Northeast Aquatic Research

Robinson Pond 2021 Water Quality and Aquatic Plant Report

Prepared for:
Taconic Shores Property Owner's Association
March 2022

Northeast Aquatic Research, LLC ⁖ 74 Higgins Highway, Mansfield, CT 06250 ⁖ 860-456-3179

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Executive Summary

- **Northeast Aquatic Research (NEAR) made monthly visits to Robinson Pond and its inlet and outlet between April and November 2021 to collect water samples and limnological information. We also conducted a survey of the aquatic plants in the pond in late June/July.**
- **Water clarity was variable, ranging from 2.7 meters to 5.5 meters.**
- **Thermal stratification and dissolved oxygen changed over the season in relation to the circulation system.**
- **Nutrient concentrations both within the pond and the Roeliff Jansen Kill indicate a highly stressed system, especially with regards to total nitrogen concentrations.**
- **During the plant survey, NEAR documented 27 species, with Eurasian Watermilfoil, Duckweed and Coontail among the dominant species.**
- **Zone 6, the subject of cattail management has shown reduced plant density via a combination of stable water levels and hydroraking efforts.**

Recommendations

Recommendations for Circulation System:

- **Adjust operation of system to run from March to the beginning of December.**
- **Increase the number of diffusers to adequately cover the deep zone.**
- **Monitor for a few years with continuous operation to assess full effectiveness and value of system.**

Recommendations for Roe-Jan Kill:

- **Explore using the cove north of Zone 8 for nutrient and sediment interception.**
    - **Solicit costs and engage DEC in preliminary permitting talks.**
- **Engage various stakeholder groups from the Roe-Jan upstream to discuss nutrient mitigation above Robinson Pond.**
    - **Move toward 9-element watershed-based plan for Roe-Jan Kill in the future.**

Recommendations For Herbicide Treatments:

- **Monitor ProcellaCOR treatment to gauge effectiveness.**
- **Investigate the use of copper-based herbicides like Komeen or Nautique for Duckweed control. Multiple treatments may be needed in consistent problem areas.**

Recommendations for Harvesting:

- **Continue to keep boating and swimming lanes accessible throughout the year.**
- **Focus on areas where herbicide will most likely not be used, such as Zones 1 and 2.**
- **Supplement data tracking with automated GPS tracking of the harvester.**
- **Determine the amount of P and N removed via harvesting efforts and compare that to annual load.**
- **Initiate aggressive end of season (late August/early September) harvesting in Zones 2 and 5 for nutrient removal.**

Introduction

Northeast Aquatic Research (NEAR) made monthly visits to Robinson Pond between April and November 2021 to collect water samples and limnological information. Robinson Pond is 115-acres, with a 21,632-acre drainage basin in Columbia County NY. Three stations were established to collect these data; a Roeliff-Jansen (Roe-Jan) Inlet station used to draw water samples from the river prior to entering the pond, a pond station used to collect pond water samples and obtain in-situ pond data, and an outlet station used to collect samples of water leaving the pond (**Figure 1**). We made monthly visits to each station to collect water samples for chemical analysis of phosphorus and nitrogen series (total nitrogen, ammonia nitrogen, and nitrate/nitrite nitrogen), and to measure water temperature, dissolved oxygen, and water clarity. Three water samples were collected at discrete depths representing the top, middle, and bottom of the water column (1m, 4m, and 7m). Once during late June/early July, we conducted a full pond-wide survey of the aquatic plants in the pond.

***Figure 1**. Locations of the in-pond water quality sampling stations, Roe-Jan inlet station, and outlet station.*

Robinson Pond is relatively shallow, with the majority of the pond being <8 feet deep (**Figure 2**). The natural part of the pond, in the northern section, is the deepest, with a maximum depth of 25.8 feet. A water circulator is installed in this section with the intention of increasing oxygen conditions and reducing harmful algae. Recreationally, swimming is generally done in this northwestern section. The northeastern section of the pond is shallow, with water depths <4 feet throughout. There is a large delta forming at the mouth of the Roe-Jan, where sediments carried by the river are being deposed. The central area of the pond is also shallow, with water depths between 4 and 7 feet. Boating and fishing is common throughout the pond.

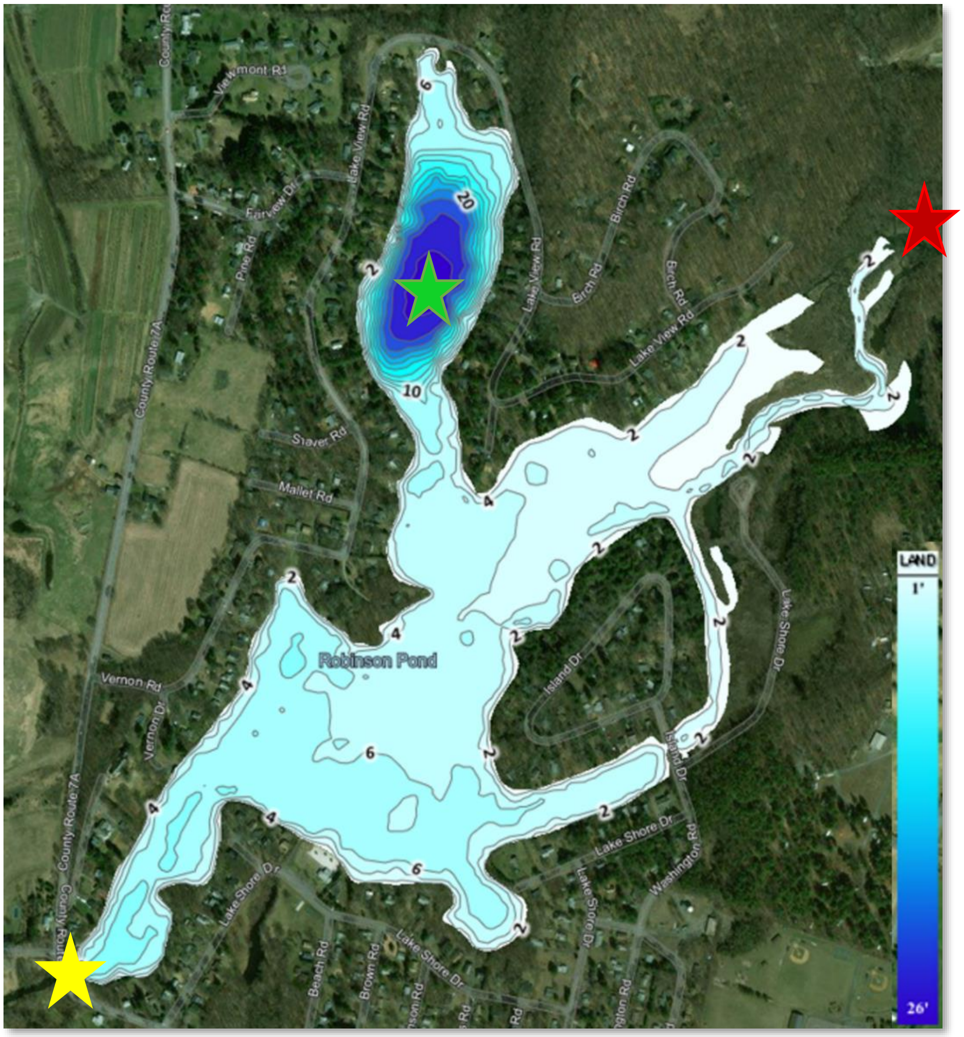


Figure 2*. Bathymetric map of Robinson Pond. Depth contour lines are 1ft. Green star denotes location of water quality monitoring station, red star indicates where the Roe-Jan enters, and yellow star is the ponds outlet.*

Management of Robinson Pond is the responsibility of the Taconic Shores Property Owners Association (TSPOA). The TSPOA sets local ordinances for pond use, oversees harvesting, water level and circulator operations, and provides educational materials for lake management. Specific to management, the TSPOA has subdivided the pond into eight management zones used to communicate priority harvesting zones, among other lake and pond management activities (**Figure 3**). These zones will be referred to periodically throughout the report.

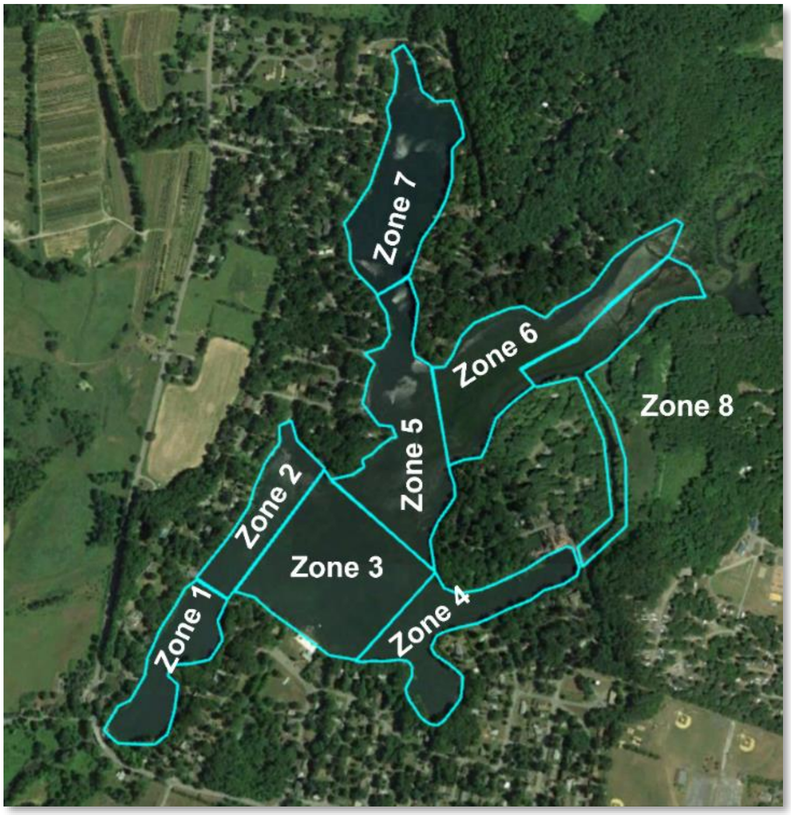


***Figure 3**. Robinson Pond Management Zones.*

Water Quality Results

Water Clarity

Water clarity was measured once a month from April through October with a Secchi disk (an 8-inch disk with black and white quadrants), that is lowered into the water until disappearing while watching with a view scope. That depth, when read with a calibrated measuring tape, is the Secchi disk depth (**Figure 4**). The Secchi disk is a reliable method of estimating the transparency of the lake water. Decreasing Secchi disk numbers are directly caused by increasing phytoplankton, generally cyanobacteria. However, in cases where stream runoff is significant, water clarity decreases with increasing quantities of suspended sediments, typically fine silt, and clay, with particle sizes between 1 and 100 µm. Water clarity of a lake generally varies seasonally due to multiple important processes with the two most important being change in plankton abundance and nutrient levels.

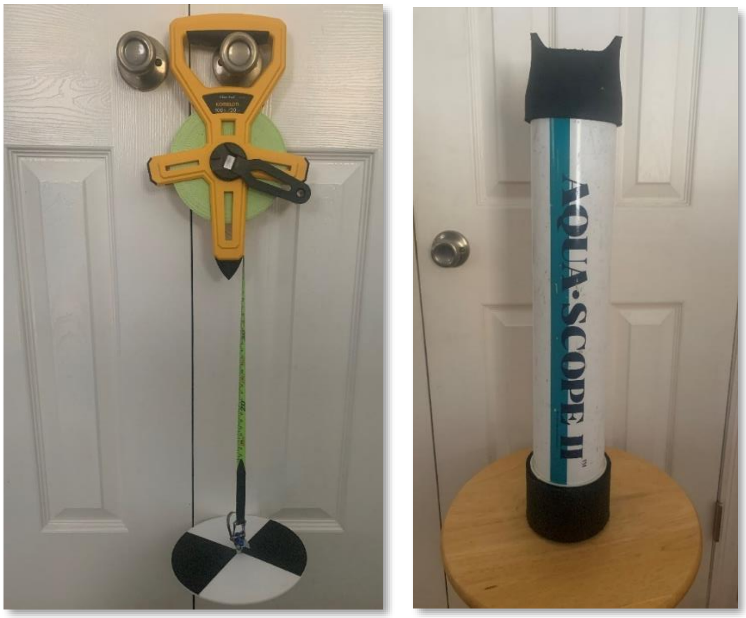


***Figure 4**. Secchi disk and view scope used to measure water clarity.*

2021 Water Clarity Results

The water clarity of Robinson Pond varied between a low of 2.7 meters and a high of 5.5 meters (**Figure 5**). Water clarity appeared strongly influenced by rainfall in the Roe-Jan watershed (**Figure 6**). Nineteen years of seasonal water clarity measurements are shown in **Figure 7**. This chart shows that the months of April through July experience a wide range of clarity values, but most were greater than 2 meters. Data from August and September show that generally water clarity has been less than 2 meters during those months.

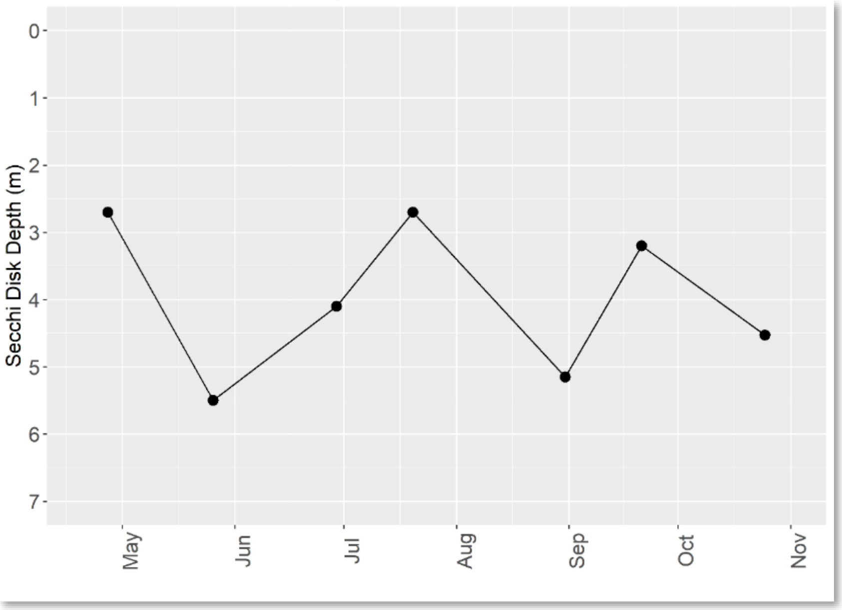


***Figure 5.** Water clarity at the deep station in 2021*

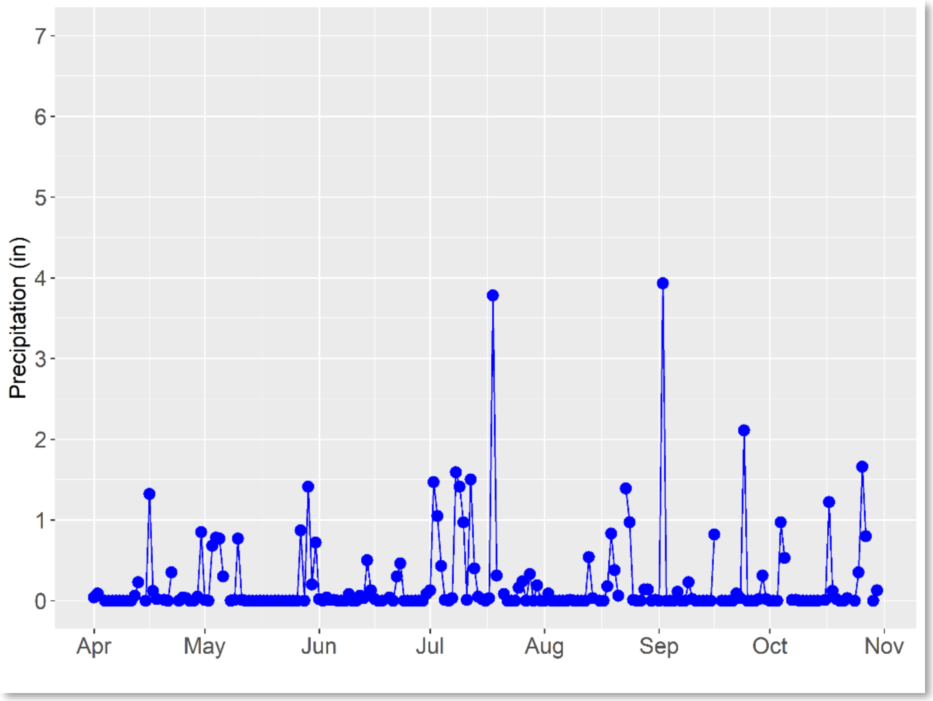


Figure 6. *Daily rainfall totals for Roe-Jan watershed in 2021*

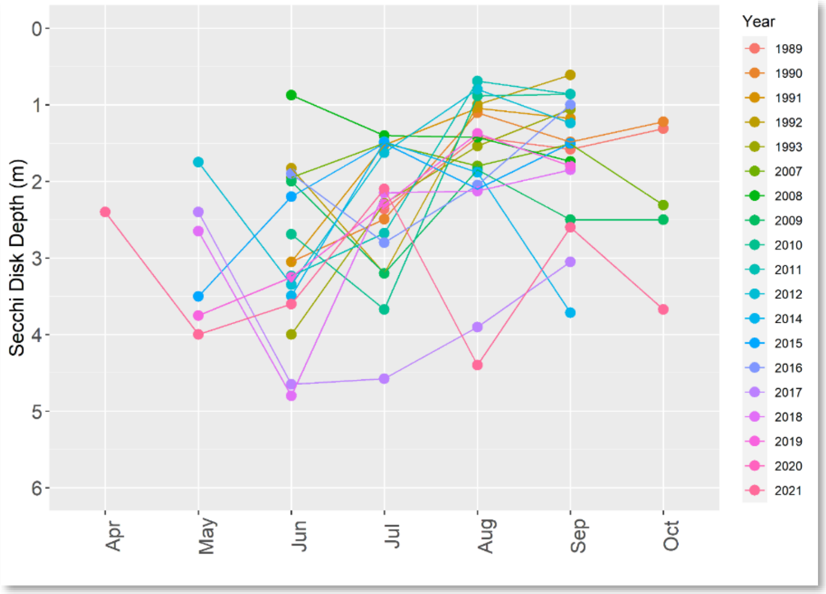
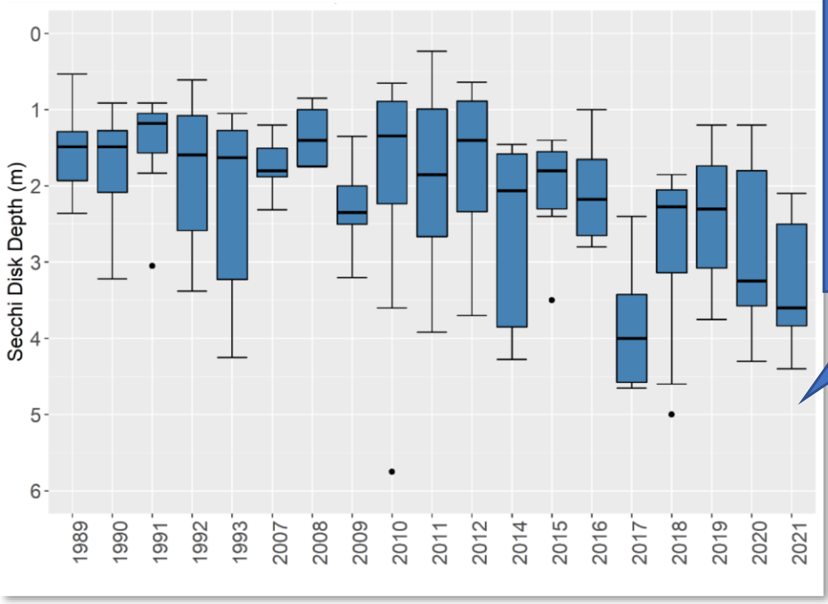


Figure 7. *Historical water clarity at Robinson Pond on a seasonal basis. Note that these values represent Secchi disk measurements taken without a scope.*

Examining mean water clarity over time shows an increase in clarity starting around 2014. Pre 2014, clarity measurements averaged 1.8 meters and post 2014, clarity averaged 2.7 meters (**Figure 8**). The variability in clarity within years can be quite high.



Box and whisker plots are a great way to visualize a large amount of data in one plot. The box (shaded blue area) represents the upper and lower quartile, with the black line represents the median, or 50th percentile of the data

Figure 8*. Yearly mean clarity measurements. Solid black line within the blue boxes indicates median value.*

Lake Water Temperature

Water temperature measurements are made at 1-meter increments from the lake surface to the bottom at the deepest location in the lake. Combined, measurements at all depth increments are referred to as a lake profile. Water temperature in lakes and ponds in the northeast follows a seasonal pattern of warming and cooling.[1] When the lake ice melts in early spring, the water column should be uniform in temperature from top to bottom. As the sun's rays penetrate the water column during the summer, the water warms; but the depth extent of this warming is dependent on the water's clarity. Clearer water allows better sunlight penetration and deeper water column warming. Thus, the depth and development of a thermocline, or the zone of rapid temperature change, is dependent on both the depth of the lake and water clarity. The thermocline influences trends in dissolved oxygen, which affects the concentrations of nutrients and metals within the water column. Cooling waters in the fall result in a weakening thermocline and eventually water "overturn", or when the temperature once again becomes uniform from top to bottom, termed isothermal conditions.

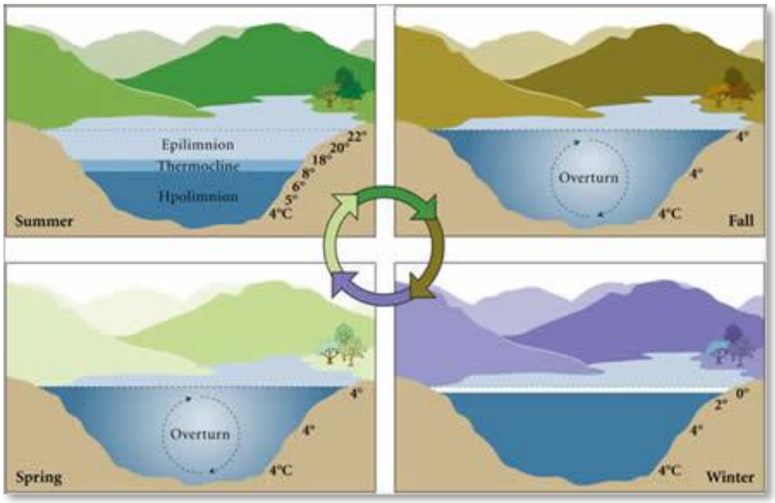


Figure 9. *Diagrammatic description of the seasonal sequence of thermal stratification in northeastern lakes.*

2021 Results

Water temperature followed a typical seasonal warming pattern, with the warmest recorded surface temperature, 29.5°C (85.1°F), occurring on June 30th (**Figure 10**). A thermocline was starting to develop during the May and June timeframe, concurrent with the circulation system having limited functionality. Temperature started to become uniform again in July and stayed isothermal from August through October (**Figure 11**). The isothermal conditions coincided with the circulation system operating more consistently post June.

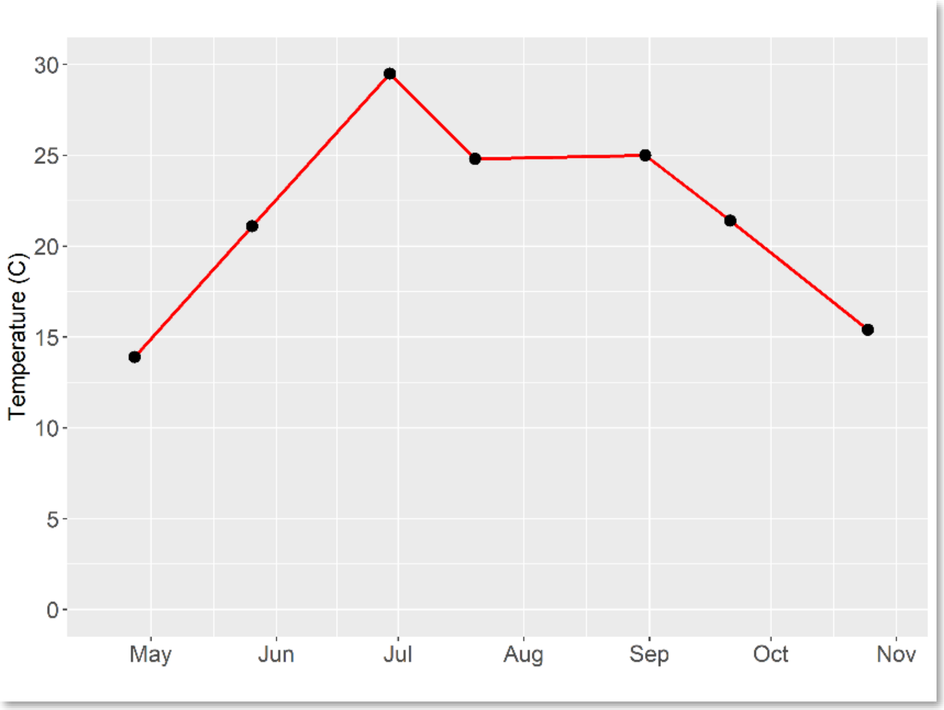


Figure 10. *Surface water temperature at Robinson Pond at deep station in 2021.*

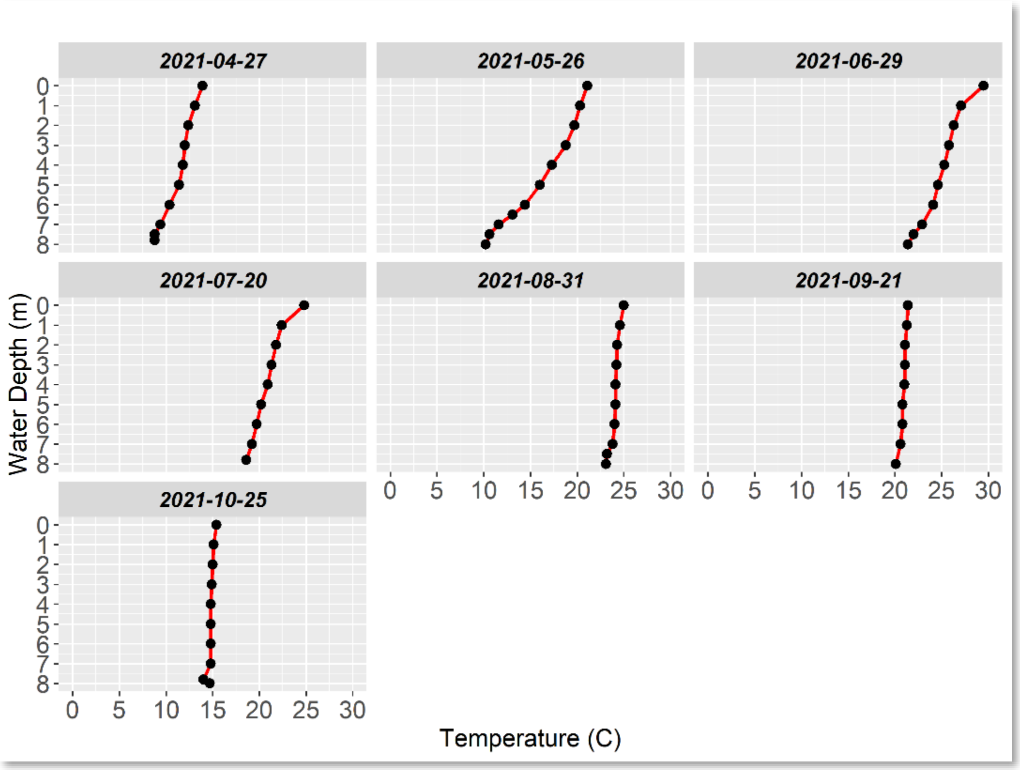


Figure 11*. Temperature profiles at the deep station in 2021.*

Relative Thermal Resistance to Mixing (RTRM) is a unit-less ratio that describes the difference in water density between each meter. As water temperature increases, its density decreases, allowing rapidly warming water to float over the cooler denser water below. In this way, distinct layers form within the water column. The larger the difference in temperature between layers, the larger the difference in density. Two layers of water with different densities require a certain amount of energy to mix them together. RTRM is used to assess how resistant a particular water column is to mixing at any given point. RTRM values under 30 indicate no resistance to mixing, values between 30 and 60 indicate weak resistance to mixing, and values above 60 indicate strong resistance to mixing.

The RTRM values at the deep station in 2021 were relatively low, with only one date having one value above 80. RTRM values were higher in total during the May and June months, with the values decreasing as the season progressed (**Figure 12**). RTRM values in 2021 were much lower than in 2012, which was the last year with semi-regular temperature and oxygen profiles at the deep station (Sutherland 2012). The difference in the RTRM values is most likely attributed to the circulation system. These systems are designed to mix the water, resulting in a water column that is uniform in temperature from the surface to the bottom. An increase in RTRM was observed in the beginning of the 2021 season, mostly due to the fact that the system was not running properly, with multiple power outages. Systems that are improperly functioning provide less than optimal release of air into the water column, which may not have the power to overcome the early summer stratification.

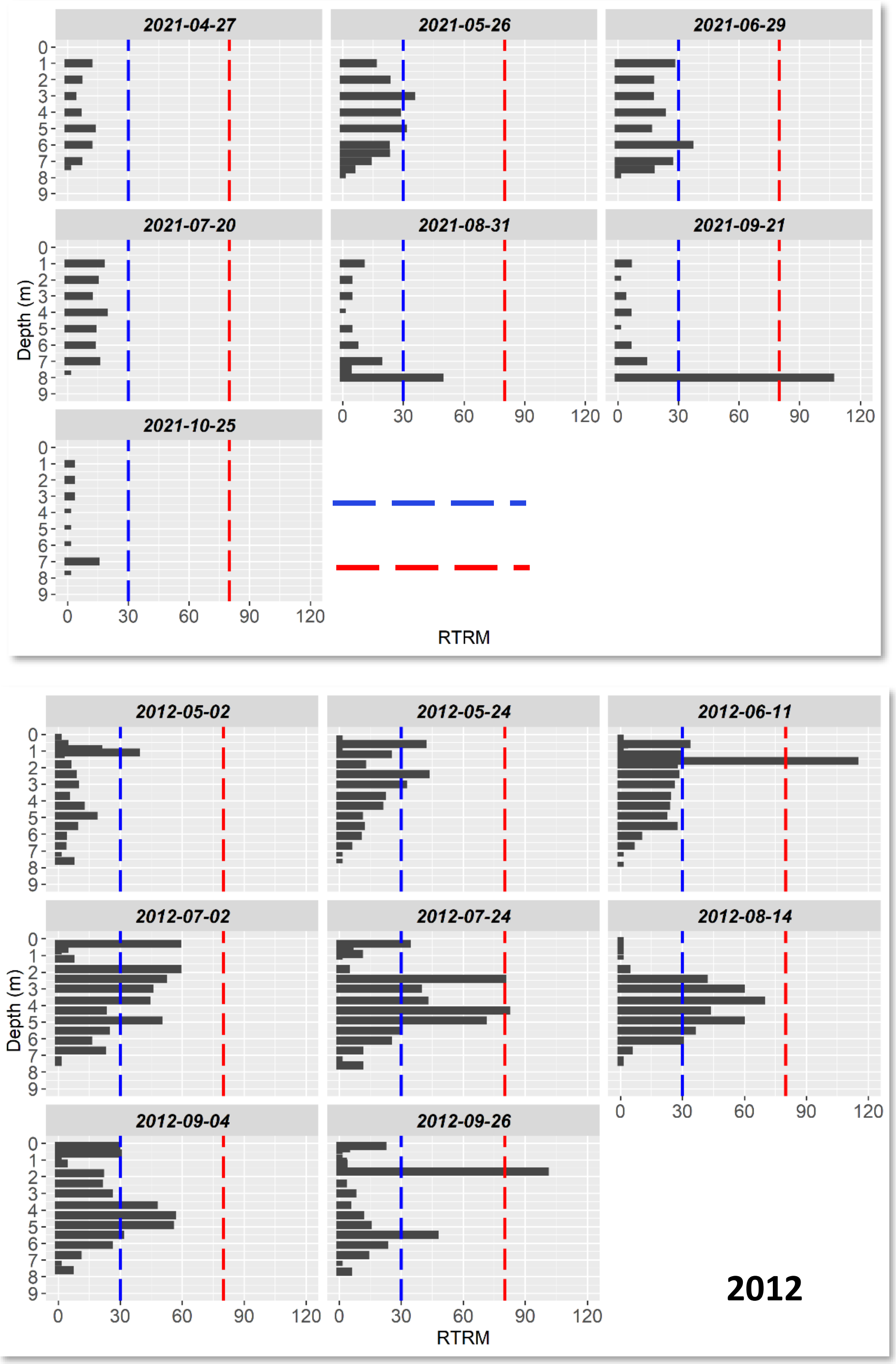


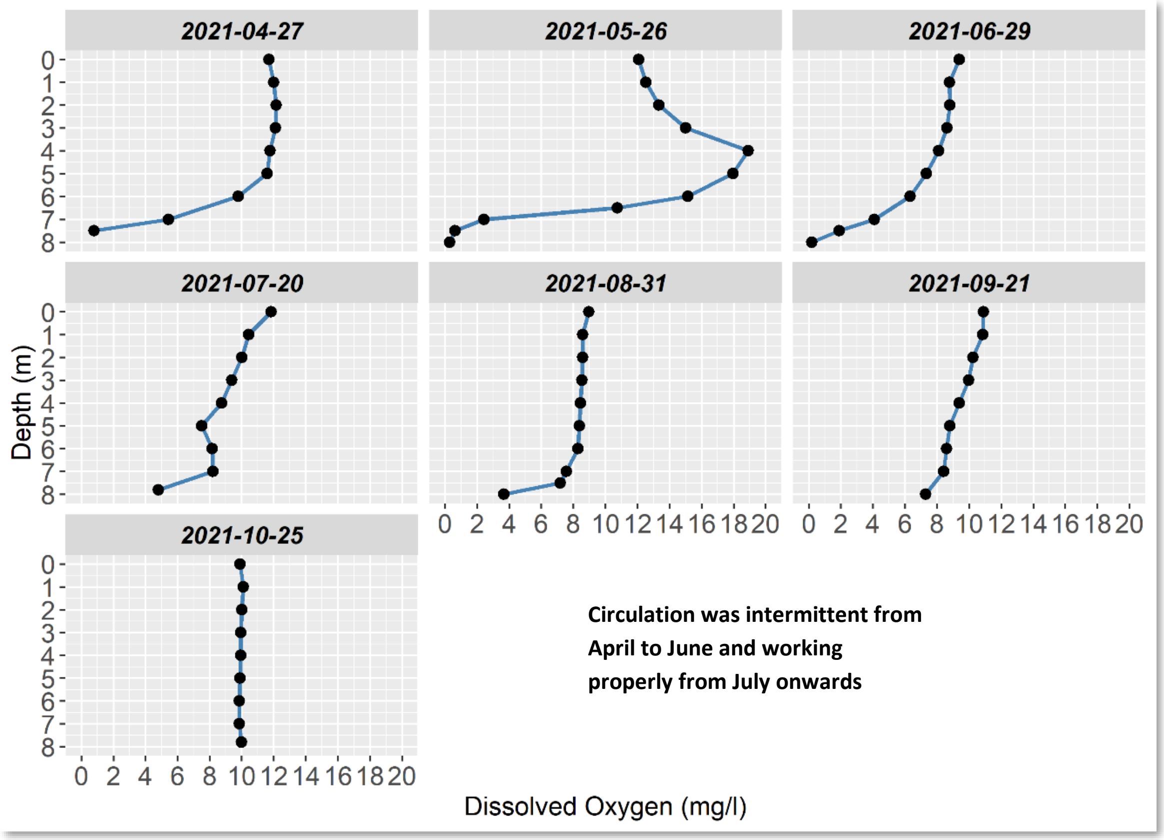
***Figure 12**. Relative thermal resistance to mixing (RTRM) at the deep station 2021 top and 2012 bottom. Values under 30 indicate no resistance to mixing, values between 30-80 indicate moderately strong resistance to mixing and values above 80 indicate very strong resistance to mixing.*

Dissolved Oxygen

As with water temperature, dissolved oxygen measurements are recorded at one-meter increments from the lake surface to the bottom at the deepest location in the lake. Dissolved oxygen in a lake is essential to aquatic organisms. At the surface of the lake, the water is in contact with the air, and atmospheric oxygen is dissolved into the water as a result of diffusion. As water mixing takes place, the dissolved oxygen is circulated throughout the water column. The decomposition of rooted aquatic plants and algae by bacteria requires dissolved oxygen (Biological Oxygen Demand) and can deplete the oxygen concentration in the bottom waters below the thermocline. This phenomenon results in anoxic (<1 mg/L) conditions in the deeper waters for much of the season in impacted lakes. It is critical to track the level of the anoxic boundary, or the depth at which dissolved oxygen is depleted. Anoxic water is not suitable for organisms such as fish and invertebrates.

2021 results

Dissolved oxygen concentrations in surface waters ranged from 9.0 to 12.1 mg/l throughout the season. Profile data shows declines in oxygen concentrations with depth for most of the season, with the most pronounced declines observed during the spring/early summer. From April through June, the bottom waters had no dissolved oxygen despite the circulators running, albeit in an intermediate fashion with multiple outages. After July, the bottom water dissolved oxygen conditions improved, with concentrations of more than 3 mg/l for the remainder of the season. After September, dissolved oxygen was at or near full saturation throughout the water column.



Circulation was intermittent from April to June and working properly from July onwards

Figure 13. *Dissolved oxygen profiles at the deep station in 2021.*

The May oxygen profile shows a large increase in the dissolved oxygen in the middle of the water column, steadily increasing from the surface to the maximum concentration at 4 meters (18.92 mg/l). This phenomenon is termed the metalimnetic oxygen maximum (MOMAX) and is most often the result of a layer of algae that is sitting at a certain depth actively photosynthesizing. NEAR did not take samples of the algae layer, so it is unknown which genera of algae constitutes this layer.

A comparison of the 2021 dissolved oxygen concentrations to the values reported in 2012 shows a drastic difference in the amount of oxygen loss in the bottom water. In 2012, oxygen loss was already severe by the beginning of May, with anoxic water present from 5.2 meters to the bottom (**Figure 14**). This translates to roughly 2.4 meters (7.9 feet) of anoxic water at the beginning of the season in May. Anoxia starts at the very bottom of a basin, at the sediment water interface, and moves up into the water column as time progresses. Oxygen loss persisted well into the end of September, with an estimated end date of oxygen loss most likely in the middle to end of October. Oxygen loss at the end of the season tends to linger, even after a lake becomes isothermal. Since the lake was still stratified at the end of October, we believe it is reasonable to assume that oxygen did not return to the bottom waters until well after the lake became mixed.

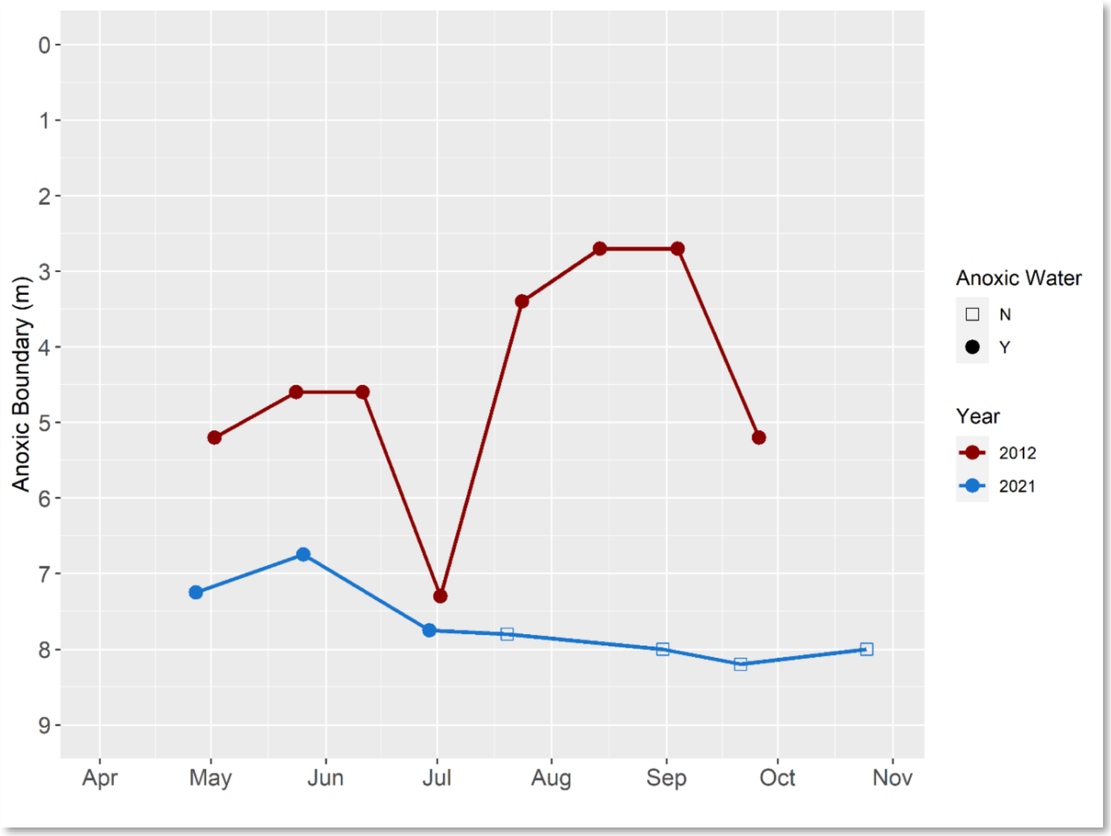


Figure 14*. Anoxic boundary at the deep station in 2012 and 2021. Anoxic boundary is defined as the depth at which dissolved oxygen concentrations are less than 1 mg/L. Closed circles represent dates where the water was anoxic and open squares represent dates where the water was oxic.*

In 2021, oxygen loss and anoxic water was present at the end of April but was restricted to the bottom 0.6 meters (2.0 feet). Oxygen loss never reached higher than 1.25 meters (4.1 feet) throughout the entire season and anoxia ended around the beginning of August. This change in oxygen concentrations from 2012 to 2021 is attributed to the circulation system.

The July 2012 anoxic boundary depth of 7.2 meters appears out of place, with the anoxic boundary being much deeper than June or August. This is due to the profile data showing oxygen conditions between 1 and 2 mg/l from 4.9 meters (16 feet) to the bottom (Sutherland 2012). NEAR uses the 1 mg/L cutoff for anoxic waters, but multiple authors consider 2 mg/L of dissolved oxygen the limit where reduction reactions occur (release of phosphorus from iron). Therefore, the anoxic boundary during the July 2012 sampling date is functionally much higher than what the graph is showing.

Phosphorus and Nitrogen

Phosphorus and nitrogen are the two principal nutrients that drive aquatic plant and algae growth in lakes. Both nutrients are present in all lakes at some level and can enter the lake from the watershed in the form of natural wetland inputs, septic leachate, farm runoff, lawn fertilizers, sedimentation from roads, and erosion from streams. When the concentrations of these nutrients, particularly phosphorus, start to increase, algae can grow rapidly and reach nuisance conditions. In freshwater systems, phosphorus tends to be the limiting factor for productivity and is therefore closely monitored for the health of inland ecosystems. Low phosphorus in a waterbody typically equates to lower phytoplankton abundance and greater overall water clarity.

Lake water should ideally remain oligotrophic, meaning total phosphorus below 10 ppb (equivalent to 10 µg/L) and total nitrogen below 200 ppb (equivalent to 200 µg/L) (**Table 1**). We use the Connecticut standard for evaluating lake trophic state, rather than the NY standards, which are too coarse-grained. Due to lake stratification, these nutrients are not present in the same quantities throughout the lake. Typically, the bottom of the lake collects more phosphorus and nitrogen as the summer progresses. Bottom-sediments release nutrients when oxygen in the bottom water is depleted. Just as the extent and duration of anoxia within a season increases over the years, phosphorus and nitrogen also tend to increase over time as a waterbody becomes more eutrophic or dominated by plants and algae. Nutrient results are compared to identify patterns in internal sediment release versus external watershed loading.

***Table 1**. Parameters and defining ranges for trophic states of lakes in Connecticut.*

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

In-Lake Nutrients 2021 results

Phosphorus

At the lake station, total phosphorus concentrations were generally over 30 ug/l at 1-meter. Only in April was the concentration below 20 µg/L (**Table 2**). Bottom water concentrations varied throughout the season, with higher concentrations in May and June (**Figure 15**). This may be a function of the circulation system, which had multiple power failures pre-July 2021. Bottom waters from April through June were anoxic, while July and August water was oxic. Anoxic water that is in contact with the sediment creates conditions where phosphorus can be liberated from iron in the sediments and moved into the water column. The circulation system adds air (and oxygen to an extent), which would keep the phosphorus bound to iron and within the sediments.

Table 2. *Total phosphorus concentrations (µg/L) in the water column of Robinson Pond during 2021. Colors indicate the rating system presented in* ***Table 1****.*

Depth	4/27/2021	5/26/2021	6/29/2021	7/20/2021	8/31/2021	9/21/2021	10/25/2021
Top (1m)	18	40	31	43	28	36	31
Middle (4m)	24	40	43	32	28	34	34
Bottom (7m)	38	52	65	24	24	22	25

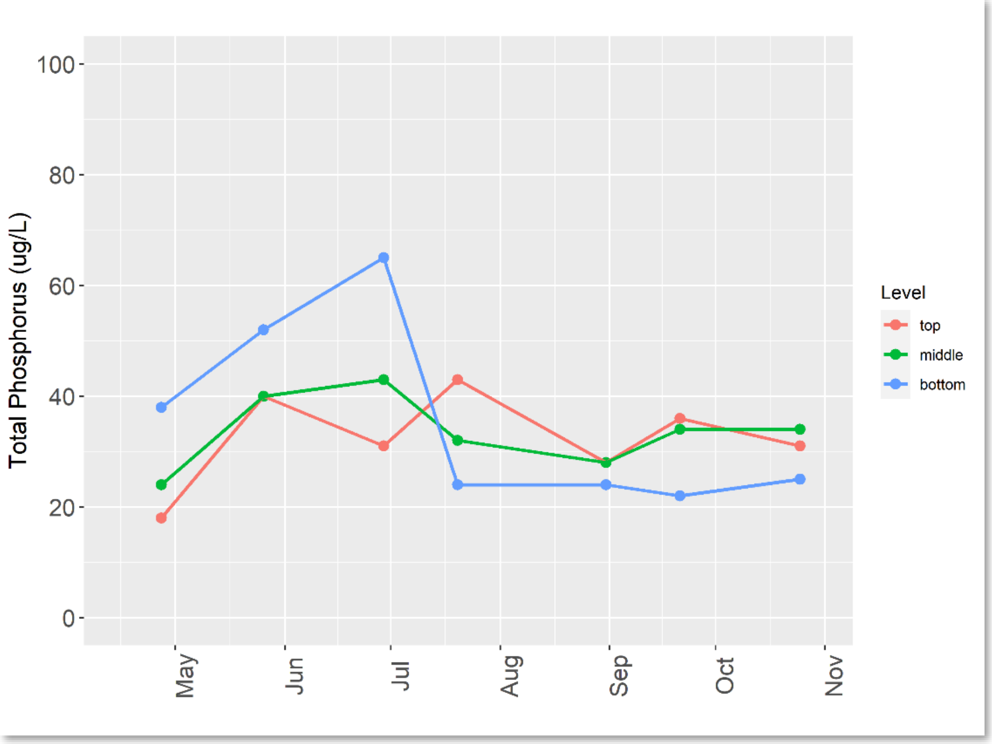


Figure 15*. Graphical representation of total phosphorus concentrations at the deep station in 2021.*

Historical phosphorus values vary greatly both within and among years (**Figure 16**). Overall, the variation in phosphorus is lower post 2015, however there are still some high concentrations documented.

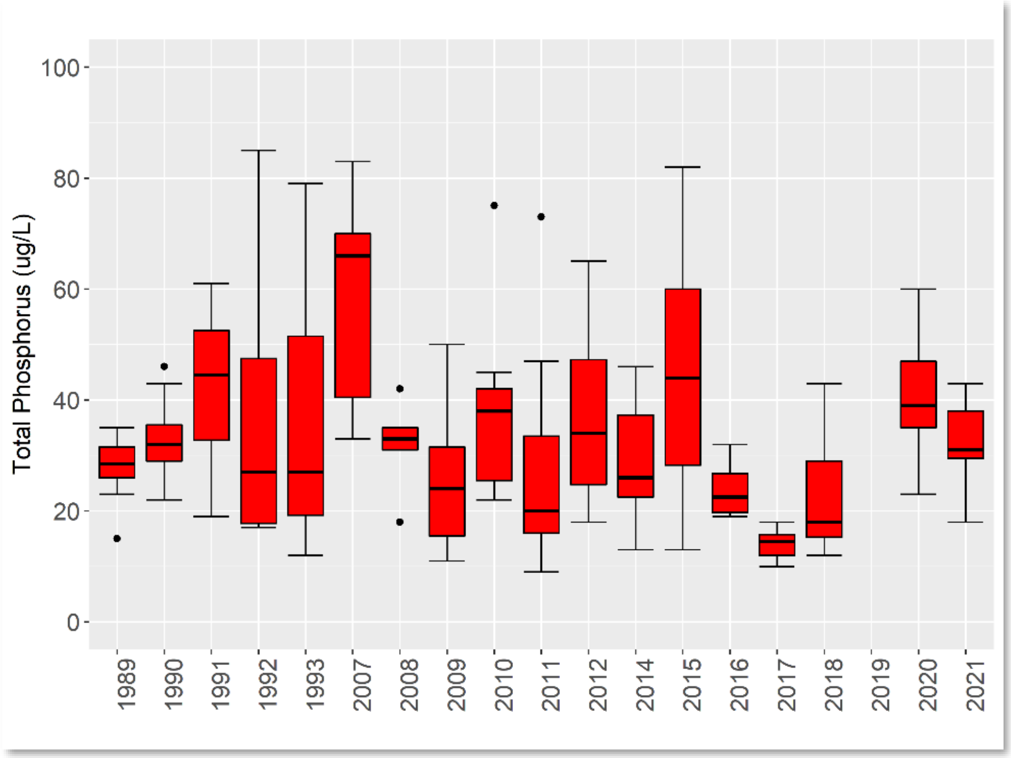


Figure 16*. Historical surface total phosphorus (µg/L) concentrations at the deep station in 2021. Two outliers (9-17-2007: 220 µg/L and 7-14-2008: 130 µg/L) not pictured for graphic clarity. No 2019 data was available from CSLAP.*

Nitrogen

Total nitrogen in the surface water was consistently high, with only one value below 1,000 µg/l (**Table 3**). Bottom water total nitrogen concentrations were slightly higher between April and July compared to the second half of the season. The highest bottom water nitrogen concentration (1,526 µg/L) occurred in July, but this was only slightly higher than April (1,481 µg/L). Bottom water total nitrogen concentrations declined slightly after July, with concentrations remaining below 1,100 g/L. Surface nitrogen in 2021 had a higher median concentration than any year within the dataset (**Figure 17**).

Table 3. *2021 deep station total nitrogen (µg/L) concentrations in water column*

Depth	4/27/2021	5/26/2021	6/29/2021	7/20/2021	8/31/2021	9/21/2021	10/25/2021
Top (1m)	1,248	1,100	798	1,289	1,039	1,105	1,129
Middle (4m)	1,374	1,430	930	1,058	916	1,094	1,320
Bottom (7m)	1,481	1,337	1,074	1,526	1,011	1,009	1,086

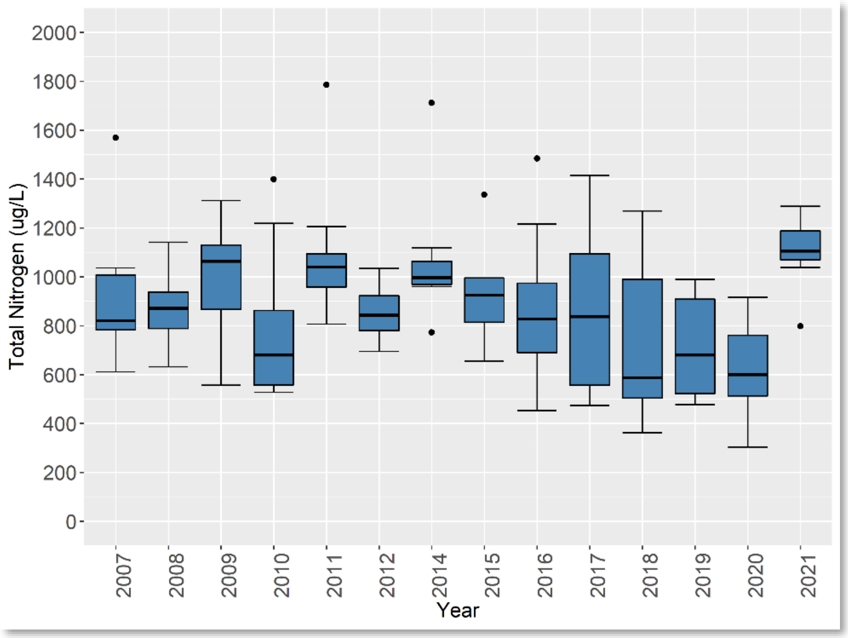


Figure 17. *Historical surface total nitrogen (µg/L) concentrations at the deep station in 2021*

Ammonia-Nitrogen

Total ammonia-nitrogen (NH_3) in the top of the water column ranged from 40 µg/L to 138 µg/L (**Table 4**). Similar to total phosphorus and total nitrogen, ammonia-nitrogen was highest in the bottom waters in the spring/early summer.

Table 4. *Total ammonia-nitrogen (NH_3) concentrations in water column.*

Depth	4/27/2021	5/26/2021	6/29/2021	7/20/2021	8/31/2021	9/21/2021	10/25/2021
Top (1m)	**69**	**68**	**138**	**40**	**108**	**NA**	**157**
Middle (4m)	**62**	**91**	**205**	**5**	**214**	**133**	**191**
Bottom (7m)	**515**	**493**	**372**	**65**	**300**	**125**	**121**

Roeliff Jansen Kill

Total phosphorus concentrations during all sample dates were above 20 µg/L. (**Table 5**). The highest documented value was 203 µg/L on September 21st. Phosphorus values generally increased during the season, with the highest values seen from July to September. Total nitrogen concentrations were high throughout the study period, with only one value under 1,000 µg/L. Total nitrogen did not follow the exact pattern of phosphorus, even though the maximum concentration (1,954 µg/L) was documented on the same date as the maximum phosphorus concentration.

Table 5. *Roe-Jan Kill total phosphorus and total nitrogen (µg/L) concentrations.*

Roe-Jan	4/27/2021	5/26/2021	6/29/2021	7/20/2021	8/31/2021	9/21/2021	10/25/2021
TP (µg/l)	**22**	**20**	**47**	**64**	**99**	**203**	**48**
TN (µg/l)	**1,117**	**1,178**	**1,618**	**1,037**	**917**	**1,954**	**1,116**

Pictures taken during the season qualitatively show the difference in the Roe-Jan turbidity over time (**Figure 18**). There are some months, April, where the water in the Kill looked extremely clear, and months like August and September when the stream looked turbid and muddy. The high turbidity water will eventually make its way to the pond, depositing nutrients and sediment.

Figure 18. *Visual conditions of the Roe-Jan Kill during select sampling dates.*

Robinson Pond Outlet

Total phosphorus concentrations in the outlet water varied from a low of 18 µg/L to a high of 55 µg/L, with the highest concentration documented during the September sampling (**Table 6**). Total nitrogen concentrations ranged from 665 to 1085 µg/L, with the highest concentration also documented in September. The high concentrations of phosphorus and nitrogen in the outlet coincide with the highest concentrations found in the Roe-Jan on the same date. No strong seasonal patterns seem to be present in either the phosphorus or nitrogen data.

Table 6. *Robinson Pond outlet total phosphorus and total nitrogen (µg/L) concentrations.*

Outlet	4/27/2021	5/26/2021	6/29/2021	7/20/2021	8/31/2021	9/21/2021	10/25/2021
TP (µg/l)	18	NA	50	20	37	55	21.5
TN (µg/l)	1,085	NA	665	811	738	1,174	885

Phytoplankton

Phytoplankton were collected using a 3-meter integrated sampler once per month from April to October at the deep station. Blue green algae and diatoms were the most abundant groups, followed by golden algae (**Figure 19**). The peak of blue green algae and diatoms occurred at time periods opposite to what is expected of northern lakes and ponds. Usually, diatoms peak in the springtime, before the pond has stratified, and cyanobacteria peak later in the season. The opposite trend observed in Robinson Pond may be attributed to the circulation system not functioning correctly from April through June and then being fully operational from July on. Circulation systems favor diatoms by keeping them from sinking out of the water column, which provides a competitive advantage over blue green algae.

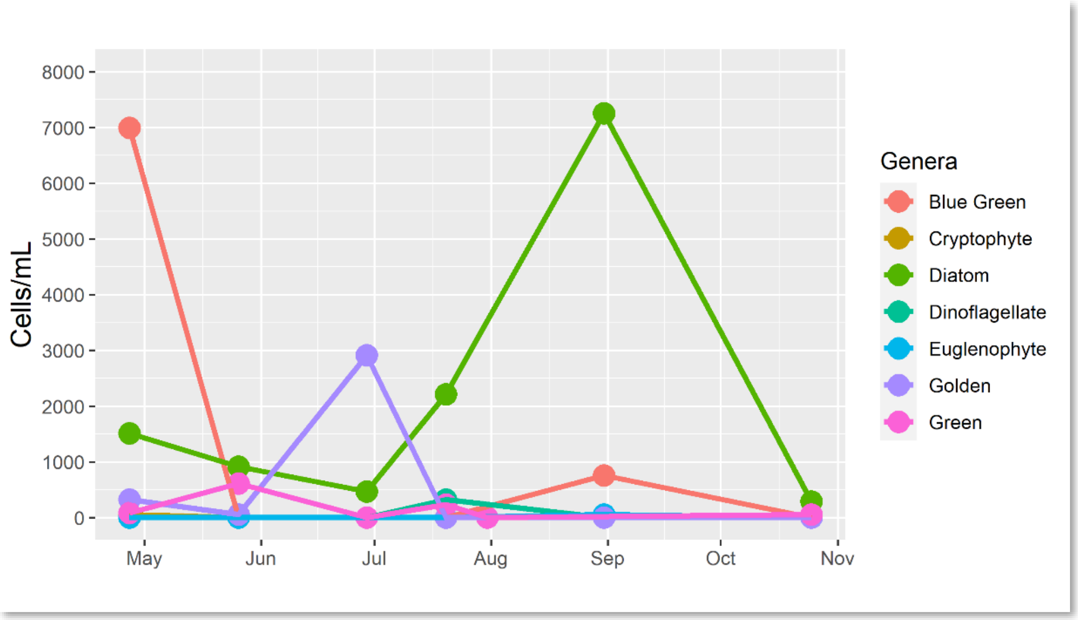


Figure 19*. Dominant phytoplankton (algae) groups were identified and enumerated in 2021 in Robinson Pond.*

Historical total chlorophyll-α concentrations have fluctuated throughout the years, with the lowest values documented post 2014 (**Figure 20**). Recently, chlorophyll-α concentrations have increased (2017-2020), while blue-green attributed chlorophyll α has declined (**Figure 21**). CSLAP determines the group of algae using chlorophyll α fluorescence that is attributed to various groups (Kring et al. 2014).

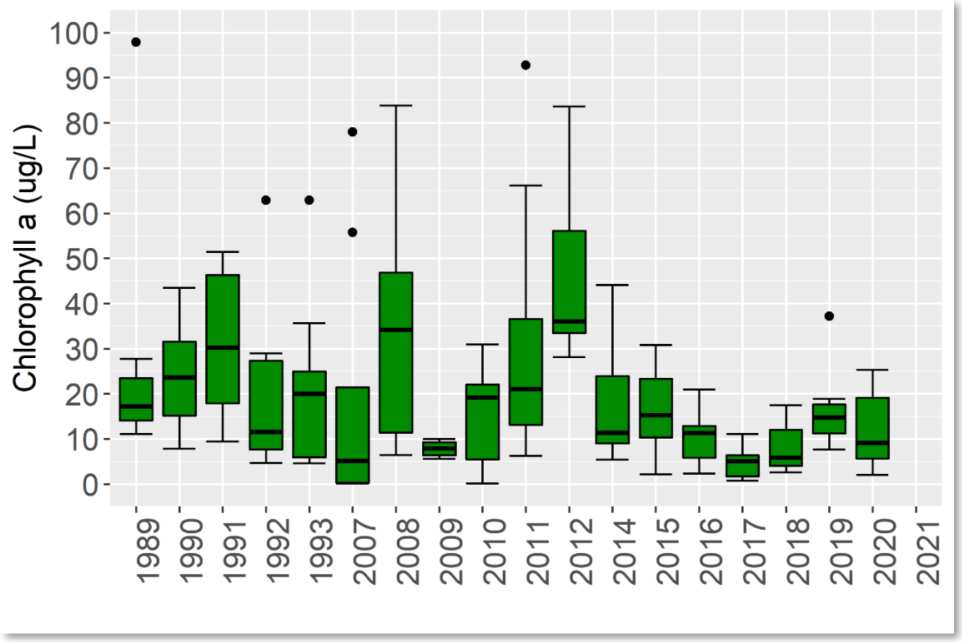


Figure 20. *Historical chlorophyll α values from CSLAP sampling.*

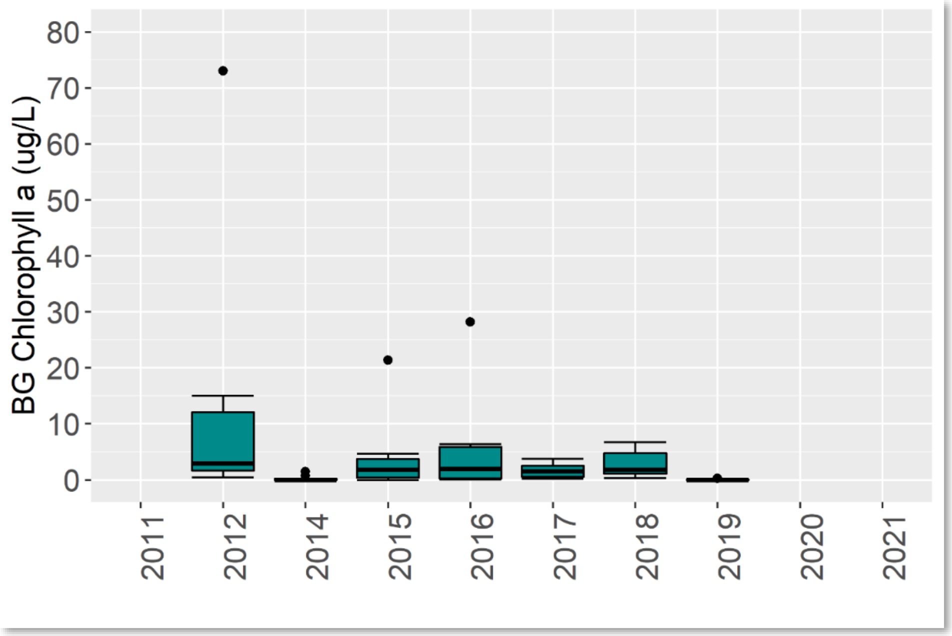


Figure 21. *Historical chlorophyll α attributed to blue-green algae via CSLAP. See Kring et al. 2014 for explanation of blue-green attributed chlorophyll α.*

Zooplankton

Zooplankton were collected using a 63-micron Wisconsin net towed vertically from 1m off the bottom to the surface. The most abundant group of zooplankton were the rotifers, which were most observed at the end of the season (**Figure 22**). Copepods, which consisted primarily of cyclopoids, were the second most abundant group, followed by cladocerans. Within the Cladocerans, which are the most important group in terms of filtering capacity, *Daphnia* was the most abundant genera overall, with peaks present in April, June, and October (**Figure 23**).

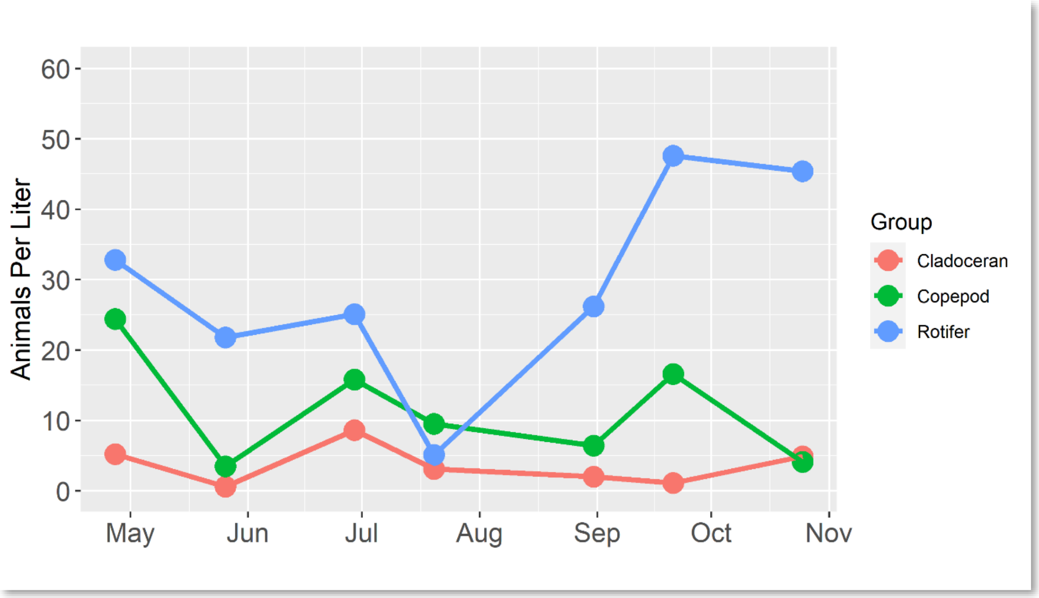


***Figure 22**. Robinson Pond major zooplankton groups at the deep station in 2021.*

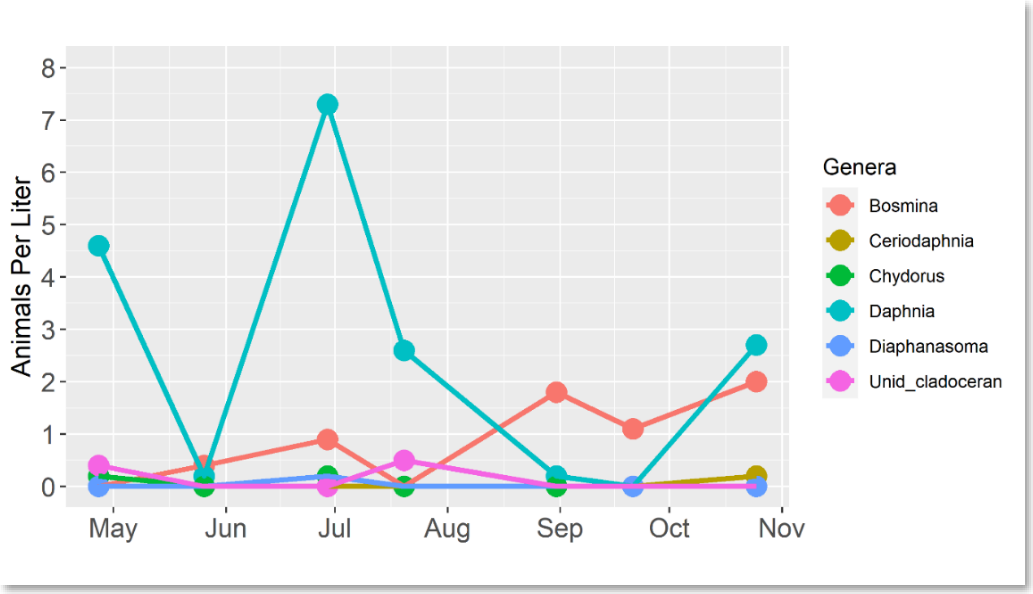


***Figure 23**. Robinson Pond Cladoceran genera at the deep station in 2021*

Daphnia, which are the single most important zooplankton taxa for water quality, were found to be mainly between 0.6 mm and 1.2 mm in length (**Figure 24**). Typically, animals will not exceed 0.4-0.6 mm under fish predation. Planktonic fish such as alewife and rainbow smelt feed aggressively on Daphnia and can reduce their numbers drastically. In turn, a pond with severely reduced numbers does not have a built-in defense against algae growth, which in turn decreases water clarity. The Daphnia length data do indicate that fish predation has not been enough to crash the population and shift to smaller size class organisms.

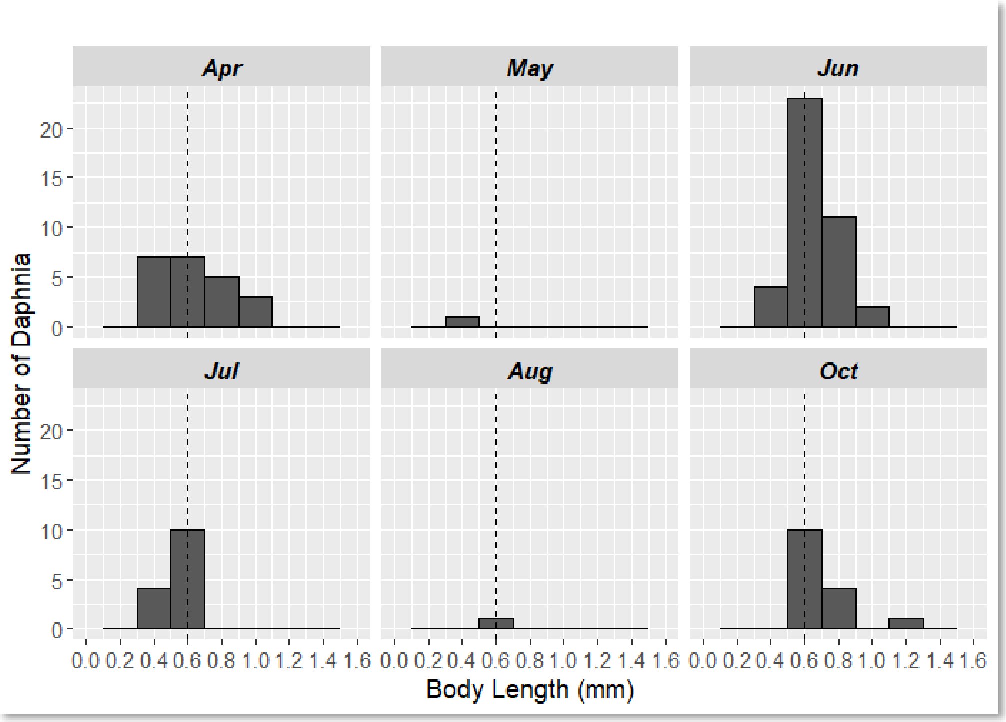


Figure 24*. Robinson Pond Daphnia length frequency (mm) for 2021 by sampling month. Dotted line indicates threshold length where fish predation is present/absent.*

Aquatic Plants

Results

NEAR conducted a full-pond aquatic plant survey of Robinson Pond over three days: on June 29th, June 30th, and July 20th, 2021. A total of 238 waypoints were created throughout the pond during the survey. Except for the deep section in Zone 7, the entire pond was covered in plants. The surface area of the pond is approximately 112 acres, and the littoral zone is approximately 105 acres. This indicates approximately 94% of the surface area of the pond is suitable for plant growth.

We found 27 species of aquatic plants in Robinson Pond during the 2021 survey (**Table 7**). The most abundant species was the invasive aquatic plant Eurasian Watermilfoil (*Myriophyllum spicatum)* followed by the tiny floating leaved plants Minor Duckweed (*Lemna minor*) and Watermeal (*Wolffia* sp), and Coontail (*Certatophyllum demersum*). Green filamentous algae was abundant in multiple locations, often intermixed with other submersed plants.

***Table 7**. Scientific and common names of all plants found during 2021 survey in order of decreasing frequency. Invasive species are highlighted in red.*

Scientific Name	Common Name	Percent Occurrence	Average Percent Cover
Myriophyllum spicatum	Eurasian Watermilfoil	78	30
Lemna sp.	Duckweed	66	25
Ceratophyllum demersum	Coontail	62	49
Spirogyra/Zignema	Green filamentous algae	62	24
Wolffia sp.	Watermeal .	41	22
Stuckenia pectinata	Sago Pondweed	15	47
Elodea canadensis	Canadian waterweed	6	6
Lyngbya sp.	Cyanobacteria mat	6	23
Najas flexilis	Nodding water nymph	6	8
Typha sp.	Cattail	5	58
Ludwigia sp.	Water purslane	4	8
Trapa natans	Water chestnut	4	8
Waternet	Hydrodictyon	4	28
Potamogeton crispus	Curly-leaf Pondweed	3	8
Najas minor	Brittle naiad	2	14
Nuphar variegata	Yellow waterlily	2	15
Ranunculus trichophyllus	Thread-leaf crowfoot	2	11
Phragmites australis	Common reed	1	60
Potamogeton foliosus	Leafy Pondweed	1	10
Potamogeton hillii	Hill's Pondweed	1	12
Potamogeton natans	Floating Pondweed	1	18
Elodea nuttalli	Nuttall's waterweed	<1	8
Nitella sp.	Stonewort.	<1	5
Nymphaea odorata	White waterlily	<1	20

Pontedaria cordata	Pickerelweed	<1	15
Potamogeton praelongus	White-stem Pondweed	<1	5
Sparganium sp.	Emergent bur-reed	<1	10

Eurasian Watermilfoil

Eurasian Watermilfoil was the most frequently observed species in the pond (78%) and was widespread throughout the entire littoral zone (**Figure 25**). The majority of plants were growing to the surface or just beneath the surface. Since the survey took place in late June/early July, the plants were still actively growing and did not reach their maximum biomass until much later in the season. Zones 1, 2, 5 and the southeastern portion of zone 6 had the most milfoil, with less observed in zone 8. Eurasian Watermilfoil was distributed well throughout Zone 4 and 3 but was not very abundant.

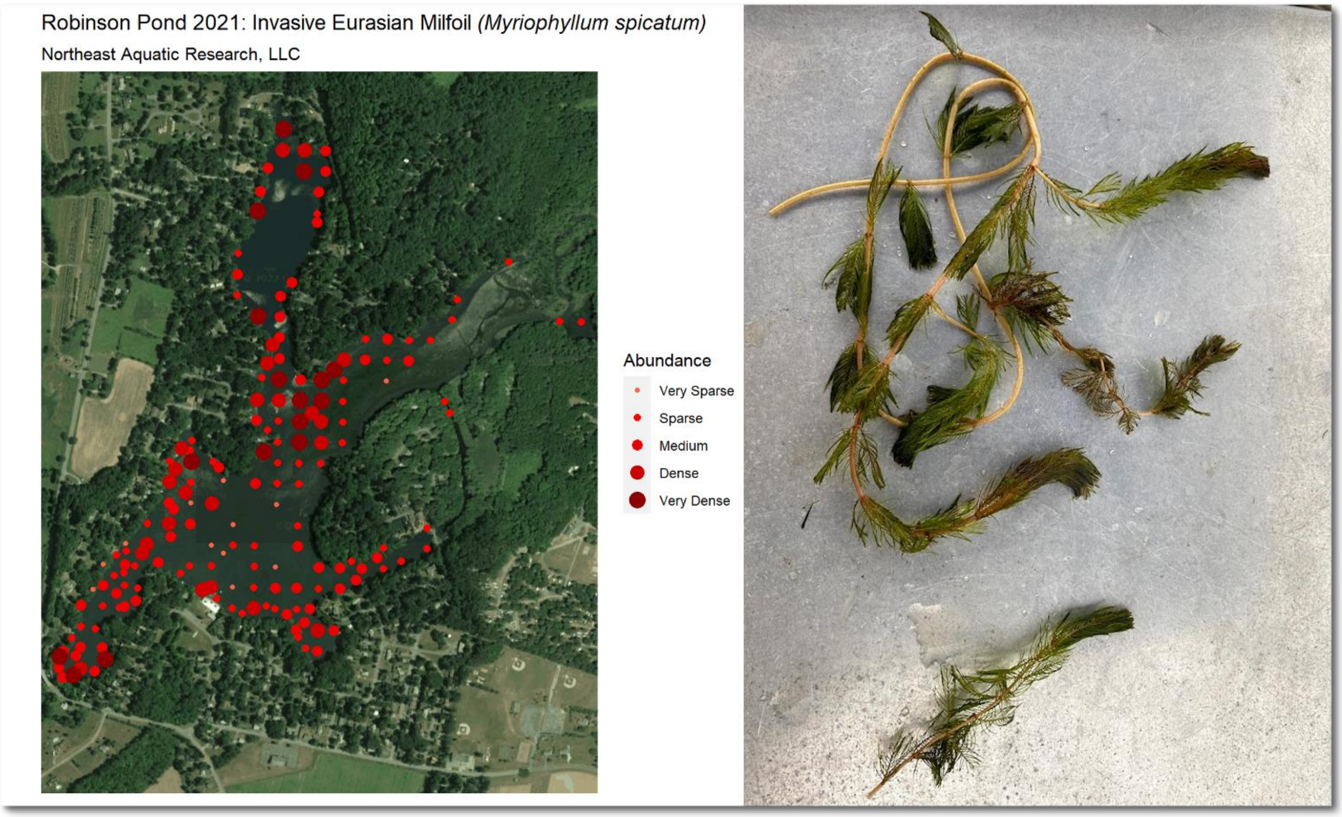


***Figure 25**. Map showing locations of Eurasian Watermilfoil in Robinson Pond 2021, left; and photograph of shoots of Eurasian milfoil, right.*

Duckweed/Watermeal

Duckweed and Watermeal (*Wolffia sp*.) were very abundant throughout the pond (**Figure 26**). Duckweed was the second most common species observed in the pond at 66% and with a mean percent cover of 25%. Watermeal was the fourth most abundant species, found at 41% frequency with an average density of 22% (**Table 7**). Together, both species were the densest in Zone 8 (**Figure 3**), where they covered the entire surface of the water (**Figure 26**, **Photos 1 and 2**). Zone 8 has long been a problem area for Duckweed/Watermeal growth. Wind most likely plays a large role in the distribution of these plants, as there was a significant amount of these plants pushed up on the beach in zone 3. The distribution for most of the lake will likely change as wind patterns change. The presence of both these species in high abundance is most likely linked to the high amount of nitrogen in the pond, and a complete lack of water circulation and flushing. Both species get 100% of their nutrients from the water column unlike most other submersed aquatic plants.

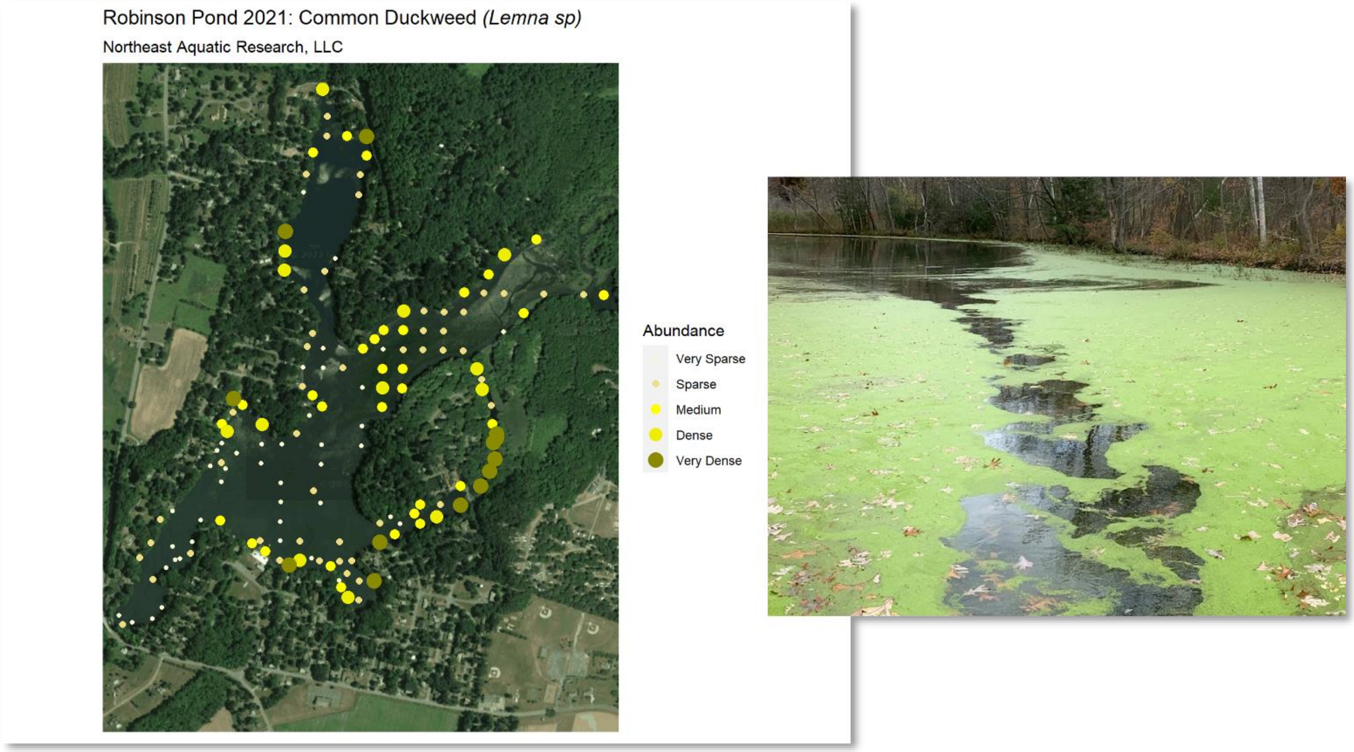


Figure 26. *Map of locations of Duckweed in Robinson Pond in 2021, left and photograph of dense cover of Duckweed/Watermeal right.*

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***Photo 1**, left, Duckweed and Watermeal growing in association with an inflow*
***Photo 2**, right, Duckweed and Watermeal along a shore of dense cattails*

Coontail

Coontail was widespread throughout the littoral zone of the pond and was the densest in the southern half of the pond in zones 1-4, along with around the edges of zone 7. (**Figure 27**). Coontail was not as abundant in Zone 6 (**Figure 3** pg 8). It was found at 62% frequency and an average density of 49% (Table 1). Similar to Duckweed and Watermeal, Coontail derives a substantial amount of its nutrients from the water column, allowing high grow rates when the phosphorus concentration in the pond water is high.

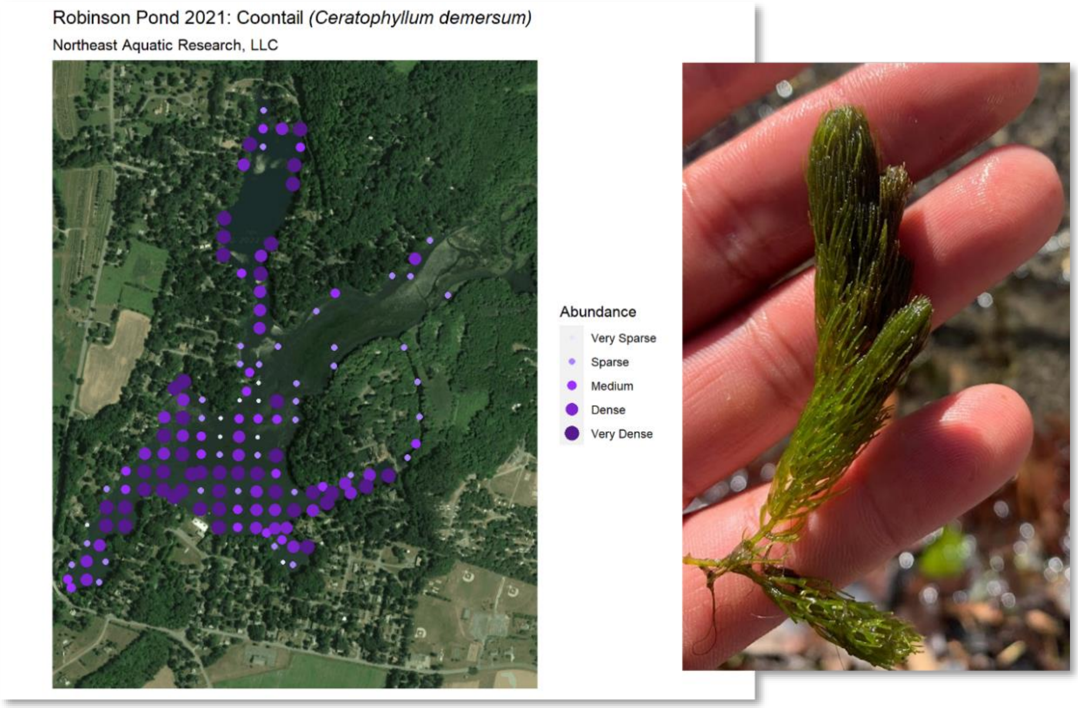

***Figure 27**. Map of locations and densities of Coontail in Robinson Pond in 2021 left, and photograph of Coontail close up right.*

Cattail Management

2021 saw an expansion of the useable open area in zone 6 (**Figure 3** pg 8) via the reduction in cattails. Cattails in this area were reduced primarily via three forces: increased water level, mechanical harvesting effort, and hydro raking efforts. Water levels in Robinson Pond were returned to normal fluctuations in 2021 as compared to 2020, making much of the expanded cattail habitat uninhabitable for the species. Water level stabilization especially affected plants that were cut below the water line during 2020 and 2021 (**Photo 3**). Cutting cattails below the waterline effectively drowns the plants. The hydro raking also helped to clear the channel where growth was inhibiting navigation the most. By the end of October, the open water area returned to the original extent of the cattails prior to drawdown.

***Photo 3**. Cattail stalks cut below the surface via the harvester*

***Figure 28**. Sequence of cattail management October 2020 through October 2021 in zone 6. All photos are looking south from same position.*

Discussion

General Conclusions

Based on the collected data, Robinson Pond is a stressed, eutrophic waterbody with reduced recreational opportunities. Phosphorus concentrations often exceeded 30 µg/L, the threshold for cyanobacteria dominance. Aquatic plants, both submersed and tiny floating leaved species, were abundant to very abundant in the pond. Dense beds of aquatic plants and surface covering by floating plants can cause significant internal loading rates from bottom sediments and from decomposition of sluffing plant parts during the season. In the short term, management should be geared at maximizing the recreational opportunities while maintaining the positive functioning the plants provide. Longer term management should be aimed at reducing the nutrient inputs into Robinson Pond, which will help mute any negative effects from aggressively managing vegetation and should reduce the quantity of nuisance plants.

Long-term management of Robinson Pond is needed but will be difficult because the pond is essentially a sediment detention basin for the entirety of the Roe-Jan Kill watershed. It is expected that a large fraction of the sediment load of the river is retained in the pond. Removing all this material from the pond would be a lengthy and extremely expensive project with no guarantee that the project would be permittable. The strategies we are proposing, even in the long term, will not be enough to completely change the dynamics of the system. Short of removing all the sediments, putting the entirety of the pond on sewer and transforming the entirety of the watershed back into forested land, Robinson Pond will remain largely a shallow, productive system supporting dense vegetation growth. Our short- and long-term strategies are aimed at maximizing the uses of the pond, while understanding the limitations presented via the landscape and position of Robinson Pond along the Roe-Jan.

Circulation System

The circulation system, in operation since 2018, is naturally a large focus of the water quality of Robinson Pond. Zone 7 (**Figure 3,** pg. 6) represents the deepest and most weed-free section of the pond, where many boaters and swimmers enjoy the open water. Based on the data collected during the 2021 season and comparisons with previous data, the effects of the circulation system are a mixed bag. On one hand, the circulation system, when operating properly, did break stratification and increase oxygen concentrations at the pond bottom. This increase in dissolved oxygen did seem to lead to a decrease in bottom phosphorus concentrations. Blue green algae attributed chlorophyll α decreased in year 2 and 3 of operation. On the other hand, surface phosphorus has not significantly changed and is still mostly within the eutrophic range and while water clarity has increased, the increase started before the system was installed. Chlorophyll-α has increased in the three years of operation. In addition, the sediments still lack oxygen even when the overlying waters have oxygen suggesting that internal loading may still be happening. Underwriting all of this is the operation timeline which is full of outages and less than optimal performance.

Timeline of Circulation (Derived from Billiing Records and Notes from TSPOA Office):
2017: System proposed by Solitude Lake Management
2018: System installed by Solitude Lake Management
2018-2020: System operating properly
Early 2021: System not working, multiple power outages shut system off. Maitenance replaced a significant amount of the system.
July 2021: System fully operational
September 2021: Slight outage
January 2022: Pressure value went and system is currently down

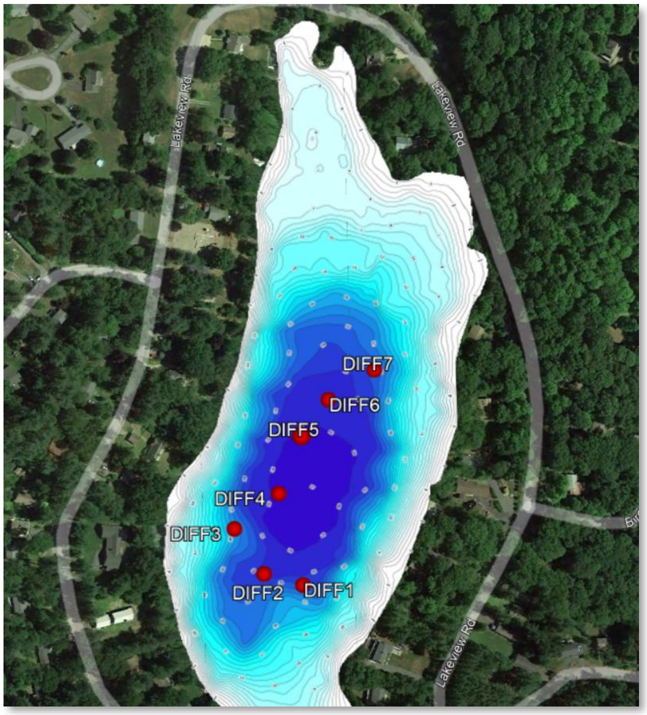

***Figure 29**. Current spacing of diffusers operational as of 8-31-21*

Without continuous proper operation and the solid monitoring data to back it up, it is difficult to ascertain how effective the system has been. Based on the extent of anoxia documented in 2012, prior to system installation (**Figure 14**), there is a compelling reason to have a system in place to increase oxygen. NEAR recomends that the diffusers remain in place for now, as there has not been any large negative effects observed. There are a few operational aspects that can be improved upon to give the system the best chance of maximizing its potential. First, the system should be fully operational before the stratification season sets in. A circulation system is most effective when it prevents the lake from stratifying, not breaking stratification after it has happened. Earlier operation keeps oxygen loss from accumulating, thereby providing more favorable conditions for the season. To save power, the circualtion system does not need to operate during the winte months. There is very little benefit to operating the system during winter as the benefits of the system are most realized during the summer season. Turning the system off in mid November and restarting in March allows for maitenance of the lines/compressors and saves on electricity costs.

The TSPOA should also invest in a few more diffuser lines to cover more of the deep zone. Currently, the system appears to be undersized, as the distance between diffusers being 130-150ft is too large of a gap to facilitate proper mixing and entrainment of algae. Circulation systems only have a strong field of effect roughly twice the horizonal distance of the depth at which they are placed at (Zic and Stefan 1994). Meaning that the diffusers that are placed in 25 feet of water only have a fuctional impact at distances no farther than 50 feet away. Placing diffusers within 50 feet of eachother while covering the entire deep zone would mean more than doubling the amount of diffusers, which may not be feasible based on compressor capacity. NEAR recomends adding enough diffusers to achieve a maximum distance of 100ft between units to maximize circulation impacts.

These changes should be monitored for 2-3 years to ascertain how the system perfomes. At the end of this period, the value of the system can be re-evaluated and a decision be made concering keeping it in place, or moving in a different direction.

Recommendations for Circulation System:

- **Adjust operation of system to run from March to the beginning of December.**
- **Increase the number of diffusers to adequately cover the deep zone.**
- **Monitor for a few years with continuous operation to assess full effectiveness and value of system.**

Influence of the Roeliff-Jansen Kill

Lakes and ponds are often reflections of their watersheds. The more developed a watershed becomes, the more pollutants reach the receiving waterbody. This is true for Robinson Pond, which has an extremely large watershed relative to its size. Waterbodies with watersheds that are more than 10 times larger than itself are greatly influenced by the surrounding landscape. The watershed for Robinson Pond is 21,632 acres, which is ~206 times the size of the pond. Therefore, the watershed and quality of the incoming water has a tremendous impact on water quality within the pond itself. The watershed contains a large amount of agricultural land, which adds a lot of nitrogen and phosphorus to the surrounding streams.

Within the Robinson Pond watershed, the Roe-Jan Kill makes up the vast majority of watershed area (96%). Because of this, any management of Robinson Pond’s water quality should start with the management of the Roe-Jan. Managing large river systems is incredibly complicated due to the diversity of land uses and multiple stakeholders. NEAR is proposing a two-pronged strategy for nutrient management: first, nutrient filtering and interception at the point of entry and second, watershed management for long term nutrient reductions.

Nutrient and Sediment Interception at Roe-Jan Inlet

Filtering nutrients out of the Roe-Jan Kill involves the construction of a settling complex using a combination of wetland plants and filtering devices. NEAR believes the most convenient place for this is at the cove area above zone 8 (42.120797, -73.548186). This is a naturally shallow area that can be used to diffuse flow over a wide area, settling out large particulates. The area would have a combination of wetland plants sufficiently able to uptake phosphorus and nitrogen and nutrient removal technologies such as Biochar and Eutrosorb™ (**Figure 30**).

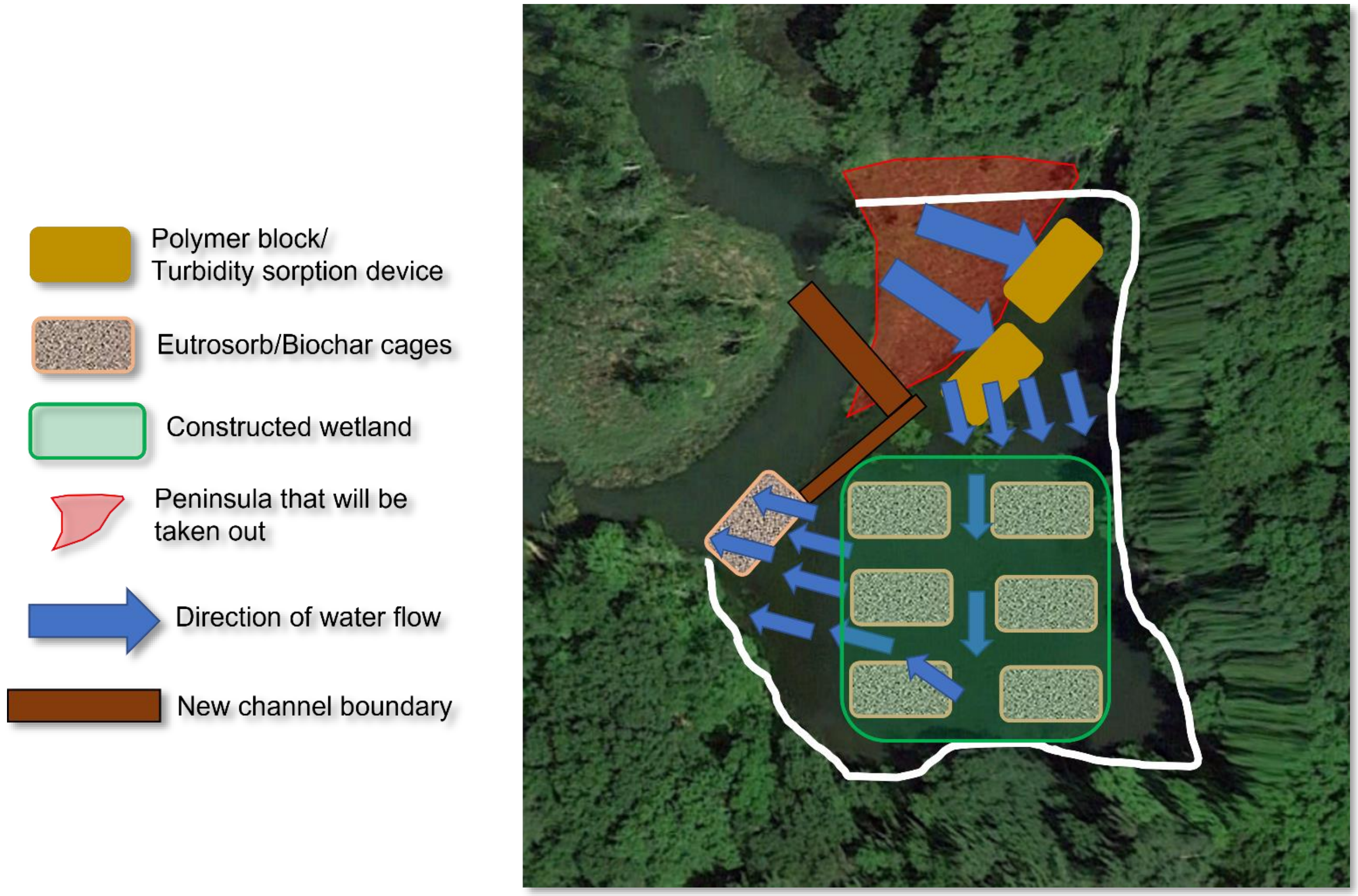

Figure 30*. Conceptual design for Roe-Jan filtering apparatus.*

Figure 30 shows one conceptual design for reducing nutrient and sediment inputs from the Roe-Jan. In this design, the peninsula shaded in red would be removed and the material placed as a new bank, extending the southern bank of the river (Brown rectangle). This will open the mouth of the river up and spread the flow out, reducing its velocity. At this point, the flow will encounter either a polymer block/turbidity sorption device or a settling basin aimed at settling out larger particulates. From there, the flow will move into a constructed wetland filled with plants that are efficient at up taking both phosphorus and nitrogen. Filtering media such as Eutrosorb™ and/or biochar can be placed within the constructed wetland to aid in nutrient uptake. Once the water makes its way through the wetland, it will reenter the channel where additional filtering apparatuses are placed to provide additional nutrient removal.

Eutrosorb™ and biochar can be placed in more than just the constructed wetland area. Both products are contained within porous filter bags that can be placed in a variety of locations. Eutrosorb™ is a filtering technology that specifically targets soluble phosphate ions, which is the most readily available form for algae and plant uptake. Biochar is a charcoal-like substance that’s made by burning organic material in a controlled process called pyrolysis. Biochar also removes soluble phosphate along with a few other organic pollutants.

It is important to stress that this is only one kind of design, and these sorts of constructed wetlands/nutrient mitigation strategies can take on a variety of forms depending on the site-specific conditions. NEAR suggests that the TSPOA start the process of soliciting designs and cost estimates from engineering firms to assess feasibility. Constant communication with DEC staff should take place throughout the entirety of the process to ensure any designs comply with regulations and proper permits are in place.

Large-scale Watershed Management

Taking a larger view of the Roe-Jan nutrient inputs, all the water and pollutants entering the pond, and what the filtering design attempts to capture, originates within the large and complex watershed. The summation of land use practices across the landscape is represented in the amount of nutrients flowing into the pond. If nutrient concentrations are ever going to be reduced in a meaningful way, mitigation of upstream sources of pollution must be undertaken.

The land-use of the Robinson Pond watershed is filled with agricultural practices which invariably increase the amount of nitrogen and phosphorus entering the Roe-Jan. This is not intentional pollution, just a consequence of that particular land-use practice happening near a stream. It is difficult to pinpoint nutrient hotspots within such a large area, meaning it could be from one source or from multiple locations.

NEAR suggests that the TSPOA engage some of the key stakeholders in the Roe-Jan Kill watershed to address watershed wide nutrient pollution issues. Groups to reach out to include but are not limited to the Roe-Jan Watershed Community, National Resource Conservation Service, Department of Environmental Region 4 Offices, Cornell Cooperative Extension Office and Columbia County Soil and Water Conservation District. Each of these groups have differing perspectives and ideas concerning management of the river.

Recommendations for Roe Jan Kill

- **Explore using the cove north of zone 8 for nutrient and sediment interception.**
    - **Solicit costs and engage DEC in preliminary permitting talks.**
- **Engage various stakeholder groups from the Roe-Jan upstream to discuss nutrient mitigation above Robinson Pond.**
    - **Move toward 9-element plan for Roe Jan Kill in the future.**

Aquatic Plant Management

Due to the shallow nature of Robinson Pond along with significant nutrient inputs, excess vegetation will most likely continue to be a major issue for recreational lake users. As discussed in the general conclusions section, management of vegetation needs to consider the interlinked nature of vegetation and water quality. In the very long term, nutrient reduction should help slow the growth of aquatic plants, but this may not happen for decades, even with successful nutrient input reductions. Therefore, we will discuss management techniques to limit aquatic plant growth to increase recreational opportunity while being careful to not remove too much vegetation.

Eurasian Watermilfoil

For Eurasian Watermilfoil, Florpyrauxifen-benzyl (Trade name: ProcellaCOR) is an excellent option for control. With short required contact time (a few hours at most), low non-target impacts (Beets et al. 2019; Buczek et al. 2020) and low use rates for milfoil control (Beets et al. 2019; Mudge et al. 2021), ProcellaCOR can effectively control milfoil in a variety of application scenarios. The TSPOA is planning on using ProcellaCOR to control milfoil within Zone 5 and parts of Zone 6. Monitoring of the plant community post treatment should allow us to understand how effective the treatment is and if this practice should continue in the future.

Duckweed

Duckweed control presents more complications than Eurasian Watermilfoil control. Duckweed plants can rapidly reproduce and repopulate after control efforts, so outside of nutrient reduction to the point where the water chemistry does not favor Duckweed growth, long term control is limited. Fluridone would normally be a good option for control, but the short residence time in Robinson Pond and the inability to completely retain site water makes this herbicide infeasible. Flumioxazin and Diquat despite being contact herbicides require significant use restrictions (5 and 14 day respectively). NEAR believes the best option for short term Duckweed control is the use of a copper-based herbicide, either Nautique or Komeen applied multiple times per year. Both have very limited use restrictions and can also have activity on filamentous algae, which can be a nuisance as well. As with Eurasian Watermilfoil, post treatment monitoring should elucidate how successful this approach is and adjustments can be made depending on the monitoring data.

Recommendations:

- **Monitor ProcellaCOR treatment to gauge effectiveness.**
- **Investigate the use of copper-based herbicides like Komeen or Nautique for Duckweed control. Multiple treatments may be needed in problem areas.**

Plant Harvesting

Harvesting for Plant Control

Controlling Eurasian Watermilfoil and Duckweed using herbicides is a targeted approach but will not address general plant growth throughout the lake that may interfere with recreational uses. The plant harvester can continue to clear access lanes for boating and swimming throughout all zones of the lake. Even though the results do not last the entire season, owning the harvesting infrastructure allows for multiple passes through a particular area leading to longer control at a reasonable expense. The harvester should focus on creating lanes for swimming and boating which allow for recreation to occur, but also leaving some native vegetation in place. Having stands of dense vegetation here and there is not the worst thing especially if there is an adequate amount of open water where recreation can occur. This matrix of vegetated and non-vegetated areas creates edge habitats which are ecologically rich, providing key habitat for fish and macroinvertebrates. The goal should not be to remove all native vegetation, just enough to have sufficient recreational opportunities along with ecological stability. Zones 1 and 2 may need additional attention from the harvester as it is unlikely these areas being so close to the outlet will receive significant plant control from the harvester.

Harvesting Tracking

Current tracking methods employed by the TSPOA are extremely thorough, with daily logs detailing everything from number of loads and disposal runs, start time and end time, plant composition, weather conditions and wildlife presence. These records provide excellent context and insight into what has been done in the previous year. To supplement the written data tracking, NEAR suggests that the TSPOA investigates the use of an automated GPS tracker that would be installed on each harvester. This allows the harvester's movements to be automatically tracked, providing detailed information on harvesting times and usage both on a daily, weekly and seasonal basis. NEAR has worked with one client in the past who has used this technology to great effect. Areas that are frequently harvested can be effectively categorized and decisions concerning efficacy can be made (**Figure 31**). This automated tracking can also reduce the amount of record keeping required from the harvesting crew. This data also provides context for future plant surveys; the 2021 plant survey was done at a time when the harvest was actively working around the lake, which influences the results of the survey.

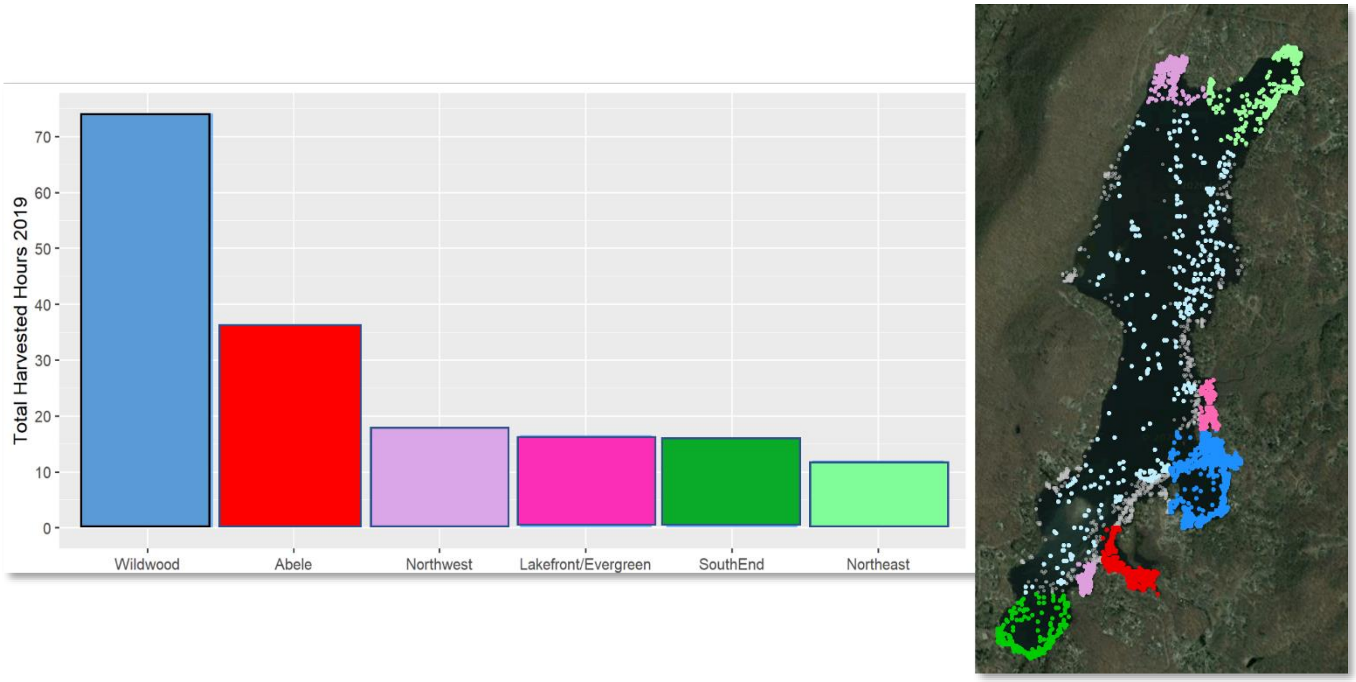

***Figure 31**. Example of data from automated data tracker for harvesting effort. With this data, the association will be able to pinpoint the exact locations where harvesting efforts take place.*

Harvesting for Nutrient Removal

There is potential for removal of nutrients through harvesting methods. With over 80% of the lake's surface area vegetated, these plants certainly play a large role in nutrient cycling and lake functioning. Plants help reduce nutrients in the water column by slowing water flow and settling out sediment particles. These sediment particles have nutrients attached to them, which move to the sediments. Plants like Duckweed, Watermeal, and Coontail uptake nitrogen and phosphorus from the water column, which makes those nutrients unavailable for algae growth.

Plant harvesting can have a significant effect on the total nutrient load of shallow lakes and ponds. At Lake Wingra, harvesting has removed an estimated 37% of the net load of P from the lake (Carpenter and Adams 1978). A small, urban lake in Minnesota was able to remove 57% of its phosphorus load using harvesting (Bartodziej et al. 2017). Both lakes had a significant amount of their littoral zone covered in plants, similar to Robinson Pond.

Plant harvesting in Robinson Pond is already an established technique aimed at increasing navigation and recreational opportunities. NEAR suggests that the amount of nutrient removal from harvesting be calculated in 2022 using existing harvesting loads. From that figure, we can estimate the total amount of phosphorus removed and determine how much harvesting effort is needed to make a difference in nutrient amounts. This can also be done for the skimming operation with Duckweed and filamentous algae.

Timing of Harvesting

The timing of harvesting is dependent on when plant growth is starting to interfere with recreation. This can be considerably earlier than when harvesting will be at its most effective for nutrient removal. Most lakes in the northeast will reach maximum plant biomass in August and September, which is the best time to remove them. Earlier removal limits the amount of plant uptake and later removal means that the plants dying off have already released a portion of their nutrients into the water column. Depending on the other management techniques implemented, most of the harvesting effort can be pushed into the end of August/early September. Earlier harvesting can occur to clear boat lanes and skim for Duckweed/Watermeal. The use of herbicides can also assist in knocking down milfoil earlier in the season to allow for recreation.

Location of Harvesting

Based on the 2021 plant survey, most of the dense growth occurs in zones 2 to 5. These areas have a ton of coontail that is a great candidate for nutrient removal. This should be the focus area for August/September harvesting.

Recommendations for Harvesting

- **Continue to keep boating and swimming lanes accessible throughout the year.**
- **Focus on areas where herbicide will most likely not be used such as zones 1 and 2.**
- **Supplement data tracking with automated GPS tracking of the harvester.**
- **Determine the amount of P and N removed via harvesting efforts and compare that to annual load.**
- **Initiate aggressive end of season (late august/early September) harvesting in zones blank and blank for nutrient removal.**

Summary of Recommendations

Recommendations for Circulation System:

- **Adjust operation of system to run from March to the beginning of December.**
- **Increase the number of diffusers to adequately cover the deep zone.**
- **Monitor for a few years with continuous operation to assess full effectiveness and value of system.**

Recommendations for Roe-Jan Kill

- **Explore using the cove north of zone 8 for nutrient and sediment interception.**
    - **Solicit costs and engage DEC in preliminary permitting talks.**
- **Engage various stakeholder groups from the Roe-Jan upstream to discuss nutrient mitigation above Robinson Pond.**
    - **Move toward 9-element plan for Roe-Jan Kill in the future.**

Recommendations For Herbicide Treatments

- **Monitor ProcellaCOR treatment to gauge effectiveness.**
- **Investigate the use of copper-based herbicides like Komeen or Nautique for Duckweed control. Multiple treatments may be needed in consistent problem areas.**

Recommendations for Harvesting

- **Continue to keep boating and swimming lanes accessible throughout the year.**
- **Focus on areas where herbicide will most likely not be used such as zones 1 and 2.**
- **Supplement data tracking with automated GPS tracking of the harvester.**
- **Determine the amount of P and N removed via harvesting efforts and compare that to annual load.**
- **Initiate aggressive end of season (late august/early September) harvesting in zones blank and blank for nutrient removal.**

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Appendix

Survey Methods

General survey methods involved using a combination of pre-determined waypoints that can be re-visited and supplemental to add to distribution and abundance information. In the point-intercept survey style, waypoints were pre-determined at fixed intervals (~150ft) throughout the littoral zone (area where plants can grow based on available light). These points were generated using the ARC GIS fishnet tool. Pre-determined waypoints can be used for replication in future years, to assess changes over time or in response to plant management actions. However, pre-determined waypoints may underestimate true plant coverage, in that they can sometimes underestimate the true heterogeneity of a plant community. Supplemental points made in the field can help complete the survey picture.

At each waypoint, either a long-handled (16ft) rake, or a 14-tine double-sided garden rake attached to a 10m rope, was used to collect specimens of all species at that point. The water depth and plant density were recorded at each waypoint. Plant coverage was determined using a combination of three methods. The visual density determination method is based solely on what is visible from the surface. This method involves using a hypothetical quadrat (**Figure 32**). In this method, the surveyor visually estimates how much area is covered by the plant in question. Surveyors visualized a hypothetical quadrat approximately 15ft X 15ft around the boat, then estimated coverage accordingly. Visual estimates are made by a single person during the survey, but the entire team has input on the final estimate to ensure accuracy.

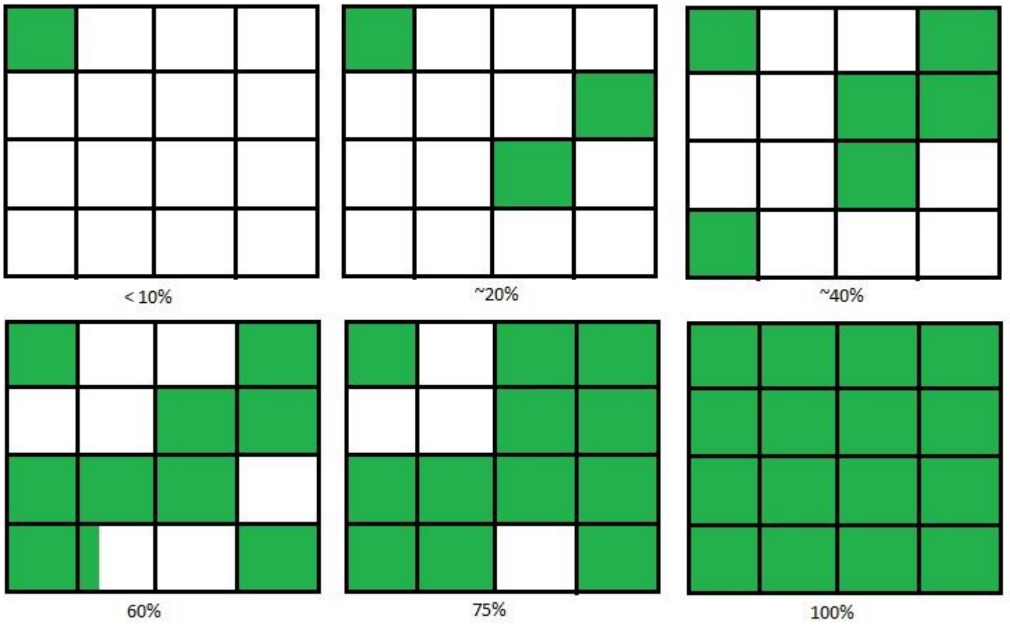

Figure 32. *Example of hypothetical quadrat that is visualized by the surveyors*.

The second method used to estimate the percent coverage of vegetation is to use the down-imaging SONAR images of the plants as the boat passes above (**Figure 33**). In areas where plants cannot be seen from the surface, the SONAR images become extremely useful for percent coverage estimations, along with weed-rake tosses. The third method involves stopping the boat and throwing the 10m tow line and rake head and/or raking the bottom with the long-handled rake through the plant bed. SONAR and visual estimates are corroborated by rake tosses. When possible, all three ways of estimating the percent cover are used at each waypoint, and the resulting estimate is recorded on the datasheet. Using those three measurements in conjunction with themselves achieves the most accurate estimate of plant coverage possible during surveying.

Figure 33. Sonar imagery of plant height during survey. The red circle indicates low growing plants on sonar down scan unit.