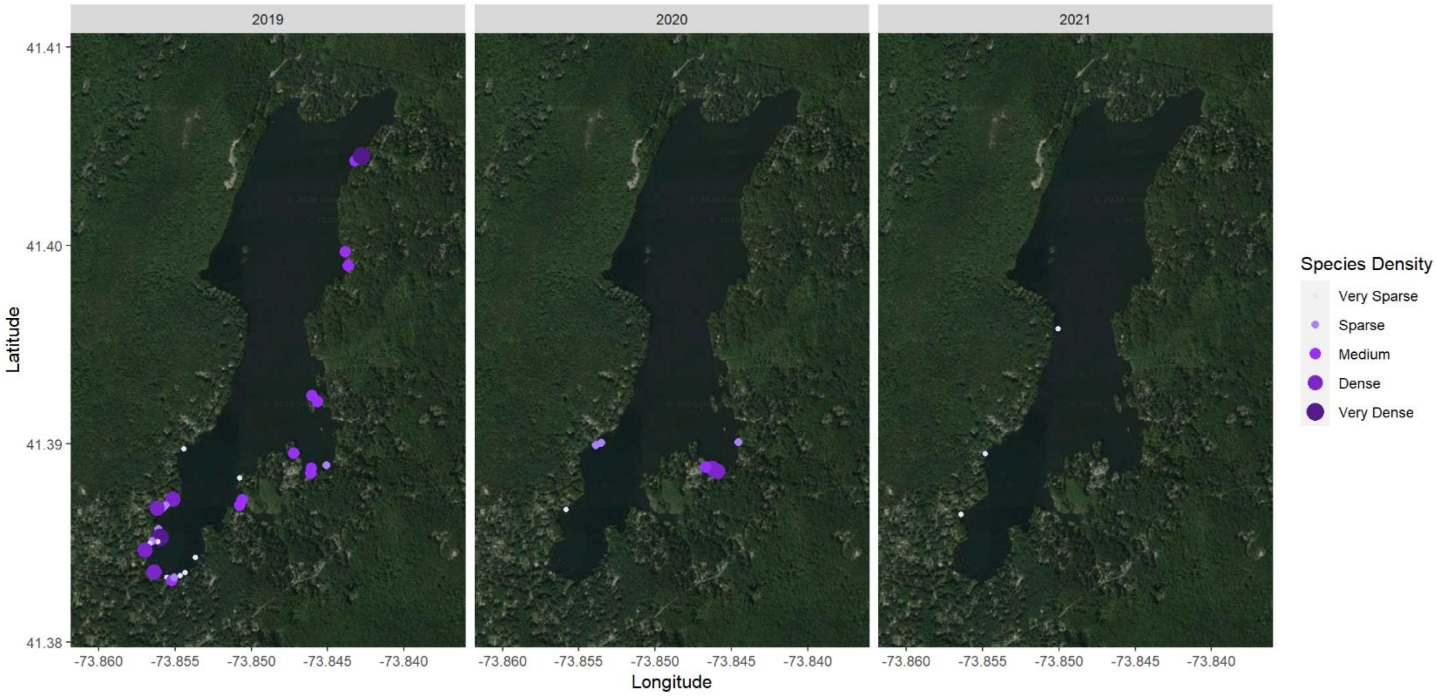
Map 4. Invasive Eurasian Milfoil (Myriophyllum spicatum) 2019-2021 Compared



Map 5. Large-leaf Pondweed (Potamogeton amplifolius) 2019-2021 Comparison

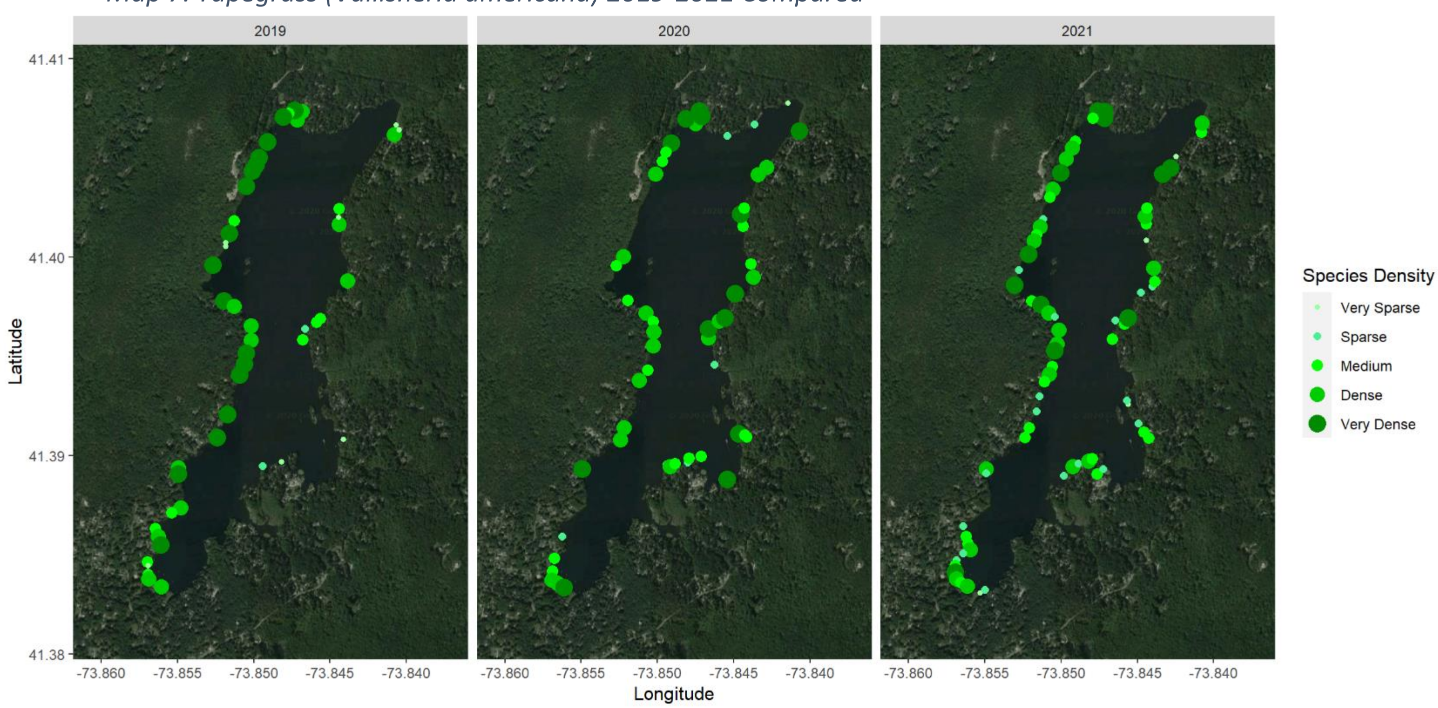


Map 6. Robbin's Pondweed (Potamogeton robbinsii) 2019-2021 Compared



There appears to be a reduction of Robbin's pondweed over the last three years at Lake Oscawana. This reduction could be related to grass carp feeding.

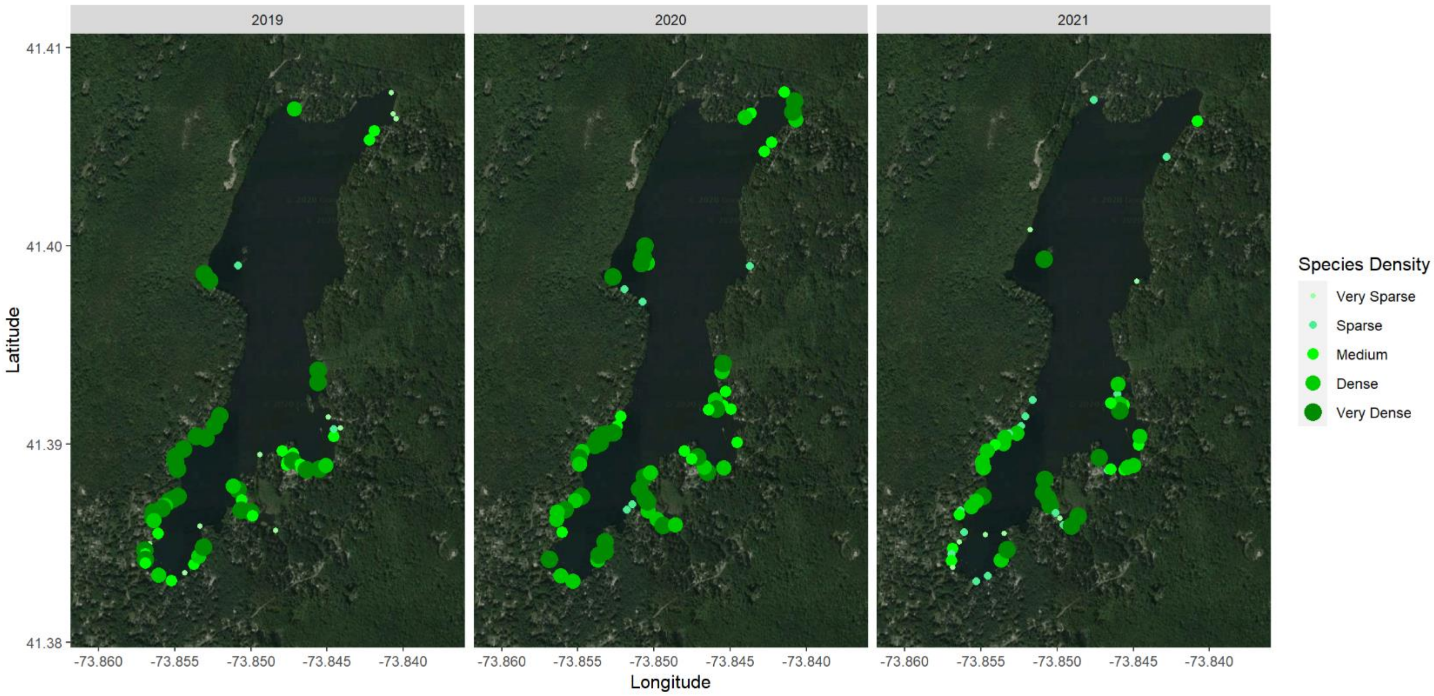
Map 7. Tapegrass (Vallisneria americana) 2019-2021 Compared



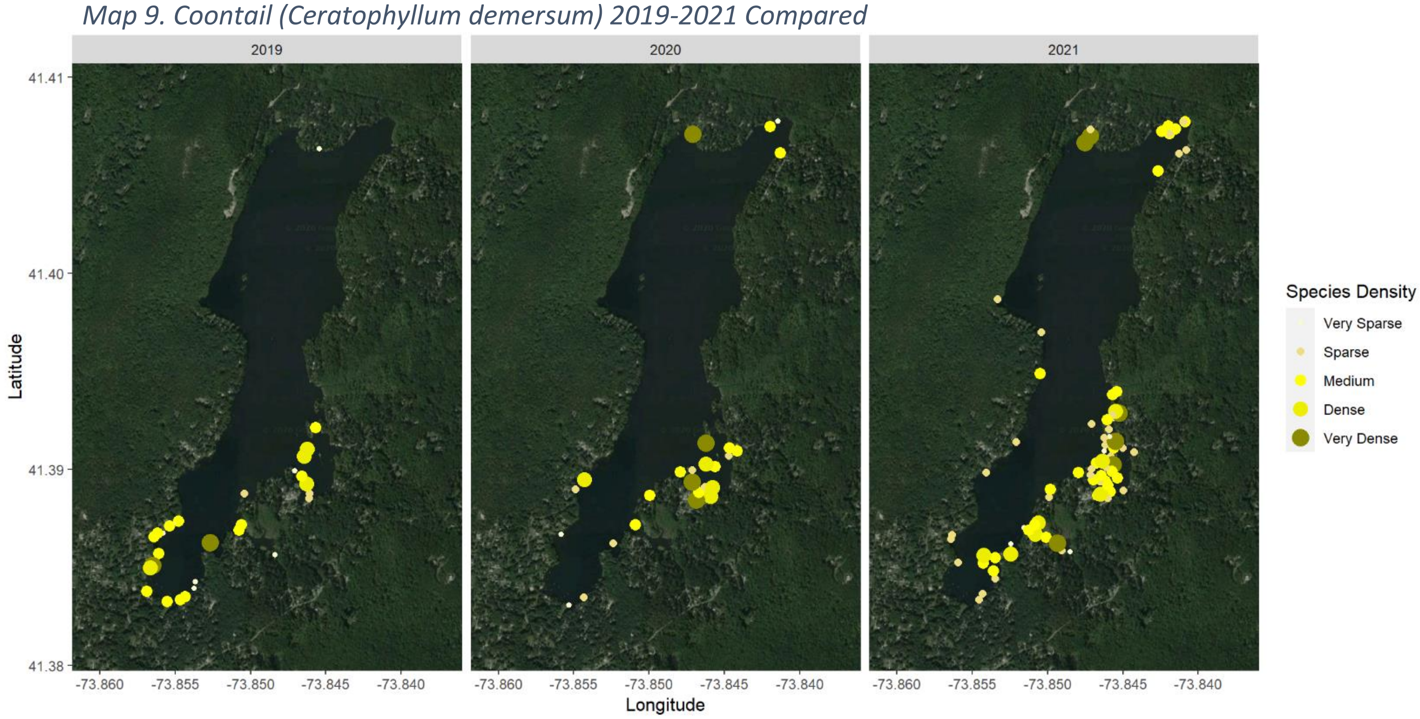
The density of Tapegrass has varied slightly from year to year, and may be related to the changes in annual weather or harvesting, yet the overall locations of this species have remained fairly constant.

The lake-wide frequency and coverage of White-water lilies has remained constant over the last three years, with some natural fluctuation in density, depending on the weather and time of year of the aquatic plant survey (**Map 8**). Water lilies are not the target of mechanical weed harvesting, but in cases where residential access is impeded by lily growth, there are cases where harvesting has removed lilies in the past. Coontail coverage (**Map 9**) appears to be increasing in the northeast cove and Wildwood Cove over the last three years.

Map 8. White Water Lily (Nymphaea odorata) 2019-2021 Compared



Map 9. Coontail (Ceratophyllum demersum) 2019-2021 Compared



Weed-Harvesting Tracker Data

There was no weed-harvester operation or tracker data in 2020, due to the COVID-19 pandemic and inability to get essential harvester repairs. The Town put out a competitive bid for private mechanical harvesting operation, but unfortunately there were no qualified bidders. During the annual aquatic plant survey, we noticed that most beach associations had taken their own plant control measures by raking and hand-removal of floating aquatic vegetation. The large amount of floating aquatic vegetation seen in Wildwood Cove was native Tapegrass (*Vallisneria americana*), which is a robust native plant that can be easily uprooted by boat propellors.

The 2020 aquatic plant survey results demonstrated that the mechanical harvesting program at Oscawana is not just targeting invasive Eurasian milfoil. In fact, it was noted that Coontail, Tapegrass, and Large-leaf pondweed were all dominant in Wildwood Cove, one of the major areas for annual mechanical harvesting.

In 2021, weed harvesting resumed with the purchase of a new and larger mechanical harvester and mostly full-time operation. However, the harvester tracker device was not used in 2021 due to subscription issues with Verizon. The harvester is now equipped with an onboard depth sounder and chart plotter that records active motions and the track of the harvester when in operation, but these files were unretrieved for 2021. The harvester operator must record tracks manually on the chart plotter/depth sounder in order to report them to LOMAC in the future.

Update on Plant Management Activities

Based on the aquatic plant survey results in 2020 and little to no change in both native and invasive species presence or density since the 2016 grass carp stocking, we supported the resident desire for another round of conservative grass carp stocking – 600 fish were chosen for spring 2021 stocking. Details behind this decision are explained in the September 10th, 2020 letter to NY DEC. Overall, our recommendations for long-term aquatic plant management have not changed considerably in the last few years. We believe that mechanical harvesting is not the most cost-effective or efficient means of invasive Eurasian milfoil control.

For that reason, the 2020 Lake Oscawana Management Plan recommended doing a selective herbicide treatment of Eurasian milfoil in high density areas of Abele Cove and Wildwood Cove. This potential use of ProcellaCOR herbicide was discussed at various public meetings in 2020 and 2021. Residents had an opportunity to ask questions and receive answers about the NY aquatic herbicide laws, permitting process, and about how the proposed treatment would affect native plants and organisms in the lake. NEAR attempted to answer all resident questions and concerns at these meetings. Because the NY permitting process takes several months, the Town of Putnam Valley applied for a permit for ProcellaCOR use in Wildwood and Abele Coves. The permit acquisition process was just a first step and the Town had not committed funding to a treatment and had not selected a competitively-bid and licensed aquatic herbicide applicator. However, the Town authorized the Pond and Lake Connection, a NY-licensed applicator, to sign off of the herbicide permit application. In order to approve a permit NYDEC requires that the applicator perform downstream modeling of the herbicide and notify abutting property owners of the intended treatment.

Conclusions & Recommendations

In terms of water quality management, this annual report revisited several management options to control in-lake and watershed nutrient inputs, which have been previously discussed in the 2020 Lake Oscawana Management Plan and the 2020 and 2021 public NEAR presentations. Several modified presentation slides were included in this 2021 annual monitoring report to serve as a reminder of key recommendations regarding the limitations and feasibility of various in-lake management options to improve dissolve oxygen or to lower phosphorus nutrient concentrations that are annually derived from internal sediment recycling. In summary, aeration or oxygenation were not determined to be the best course of management action for Lake Oscawana at this time. High costs and limited ability of the various types of aeration or oxygenation will not dramatically improve Oscawana's water quality if the watershed nutrient inputs remain high.

Similarly, in-lake phosphorus reduction (phosphate-binding treatments) using products such as Phoslock, Eutrosorb-WC, or Alum are presently hindered by the NYDEC permitting process. It is uncertain in NYDEC will allow more widespread in-lake phosphate-binding treatments in the state in the near future, but these products have been used very successfully across the US and the world, including remediation applications in the northeast. They remain potentially viable options in the future, but cannot be used at this time.

Septic systems have been a long-time contributor of nutrient pollution to Lake Oscawana, and LOMAC and NEAR have been communicating with Town officials and Putnam County Health officials in order to continue the uphill effort in septic pump-outs and upgrades in the watershed. The 2020 and 2021 E. coli data collected as part of this lake inlets and watershed monitoring program has allowed the Putnam County Health District to pursue potentially failed septic system upgrades uphill from the long-polluted Inlet 4 stream that feeds Oscawana Lake. The Town has continued to record septic pump-outs through the building department and this information should be copied over into LOMAC files that are stored in Town Hall.

The Town has continued to pursue state grant opportunities to improve watershed runoff from various Town roads. The Winnebago and Chippewa roads continue to be a high priority for necessary stormwater management improvements. LOMAC will continue to be involved in watershed and MS4 proposed projects that affect Lake Oscawana.

Appendix

Raw Water Quality Data 2021

Appendix Table 1. 2021 raw nutrient data

Blank rows indicate samples were not run for that analysis.
"ND" indicates sample was not detected.

				TP	NH_3	TN
Date	**Station**	**Secchi (m)**	**Depth (m)**	**µg/L**	**µg/L**	**µg/L**
4/12/2021	1	2.35	1	13		266
4/12/2021	1		4	13		272
4/12/2021	1		6	17		295
4/12/2021	1		9	24	23	310
4/12/2021	2	2.3	1	13		270
4/12/2021	2		7	20		288
4/12/2021	3	2.4	1	14		294
4/12/2021	3		7	16		296
5/12/2021	1	2.9	1	16		246
5/12/2021	1		4	15		125
5/12/2021	1		6	13		197
5/12/2021	1		9	24	42	259
5/12/2021	2	2.85	1	17		175
5/12/2021	2		7	19		226
5/12/2021	3	2.8	1	20		264
5/12/2021	3		7	19		225
6/11/2021	1	3.6	1	19	177	277
6/11/2021	1		4	28		314
6/11/2021	1		6	36		285
6/11/2021	1		9.9	95	177	603
6/11/2021	2	3.6	1	23		296
6/11/2021	2		7.3	46		342
6/11/2021	3	3.8	1	29		300
6/11/2021	3		6.7	43		341
7/12/2021	1	3.6	1	14		267
7/12/2021	1		4	19		281
7/12/2021	1		6	62		681
7/12/2021	1		9.8	207	442	691
7/12/2021	2	3.75	1	14		269
7/12/2021	2		7.2	56		317
7/12/2021	3	3.55	1	17		246
7/12/2021	3		6.4	35		318
8/11/2021	1	3.9	1	23		340
8/11/2021	1		4	23		322

8/11/2021	1		6	43		469
8/11/2021	1		9.8	732	109	1357
8/11/2021	2	3.75	1	21		269
8/11/2021	2		7	117		332
8/11/2021	3	3.9	1	20		283
8/11/2021	3		6.5	88		724
9/10/2021	1	2.45	1	22		362
9/10/2021	1		4	22		367
9/10/2021	1		6	47		450
9/10/2021	1		10.2	1266	2755	3556
9/10/2021	2	2.3	1	22		339
9/10/2021	2		7.5	304		1185
9/10/2021	3	2.2	1	21		348
9/10/2021	3		6.8	85		653
10/14/2021	1	1.95	1	26		415
10/14/2021	1		4	24		404
10/14/2021	1		6	22		407
10/14/2021	1		9.4	1064	2749	3785
10/14/2021	2	1.9	1	24		386
10/14/2021	2		7.3	23		376
10/14/2021	3	1.65	1	25		386
10/14/2021	3		6.5	31		529

Appendix Table 2. 2021 raw profile data

Date	**Station**	**Depth (m)**	**Temp (ºC)**	**O_2 mg/L**	**O_2_sat %**	**Conductivity µs/cm**	**pH**
4/12/2021	1	0	12.1	11.5	110	240	8.5
4/12/2021	1	1	12.3	11.5	110	240	8.4
4/12/2021	1	2	12.3	11.5	110	240	8.4
4/12/2021	1	3	12.3	11.4	109	240	8.3
4/12/2021	1	4	12.1	11.2	107	240	8.3
4/12/2021	1	5	10.1	10.7	97	235	8.2
4/12/2021	1	6	9.2	10.2	91	235	8.1
4/12/2021	1	7	8.9	9.9	87	235	8.0
4/12/2021	1	8	8.6	9.5	84	236	7.9
4/12/2021	1	9	8.6	9.3	82	236	7.9
4/12/2021	1	10	8.4	7.4	64	239	7.8
4/12/2021	1	10.5	8.4	7.3	63	239	7.7
4/12/2021	2	0	12.6	11.6	110	240	8.2
4/12/2021	2	1	12.7	11.6	111	240	8.2
4/12/2021	2	2	12.6	11.5	110	240	8.2
4/12/2021	2	3	12.5	11.4	109	241	8.2

4/12/2021	2	4	11.5	11.3	106	237	8.1
4/12/2021	2	5	10.6	11.4	104	234	8.1
4/12/2021	2	6	9.9	10.7	96	233	8.0
4/12/2021	2	7	9.1	10.1	89	235	7.9
4/12/2021	2	8	9	9.9	87	235	7.9
4/12/2021	2	8.1	8.8	8.4	74	234	7.6
4/12/2021	3	0	12.9	11.4	110	239	8.1
4/12/2021	3	1	12.9	11.4	110	239	8.2
4/12/2021	3	2	12.9	11.4	109	239	8.2
4/12/2021	3	3	12.9	11.4	109	239	8.2
4/12/2021	3	4	12.8	11.3	109	239	8.2
4/12/2021	3	5	10.8	11.1	101	236	8.1
4/12/2021	3	6	9.6	10.2	91	235	8.1
4/12/2021	3	7	9.3	9.5	84	235	8.0
4/12/2021	3	7.5	9.2	9.3	82	235	7.8
5/12/2021	1	0	15.4	10.5	107	251	8.1
5/12/2021	1	1	15.3	10.5	107	251	8.1
5/12/2021	1	2	15.2	10.5	106	251	8.0
5/12/2021	1	3	15.2	10.5	106	251	8.0
5/12/2021	1	4	15.1	10.5	105	252	8.0
5/12/2021	1	5	13.3	7.8	75	251	7.7
5/12/2021	1	6	12.2	5.6	53	250	7.5
5/12/2021	1	7	11.4	4.1	38	249	7.4
5/12/2021	1	8	11	3.2	11	251	7.3
5/12/2021	1	9	10.9	2.4	11	253	7.3
5/12/2021	1	10	10.6	0.6	6	258	7.2
5/12/2021	2	0	15	10.7	107	250	8.0
5/12/2021	2	1	15	10.6	107	251	8.0
5/12/2021	2	2	14.9	10.6	106	251	8.0
5/12/2021	2	3	14.8	10.5	106	251	8.0
5/12/2021	2	4	14.4	10.0	99	251	8.0
5/12/2021	2	5	13.5	8.8	84	250	7.7
5/12/2021	2	6	11.9	6.2	58	250	7.5
5/12/2021	2	7	11.3	4.1	38	250	7.4
5/12/2021	2	7.5	11	2.9	26	252	7.3
5/12/2021	2	8	10.9	2.4	22	254	7.3
5/12/2021	2	8.4	10.8	1.9	18	257	
5/12/2021	3	0	15.4	10.6	107	251	8.0
5/12/2021	3	1	15.2	10.6	107	251	8.0
5/12/2021	3	2	15	10.6	107	251	8.0
5/12/2021	3	3	14.9	10.6	106	252	8.0
5/12/2021	3	4	14.2	10.5	105	253	8.0

5/12/2021	3	5	14	9.5	93	251	7.9
5/12/2021	3	6	13.2	8.0	76	250	7.6
5/12/2021	3	7	12	4.4	41	251	7.4
5/12/2021	3	7.8	11.2	2.2	21	256	7.3
6/11/2021	1	0	25.1	9.6	118	256	8.2
6/11/2021	1	1	25.1	9.5	118	253	8.3
6/11/2021	1	2	24.7	9.7	118	252	8.2
6/11/2021	1	3	23.4	10.0	127	251	8.5
6/11/2021	1	4	19.3	8.6	95	245	7.7
6/11/2021	1	5	16.7	5.4	57	247	7.3
6/11/2021	1	5.5	14.2	3.0	29	249	7.2
6/11/2021	1	6	13.9	0.7	6	252	7.1
6/11/2021	1	7	13	0.2	2	256	7.0
6/11/2021	1	8	12.6	0.2	2	260	7.0
6/11/2021	1	9	12.3	0.1	1	263	7.0
6/11/2021	1	10	12	0.1	1	272	7.0
6/11/2021	1	10.5	11.6	0.1	1	426	7.4
6/11/2021	2	0	25.1	9.3	115	248	8.2
6/11/2021	2	1	25.3	9.2	114	247	8.1
6/11/2021	2	2	24.6	10.1	124	249	8.2
6/11/2021	2	3	22.6	10.3	121	244	8.4
6/11/2021	2	4	19.2	9.2	102	240	8.0
6/11/2021	2	5	16.2	6.1	64	245	7.4
6/11/2021	2	5.5	14.6	3.4	34	247	7.2
6/11/2021	2	6	14.1	1.0	10	243	7.1
6/11/2021	2	7	13.3	0.3	3	247	7.0
6/11/2021	2	8	12.6	0.2	2	255	7.0
6/11/2021	3	0	24.9	9.7	120	248	8.4
6/11/2021	3	1	25	9.6	118	245	8.4
6/11/2021	3	2	24.9	9.4	116	243	8.3
6/11/2021	3	3	23.3	10.4	124	243	8.4
6/11/2021	3	4	18.9	9.0	99	239	7.8
6/11/2021	3	5	16.2	4.4	46	239	7.3
6/11/2021	3	5.5	14.5	1.9	19	245	7.1
6/11/2021	3	6	13.7	0.4	3	244	7.1
6/11/2021	3	7	12.9	0.2	2	251	7.0
6/11/2021	3	7.5	12.5	0.1	1	259	7.0
7/12/2021	1	0	25	8.3	102	242	7.2
7/12/2021	1	0.5	25.1	8.3	102	242	7.4
7/12/2021	1	1	25.2	8.2	101	241	7.4
7/12/2021	1	2	25.3	8.2	101	241	7.5
7/12/2021	1	3	25.3	8.1	100	241	7.5

7/12/2021	1	4	24.8	6.8	83	238	7.5
7/12/2021	1	5	21.6	3.3	38	238	7.4
7/12/2021	1	5.5	18.6	1.3	14	239	7.2
7/12/2021	1	6	17.4	0.8	8	240	7.1
7/12/2021	1	7	15.3	0.2	2	247	7.0
7/12/2021	1	8	14.3	0.1	1	257	6.9
7/12/2021	1	9	13.8	0.1	1	263	6.9
7/12/2021	1	10	13.3	0.1	1	273	6.9
7/12/2021	1	10.8	12.6	0.1	1	295	7.2
7/12/2021	2	0	25.8	8.1	101	238	7.2
7/12/2021	2	1	25.6	8.1	100	238	7.3
7/12/2021	2	2	25.4	8.0	99	236	7.3
7/12/2021	2	3	25.4	8.0	99	236	7.4
7/12/2021	2	4	24.8	6.6	81	247	7.4
7/12/2021	2	5	21.5	3.8	43	233	7.1
7/12/2021	2	6	17.4	0.7	7	239	7.1
7/12/2021	2	7	15.8	0.2	2	243	7.0
7/12/2021	2	8	14.3	0.1	1	255	6.9
7/12/2021	2	8.2	13.9	0.1	1	261	7.0
7/12/2021	3	0	25.7	8.4	104	241	7.5
7/12/2021	3	1	25.5	8.3	102	240	7.6
7/12/2021	3	2	25.5	8.2	101	239	7.6
7/12/2021	3	3	25.4	8.2	101	238	7.6
7/12/2021	3	4	25.1	7.2	88	237	7.6
7/12/2021	3	5	22.2	4.1	47	237	7.3
7/12/2021	3	5.5	18.8	1.3	14	237	7.2
7/12/2021	3	6	17.1	0.5	5	238	7.1
7/12/2021	3	7	15.5	0.2	2	251	6.9
7/12/2021	3	7.4	14.6	0.1	1	257	6.9
8/11/2021	1	0	25.5	9.1	113	253	8.2
8/11/2021	1	1	25.6	9.1	113	253	8.3
8/11/2021	1	2	25.7	9.1	113	252	8.4
8/11/2021	1	3	25.5	8.3	103	251	8.3
8/11/2021	1	4	24.9	8.5	105	249	8.2
8/11/2021	1	5	23.3	5.7	68	248	7.5
8/11/2021	1	6	19.2	1.9	20	243	7.1
8/11/2021	1	6.5	17.5	0.3	3	251	7.0
8/11/2021	1	7	16.4	0.2	2	282	6.9
8/11/2021	1	8	14.8	0.1	1	301	7.0
8/11/2021	1	9	14	0.1	1	310	7.1
8/11/2021	1	10	13.3	0.1	1	328	7.2
8/11/2021	1	10.5	12.8	0.1	1	346	7.2

8/11/2021	1	10.8	12.6	0.1	1	436	7.0
8/11/2021	2	0	26.4	9.1	115	250	8.4
8/11/2021	2	1	26.2	9.1	115	252	8.5
8/11/2021	2	2	26.1	9.1	115	252	8.6
8/11/2021	2	3	26	9.1	114	252	8.6
8/11/2021	2	4	25.4	8.5	105	250	8.2
8/11/2021	2	5	23.6	6.0	72	249	7.7
8/11/2021	2	6	19.8	1.6	18	242	7.6
8/11/2021	2	6.5	17.6	0.8	9	236	7.0
8/11/2021	2	7	16.3	0.2	2	260	6.8
8/11/2021	2	8	14.7	0.1	1	361	7.0
8/11/2021	3	0	26.6	8.8	120	251	8.2
8/11/2021	3	1	26.2	9.1	114	253	8.4
8/11/2021	3	2	25.9	8.7	109	252	8.5
8/11/2021	3	3	25.6	8.6	107	251	8.4
8/11/2021	3	4	24.9	8.3	102	250	8.3
8/11/2021	3	5	22.5	3.8	45	247	7.5
8/11/2021	3	5.5	20.1	1.5	17	246	7.2
8/11/2021	3	6	19	1.5	17	247	7.2
8/11/2021	3	7	16.5	0.2	17	274	7.0
8/11/2021	3	7.5	15.4	0.1	1	385	7.1
9/10/2021	1	0	22.5	8.5	100	242	7.3
9/10/2021	1	1	22.9	8.3	99	240	7.3
9/10/2021	1	2	22.9	8.2	98	240	7.4
9/10/2021	1	3	22.9	8.1	96	240	7.5
9/10/2021	1	4	22.9	8.0	95	240	7.6
9/10/2021	1	5	22.9	7.9	94	240	7.6
9/10/2021	1	5.5	22.8	7.8	92	240	7.6
9/10/2021	1	6	21.8	0.9	10	217	7.0
9/10/2021	1	7	19.4	0.2	2	270	7.0
9/10/2021	1	8	16.7	0.3	1	318	7.3
9/10/2021	1	9	15.6	0.1	1	332	7.3
9/10/2021	1	10	14.4	0.1	1	363	7.3
9/10/2021	1	11	13.3	0.1	1	389	7.3
9/10/2021	2	0	22.9	9.1	108	244	6.6
9/10/2021	2	1	23.1	8.9	107	242	6.6
9/10/2021	2	2	23.1	8.9	106	242	6.6
9/10/2021	2	3	23	8.6	102	243	6.6
9/10/2021	2	4	23	8.4	99	243	6.7
9/10/2021	2	5	22.9	7.9	94	243	6.7
9/10/2021	2	5.5	22.4	4.6	54	247	6.7
9/10/2021	2	6	21.8	1.9	22	223	6.7

9/10/2021	2	7	19.4	0.2	2	269	6.7
9/10/2021	2	8	16.8	0.1	1	322	6.7
9/10/2021	3	0	22.8	9.1	108	246	7.6
9/10/2021	3	1	23.1	9.0	107	244	7.6
9/10/2021	3	2	23	8.8	105	243	7.7
9/10/2021	3	3	23	8.6	103	243	7.8
9/10/2021	3	4	22.9	8.3	99	243	7.8
9/10/2021	3	5	22.8	8.0	95	242	7.8
9/10/2021	3	6	21.8	0.7	8	228	7.2
9/10/2021	3	7	20.2	0.2	2	261	7.1
9/10/2021	3	7.8	17.8	0.1	1	280	7.1
10/14/2021	1	0	19.3	7.8	86	249	
10/14/2021	1	1	19.3	7.7	85	247	
10/14/2021	1	2	19.2	7.1	79	247	
10/14/2021	1	3	19.2	6.6	73	247	
10/14/2021	1	4	19.1	6.4	70	246	
10/14/2021	1	5	19.1	6.2	68	246	
10/14/2021	1	6	19.1	6.1	67	246	
10/14/2021	1	7	19	1.4	16	250	
10/14/2021	1	7.5	18.9	0.2	2	254	
10/14/2021	1	8	18.8	0.1	2	272	
10/14/2021	1	9	16.9	0.1	1	372	
10/14/2021	1	10	15	0.1	1	429	
10/14/2021	1	10.4	14	0.1	1		
10/14/2021	2	0	19.4	8.6	95	246	
10/14/2021	2	1	19.5	8.5	94	245	
10/14/2021	2	2	19.4	8.0	89	245	
10/14/2021	2	3	19.3	7.5	83	245	
10/14/2021	2	4	19.3	7.3	81	245	
10/14/2021	2	5	19.2	7.0	77	245	
10/14/2021	2	6	19.1	5.8	64	245	
10/14/2021	2	7	19.1	4.7	52	245	
10/14/2021	2	7.5	18.8	1.7	19	252	
10/14/2021	2	8	18	0.2	2	341	
10/14/2021	2	8.3	17.9	0.1	1	350	
10/14/2021	3	0	19.8	8.3	93	245	
10/14/2021	3	1	19.6	8.0	89	245	
10/14/2021	3	2	19.2	6.2	68	246	
10/14/2021	3	3	19.1	5.9	65	246	
10/14/2021	3	4	19.1	6.1	67	245	
10/14/2021	3	5	19.1	6.2	68	245	
10/14/2021	3	6	19	4.0	44	246	

10/14/2021	3	7	19	1.2	13	251	
10/14/2021	3	7.4	18.7	0.2	3	428	

Raw Water Quality Data 2020

Appendix Table 3. 2020 raw nutrient data.

Blank rows indicate samples were not run for that analysis.
"ND" indicates sample was not detected.

				TP	NH3	TN	Fe
Date	**Station**	**Secchi (m)**	**Depth (m)**	**µg/L**	**µg/L**	**µg/L**	**µg/L**
4/7/2020	1	3	1	16		230	
4/7/2020	1		4	17		233	
4/7/2020	1		6	19		266	
4/7/2020	1		9	22		263	
4/7/2020	2	2.85	1	14		240	
4/7/2020	2		7	19		252	
4/7/2020	3	3.1	1	17		247	
4/7/2020	3		7	18		246	
5/13/2020	1	3.65	1	27		326	
5/13/2020	1		4	15		240	
5/13/2020	1		6	21		252	
5/13/2020	1		9	17		302	
5/13/2020	2	3.55	1	16		265	
5/13/2020	2		7	21		237	
5/13/2020	3	3.2	1	15		242	
5/13/2020	3		7	13		236	
6/10/2020	1	4.1	1	15	ND	276	
6/10/2020	1		4	19	9	308	
6/10/2020	1		6	27	31	305	
6/10/2020	1		9	41	113	295	
6/10/2020	2	3.9	1	17		275	
6/10/2020	2		7	24		267	
6/10/2020	3		1	18		289	
6/10/2020	3		7	31		283	
7/17/2020	1	3	1	17	110	293	
7/17/2020	1		4	20	121	312	
7/17/2020	1		6	34	110	473	
7/17/2020	1		7	48		380	
7/17/2020	1		9	143	258	453	
7/17/2020	2	3.1	1	13		295	
7/17/2020	2		7	37		306	
7/17/2020	3	3.3	1	16		286	
7/17/2020	3		7	68		347	
8/13/2020	1	4.1	1	18	18	312	
8/13/2020	1		4	25	41	310	
8/13/2020	1		6	56	30	506	
8/13/2020	1		9	519	976	978	9726

8/13/2020	2	3.9	1	15		261	
8/13/2020	2		7	127		590	
8/13/2020	3	3.8	1	18		280	
8/13/2020	3		7	82		515	
9/9/2020	1	3.7	1	17	3	252	
9/9/2020	1		4	24	ND	263	
9/9/2020	1		6	59	7	375	
9/9/2020	1		9	644	2000	1726	
9/9/2020	2	3.05	1	19		260	
9/9/2020	2		7	91		530	
9/9/2020	3	3.3	1	20		254	
9/9/2020	3		7	160		664	
10/13/2020	1	2.85	1	20	12	248	
10/13/2020	1		4	18	17	256	
10/13/2020	1		6	20	13	257	
10/13/2020	1		9	19	18	257	
10/13/2020	2	2.8	1	21		261	
10/13/2020	2		7	22		256	
10/13/2020	3	2.95	1	19		257	
10/13/2020	3		7	22		246	

Appendix Table 4. 2020 raw profile data from Station 1

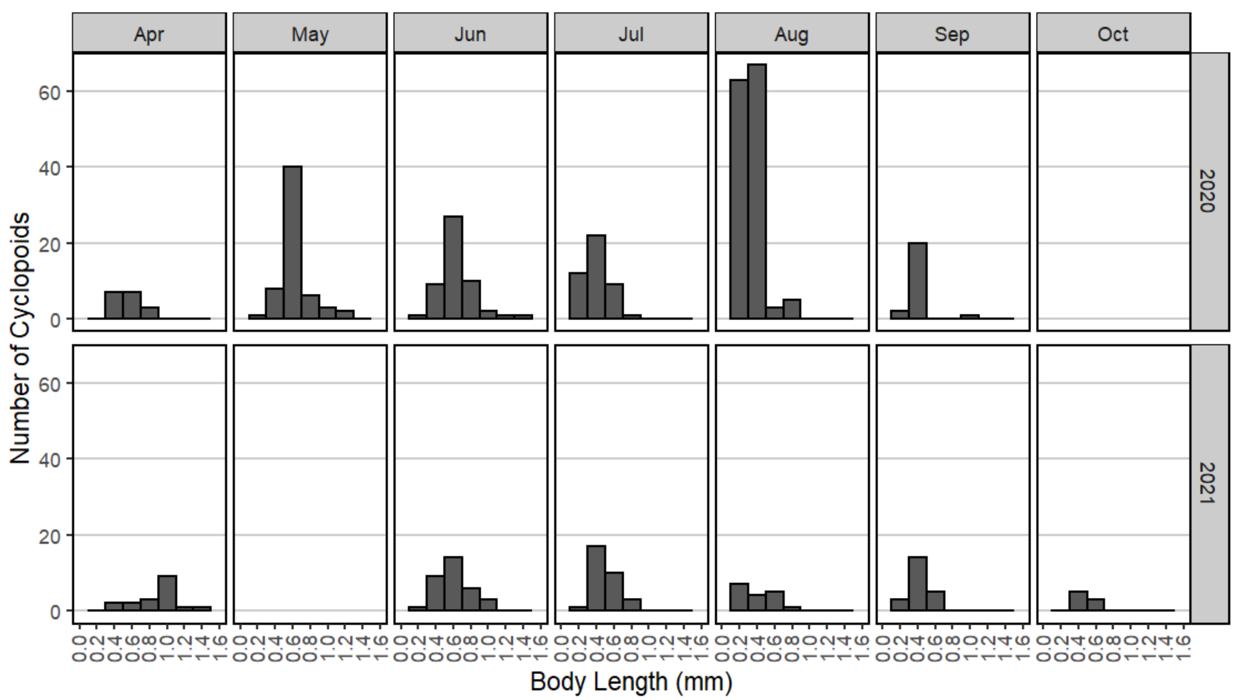
Date	Depth (m)	Temp (C)	DO mg/L	RTRM
4/7/2020	0	10.9	10.9	7
4/7/2020	1	10.3	11.1	0
4/7/2020	2	10.3	11.1	1
4/7/2020	3	10.2	11.1	3
4/7/2020	4	9.9	11.1	6
4/7/2020	5	9.3	10.8	4
4/7/2020	6	8.9	9.7	3
4/7/2020	7	8.6	9.7	1
4/7/2020	8	8.5	9.6	2
4/7/2020	9	8.3	9.5	0
4/7/2020	10	8.3	9.5	1
4/7/2020	11	8.2	9	0
5/13/2020	0	12.4	10.2	0
5/13/2020	1	12.5	10.1	0
5/13/2020	2	12.5	10.1	1
5/13/2020	3	12.4	10.1	1
5/13/2020	4	12.3	10	0
5/13/2020	5	12.3	10	1
5/13/2020	6	12.2	9.9	8
5/13/2020	7	11.6	9.1	3
5/13/2020	8	11.4	8.5	3
5/13/2020	9	11.2	7.6	4

5/13/2020	10	10.9	5.7	4
5/13/2020	11	10.6	2.8	0
6/10/2020	0	24.4	9	9
6/10/2020	1	24.1	9	12
6/10/2020	2	23.7	9.1	12
6/10/2020	3	23.3	9	83
6/10/2020	4	20.3	8.6	91
6/10/2020	5	16.4	7.3	35
6/10/2020	6	14.6	3.8	21
6/10/2020	7	13.4	1.5	11
6/10/2020	8	12.7	0.3	2
6/10/2020	9	12.6	0.2	3
6/10/2020	10	12.4	0.2	4
7/17/2020	0	25.9	8.8	0
7/17/2020	1	26.2	8.7	0
7/17/2020	2	26.3	8.6	0
7/17/2020	3	26.4	8.6	0
7/17/2020	4	26.4	8.3	89
7/17/2020	5	23.6	6.3	115
7/17/2020	6	18.4	0.3	60
7/17/2020	7	15.6	0.1	22
7/17/2020	8	14.4	0.1	14
7/17/2020	9	13.6	0.1	10
7/17/2020	10	13	0.1	5
8/13/2020	0	29.2	8.3	7
8/13/2020	1	29	8.3	4
8/13/2020	2	28.9	8.3	4
8/13/2020	3	28.8	8.2	35
8/13/2020	4	27.8	6.6	51
8/13/2020	5	26.3	5.6	134
8/13/2020	6	21.9	0.9	92
8/13/2020	7	18.3	0.2	42
8/13/2020	8	16.4	0.1	35
8/13/2020	9	14.6	0.1	14
8/13/2020	10	13.8	0.1	15
9/9/2020	0	26.1	9	20
9/9/2020	1	25.5	9.4	10
9/9/2020	2	25.2	9.3	10
9/9/2020	3	24.9	8.7	6
9/9/2020	4	24.7	8.5	9
9/9/2020	5	24.4	7.2	33
9/9/2020	6	23.3	0.9	75
9/9/2020	7	20.6	0.2	59
9/9/2020	8	18.2	0.1	47

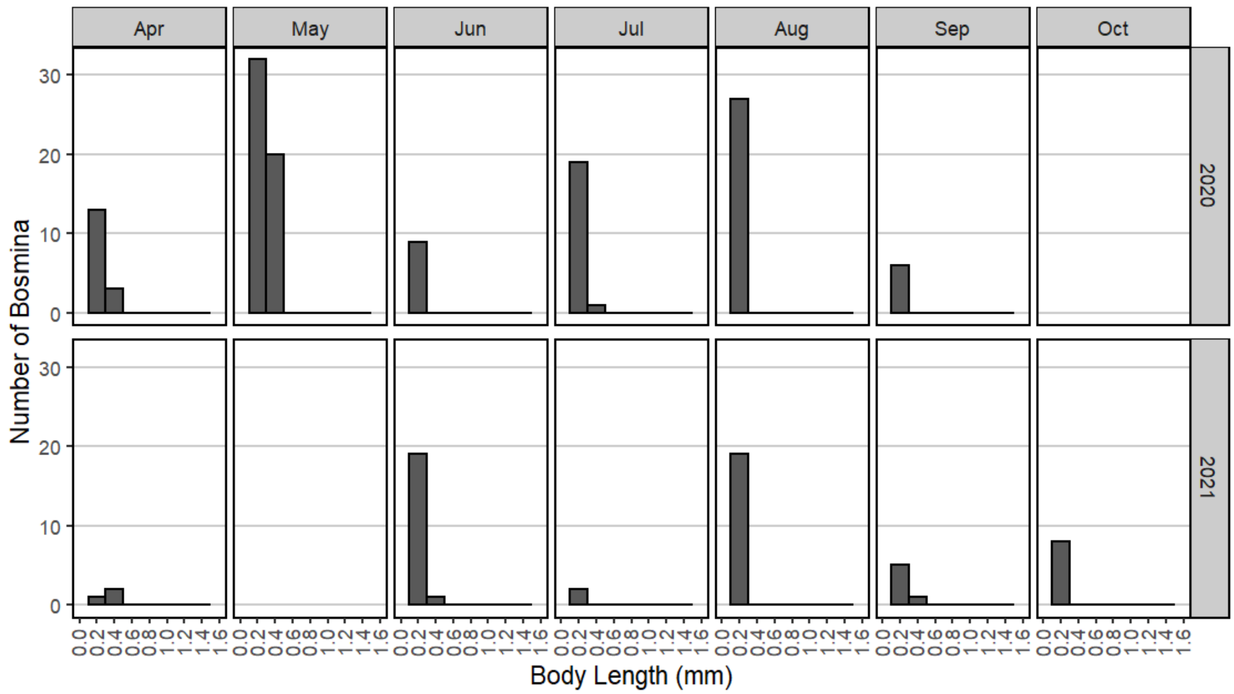
9/9/2020	9	16	0.1	30
9/9/2020	10	14.4	0.1	10
10/13/2020	0	16.8	8.8	0
10/13/2020	1	17	8.7	0
10/13/2020	2	17.1	8.6	0
10/13/2020	3	17.2	8.6	0
10/13/2020	4	17.2	8.5	0
10/13/2020	5	17.2	8.4	0
10/13/2020	6	17.2	8.4	0
10/13/2020	7	17.2	8.4	0
10/13/2020	8	17.2	8.3	0
10/13/2020	9	17.2	8.3	2
10/13/2020	10	17.1	8.2	0

Zooplankton Supplemental Figures

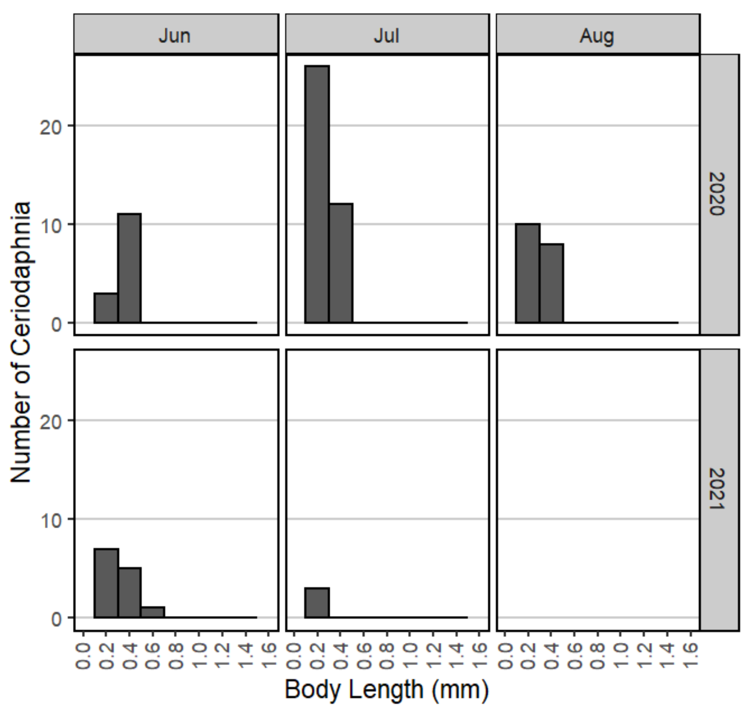
Size classes for Cladocerans and Cyclopoid Copepods are shown in the **Figures** below. The number of organisms is the total counted in the entire zooplankton net tow at Station 1, not the back-calculated organisms per Liter. Size class data from 2021 is similar to previous years, with the majority of zooplankton being less than 0.6mm in body length, indicating heavy predation pressure from alewife. Size classes are included for information purposes and are best used to pair with fisheries data and as general information for long-term comparisons.



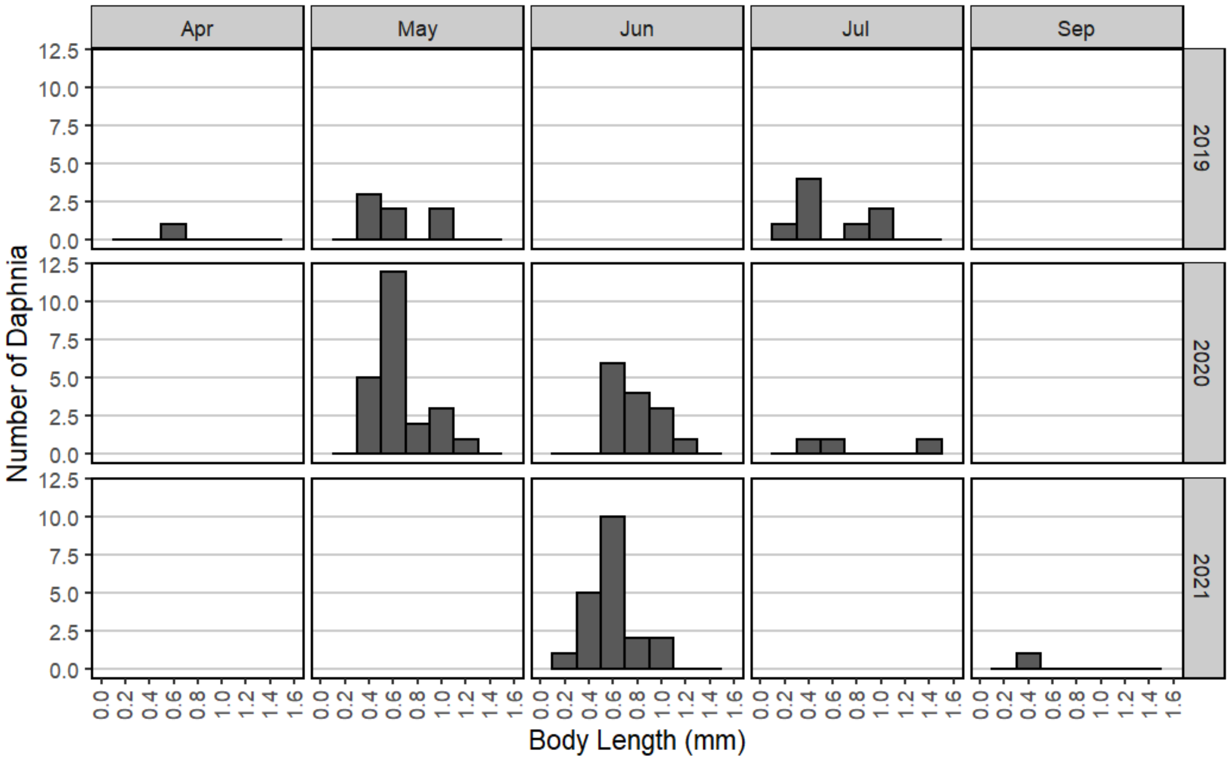
Appendix Figure 1. Cyclopoid Copepod Seasonal Size Classes 2020-2021



Appendix Figure 2. Bosmina Cladocerans Seasonal Size Classes 2020-2021



Appendix Figure 3. Cerodaphnia Cladocerans Seasonal Size Classes 2020-2021



Appendix Figure 4. Daphnia Cladocerans Seasonal Size Classes 2019-2021