

**2021 Water Quality Report
And
Historical Analysis
Long Lake
Mickey Lake
Ruth Lake**

Monitoring Years 1993-2021

Submitted to:
Long Lake Association
Long Lake Foundation
Oleson Foundation
Long Lake Township

Prepared with the assistance of:



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Reference Information



Figure 1. Water quality sampling sites on Long Lake, 1997-2021

| LAKE | SAMPLE SITE | LATITUDE | LONGITUDE |
|-------------|-------------|-----------|------------|
| Long Lake | #1 | 44.70383° | -85.74432° |
| | #2 | 44.72473° | -85.75612° |
| | #3 | 44.47409° | -85.76453° |
| Mickey Lake | #1 | 44.73257° | -85.76640° |
| | #2 | 44.73217° | -85.76867° |
| Ruth Lake | #1 | 44.69483° | -85.76255° |

Table 1. Trophic State Classification (Chapra, 1997)

| Variable | Oligotrophic | Mesotrophic | Eutrophic |
|----------|--------------|-------------|-----------|
|----------|--------------|-------------|-----------|

| | | | |
|----------------------------|-----|-------|-----|
| Total Phosphorus (µg/L) | <10 | 10-20 | >20 |
| Chlorophyll a (µg/L) | <4 | 4-10 | >10 |
| Secchi depth (m) | >4 | 2-4 | <2 |
| Hypolimnion Oxygen (% sat) | >80 | 10-80 | <10 |

Table 2. Phosphorus Data for Area Lakes and Sediments (GLEC, 2006, p. 12)

| <u>Lake</u> | <u>Water Total Phosphorus (µg/L)</u> | <u>Sediment Phosphorus (mg TP/kg DW)</u> |
|-----------------|--|--|
| Torch | 1.7 | 86 |
| Burt | 2.2 | 119 |
| Lime | 4.4 | 200 |
| Crystal | 4.8 | 332 |
| North Leelanau | 4.8 | 489 |
| South Leelanau | 4.9 | 398 |
| Glen | 5.1 | 326 |
| Little Traverse | 5.1 | 401 |
| Cedar | 5.3 | 396 |
| Platte | 7.7 | 620 |

For a comparison of lake quality in Michigan, see: *Water-Quality Characteristics of Michigan's Inland Lakes, 2001–10* https://pubs.usgs.gov/sir/2011/5233/pdf/sir2011-5233_web.pdf

Trophic Status: A measure of lake productivity

Oligotrophic Lakes: Display lower aquatic plant production and nutrient levels (typically referring to phosphorus levels). Usually deep and clear water. Cool, oxygen-rich bottom waters are home to cold-water fish, including whitefish and trout.

Eutrophic Lakes: Display high aquatic plant production and nutrient levels. Typically shallow and murky, turbid water. Oxygen-depleted bottom are home to warm water fish, including pike and bass.

Mesotrophic Lakes: Lakes that display characteristics between oligotrophic and eutrophic status. These lakes may be undergoing eutrophication.

Eutrophication: Lakes naturally move from an oligotrophic lake to a eutrophic lake throughout their lifetimes. Most lakes start very large and clear and slowly warm up and fill in with sediment over time. This is a natural process that takes thousands of years.

Cultural Eutrophication: Humans can speed up the eutrophication process by adding excess nutrients and sediments to the lake. It is important to monitor lakes to establish historical trends that will help show if cultural eutrophication is occurring there.

2021 Executive Summary of Results:

The 2021 analysis of data from Long, Mickey, and Ruth lakes showed very little change compared to previous years overall. As a reminder: only very limited testing was conducted during the 2020 season because of pandemic related limitations.

Long Lake parameters were similar to the previous testing season. Phosphorus levels fall into mesotrophic and oligotrophic levels, and were slightly lower than the previous year. Chlorophyll a levels were still within the range of an oligotrophic lake, but were higher than the previous year. Calcium levels were slightly higher, and with the discovery of Zebra Mussels within Long Lake, need to be carefully monitored even though levels are not yet at the point where large Zebra Mussel colonies can establish. Secchi depth readings remained within the oligotrophic range.

Mickey Lake parameters remain within the oligotrophic or mesotrophic levels, other than some eutrophic total phosphorus levels taken at depth. Calcium levels have reached the point at which Zebra Mussels have been able to colonize within a laboratory setting and should be closely monitored.

Ruth Lake remains a Eutrophic lake based on total phosphorus, chlorophyll a, and secchi measurements. Calcium levels have also increased but are not near the level where Zebra Mussels become a threat.

Section I: 2021 Lake Water Quality Assessment on Long Lake, Mickey Lake, and Ruth Lake

The 2021 Lake Monitoring for Long Lake, Mickey Lake, and Ruth Lake was initiated by the Long Lake Association, Long Lake Foundation, Oleson Foundation, and Long Lake Township in partnership with the Great Lakes Environmental Center (GLEC), the Great Lakes Water Studies Institute, and the Cooperative Lake Monitoring Program (CLMP). The Association is now using the CLMP protocols for water quality monitoring, including protocols for monitoring dissolved oxygen and temperature, obtaining secchi disk readings, obtaining phosphorus and chlorophyll a samples, identifying exotic aquatic plants, and conducting nearshore habitat assessments. The CLMP works with many lake associations and volunteer lake monitors around the state and has set state-wide standards for water quality monitoring. CLMP requirements included sampling in the early spring (two weeks after ice out) and sampling in the fall after the lakes have turned over. The only exception is chlorophyll a which is sampled twice yearly. The continuation of this lake monitoring program is essential for the assessment of lake water quality across the state, and it facilitates the comparison of data across monitoring years since protocols and meta data match each other across distance and time. This is crucial for establishing trends and taking appropriate actions during lake management.

Physical data collected during the 2021 water quality monitoring season was obtained with a secchi disk and a YSI multiparameter water quality probe which was graciously donated to us by the Long Lake Association, Long Lake Foundation, Oleson Foundation, and Long Lake Township. Both of these instruments measure physical water quality parameter levels such as temperature, dissolved oxygen, pH and conductivity. A plankton net was used this year, as it was in the past three years, to sample for zooplankton and phytoplankton. Water samples were taken

for the analysis of total phosphorus, both at the surface and near the bottom of the lakes.

Calcium, chlorophyll a, and nitrate/nitrite levels were also tested.

Long Lake

Water Chemistry

Total Phosphorus: Surface and bottom phosphorus were lower than levels observed in 2020, remaining in the mesotrophic and oligotrophic categories. The overall trend is remaining steady but levels should be carefully monitored. Limited testing during the 2020 season may cause a skew in the data.

Chlorophyll a: Chlorophyll a levels were higher than the 2020 levels in Long Lake, but still falling well within the oligotrophic range. This parameter should be carefully monitored as increase in Chlorophyll a levels is directly tied to the increased presence of lake nutrients.

Secchi Depth: Regular secchi depth measurements were taken this year, and readings remained within the normal range.

Calcium: Calcium levels were slightly higher than the 2020 season. The calcium level has been shown to be adequate for zebra mussels to colonize in a laboratory setting, but calcium levels are not yet thought to be high enough for lake colonization based on data focusing on European zebra mussel infestations. Small quantities of zebra mussels have been found in Long Lake.

Nitrogen (Nitrate/Nitrite): Levels remained stable throughout the sampling season and similar to 2020's levels.

Hydrolab (Physical Data)

Temperature and D.O. data shows stratification and seasonal changes as expected. Long Lake is the largest and deepest of the three lakes monitored.

Conclusions and Recommendations

Data collected during the 2021 testing season indicate Long Lake still holds the status of oligotrophic lake. While some parameters trended slightly higher and some slightly lower, all were within similar ranges of last year's data and within the range for oligotrophic status. 2020's data was limited, but this year's data falls in line with previous years as well. This is the 28th year Long Lake has maintained oligotrophic status, based on data collection that began in 1993. As development continues on the lakeshore and within the surrounding watershed it is critical that outreach and education efforts continue and focus on ways property owners can ensure Long Lake continues to be healthy. These include vegetation buffers, limited shoreline development, the emphasis of septic system monitoring and repair, and reduction of nutrient use within the watershed.

Mickey and Ruth Lake

Water Chemistry

Total Phosphorus:

- Mickey Lake: Total phosphorus levels in Mickey Lake continue to trend upwards, with depth readings at site 1 reaching Eutrophic levels. Surface levels remain on the oligotrophic and mesotrophic border.
- Ruth Lake: Total phosphorus levels remain similar to 2020's data, but, with such limited testing having occurred in 2020 it will be important to compare to upcoming year's data for a more accurate assessment.

Chlorophyll a:

- Mickey Lake: Chlorophyll a levels were lower this year than the previous year, which only had one measurement taken in the fall. Measurements remained within the oligotrophic range. Note: data variance each year should be expected as chlorophyll a is

highly sensitive to changes in plant life within the lake and the time of year measurements are taken.

- Ruth Lake: Chlorophyll a levels were in line with previous years measurements and stayed within the Eutrophic range.

Secchi Depth:

- Mickey Lake: Average secchi depth for Mickey Lake remains very close to 2020's average secchi depth, just slightly higher.
- Ruth Lake: Average secchi depth for Ruth Lake remains very close to 2020's average secchi depth, just slightly lower.

Calcium:

- Mickey Lake: Calcium levels ranged between 21.5 and 23.0 mg/L. This is within the range where Zebra Mussel colonies have been able to establish within a laboratory setting. Continued monitoring of this parameter is important.
- Ruth Lake: Calcium levels within Ruth Lake are much lower than within Long and Mickey Lake and are not within the range where Zebra Mussel colonies can occur.

Nitrogen (Nitrate/Nitrite): Levels remained low, and stable, throughout the year. This parameter was not tested on Mickey and Ruth Lake during the 2020 season.

Physical Data

Temperature and DO data showed expected temperature and dissolved oxygen relationship in both lakes. Because of their shallow nature, Mickey Lake has a subtle thermocline which Ruth Lake does not have a thermocline.

Conclusions and Recommendations

Mickey Lakes data shows the lake inching closer to mesotrophic status. Ruth Lake is still trending Eutrophic. Even though both are connected to Long Lake the channels connecting them are shallow and vary greatly based on water levels. It is important to continue taking measurements to monitor changes in eutrophication status. Because of their small size and shallow depths, Ruth Lake and Mickey Lake are particularly vulnerable to cultural eutrophication and need to be closely monitored. Long Lake, while larger and deeper, is still vulnerable because of heavy boat traffic and shoreline development. Continued education and outreach programs for property owners and visitors is especially important. The reduction or elimination of fertilizer use, establishment of vegetative shoreline buffers to catch runoff, and proper septic system upkeep are all important factors in reducing the effects of eutrophication that require property owner cooperation.eutrophication process down towards its natural pace. This could preserve the health of the ecosystems in these lakes as well as recreational and property value.

Long Lake Water Chemistry Data

Total Phosphorus (µg/L)

| | <i>May 12, 2021</i> | <i>May 12,2021</i> | <i>September 8, 2021</i> | <i>September 8, 2021</i> |
|-----------------|---------------------|--------------------|--------------------------|--------------------------|
| Location | Site 1 | Site 2 | Site 1 | Site 2 |
| Surface | 4.4 | <1.6 | 3.9 | 3.4 |
| Depth | 2.7 | 9.0 | 9.0 | 18.4 |

Chlorophyll a (µg/L)

| | <i>May 12, 2021</i> | <i>May 12,2021</i> | <i>September 8, 2021</i> | <i>September 8, 2021</i> |
|-----------------|---------------------|--------------------|--------------------------|--------------------------|
| Location | Site 1 | Site 2 | Site 1 | Site 2 |
| | 2.36 | 1.99 | 1.35 A | 1.09 |

| | | | | |
|--|--|--|--------|--|
| | | | 1.39 B | |
|--|--|--|--------|--|

Average Secchi Depth (m)

Long Lake Total Average: 8

Calcium (mg/L)

| | | | |
|---------------------|---------------------|--------------------------|--------------------------|
| <i>May 12, 2021</i> | <i>May 12, 2021</i> | <i>September 8, 2021</i> | <i>September 8, 2021</i> |
| Site 1 | Site 2 | Site 1 | Site 2 |
| 22.1 | 23.0 | 23.8 | 25.5 |

Nitrogen (mg/L) (Nitrate/ Nitrite)

| | | | | |
|-----------------|---------------------|---------------------|--------------------------|--------------------------|
| | <i>May 12, 2021</i> | <i>May 12, 2021</i> | <i>September 8, 2021</i> | <i>September 8, 2021</i> |
| Location | Site 1 | Site 2 | Site 1 | Site 2 |
| Surface | 0.0050 | 0.0074 | <0.004 | <0.004 |
| Depth | 0.0065 | 0.0082 | <0.004 | <0.004 |

Mickey Lake Water Chemistry Data

Total Phosphorus (µg/L)

| | | | | |
|-----------------|---------------------|---------------------|--------------------------|--------------------------|
| | <i>May 12, 2021</i> | <i>May 12, 2021</i> | <i>September 8, 2021</i> | <i>September 8, 2021</i> |
| Location | Site 1 | Site 2 | Site 1 | Site 2 |
| Surface | 8.6 | 8.3 | 11.1 | 9.7 |
| Depth | 25.4 | 14.4 | 25.4 | 11.3 |

Chlorophyll a (µg/L)

| | | | |
|---------------------|---------------------|--------------------------|--------------------------|
| <i>May 14, 2021</i> | <i>May 14, 2021</i> | <i>September 8, 2021</i> | <i>September 8, 2021</i> |
| Site 1 | Site 2 | Site 1 | Site 2 |
| 2.51 A | 2.36 | 1.43 | 1.69 |
| 2.59 B | | | |

Calcium (mg/L)

| | | | |
|---------------------|---------------------|--------------------------|--------------------------|
| <i>May 12, 2021</i> | <i>May 12, 2021</i> | <i>September 8, 2021</i> | <i>September 8, 2021</i> |
| Site 1 | Site 2 | Site 1 | Site 2 |
| 23.0 | 22.5 | 21.5 | 21.7 |

Nitrogen (mg/L) (Nitrate/ Nitrite)

| | | | | |
|-----------------|---------------------|---------------------|--------------------------|--------------------------|
| | <i>May 12, 2021</i> | <i>May 12, 2021</i> | <i>September 8, 2021</i> | <i>September 8, 2021</i> |
| Location | Site 1 | Site 2 | Site 1 | Site 2 |
| Surface | <0.004 | <0.004 | <0.004 | 0.0061 |
| Depth | <0.004 | <0.004 | <0.004 | <0.004 |

Average Secchi Depth (m)

Mickey Lake Total Average: 4.38

Ruth Lake Water Chemistry Data

Total Phosphorus (µg/L)

| | <i>May 14, 2021</i> | <i>September 8, 2021</i> |
|-----------------|---------------------|--------------------------|
| Location | Site 1 | Site 1 |
| | 35.4 | 19.6 |

Chlorophyll a (µg/L)

| <i>May 14, 2021</i> | <i>September 8, 2021</i> |
|---------------------|--------------------------|
| Site 1 | Site 1 |
| 11.37 | 4.88 |

Calcium (mg/L)

| <i>May 14, 2021</i> | <i>September 8, 2021</i> |
|---------------------|--------------------------|
| Site 1 | Site 1 |
| 8.3 | 8.3 |

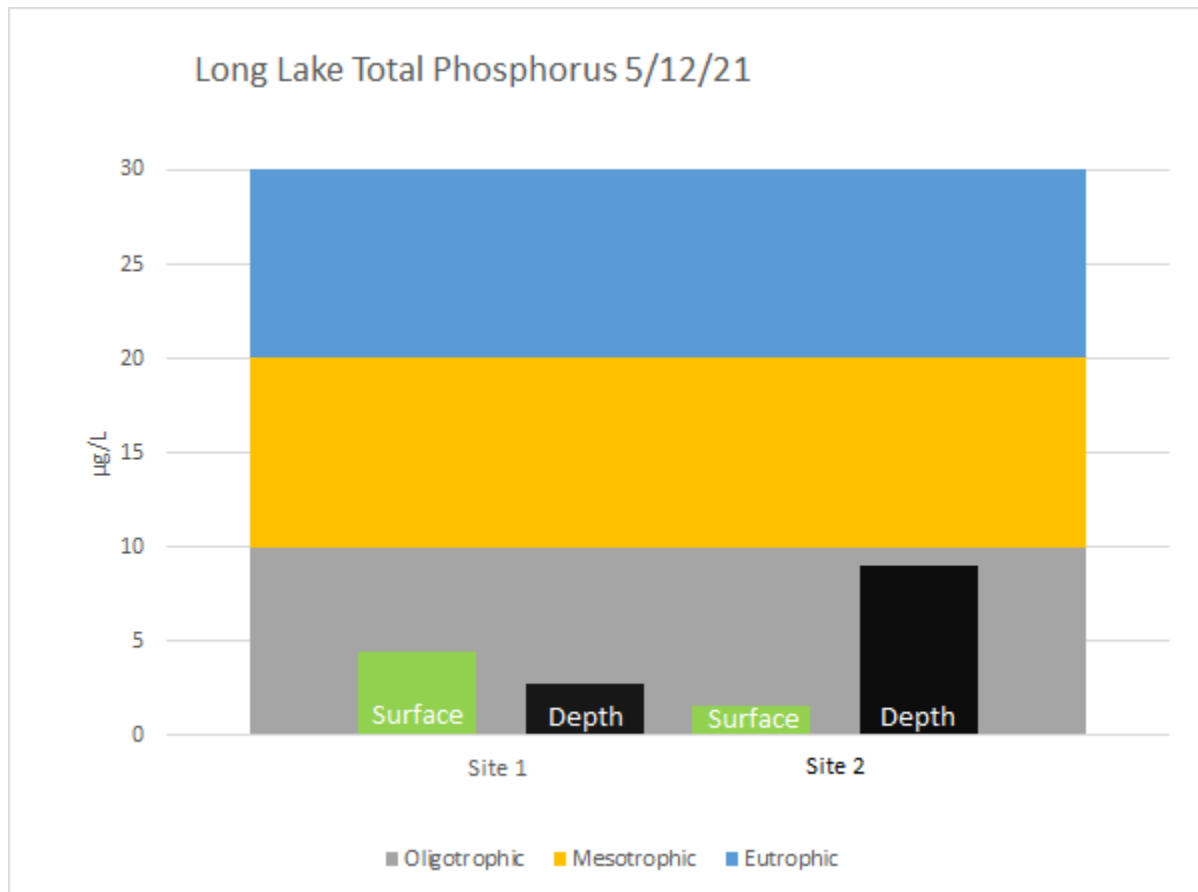
Nitrogen (mg/L) (Nitrate/ Nitrite)

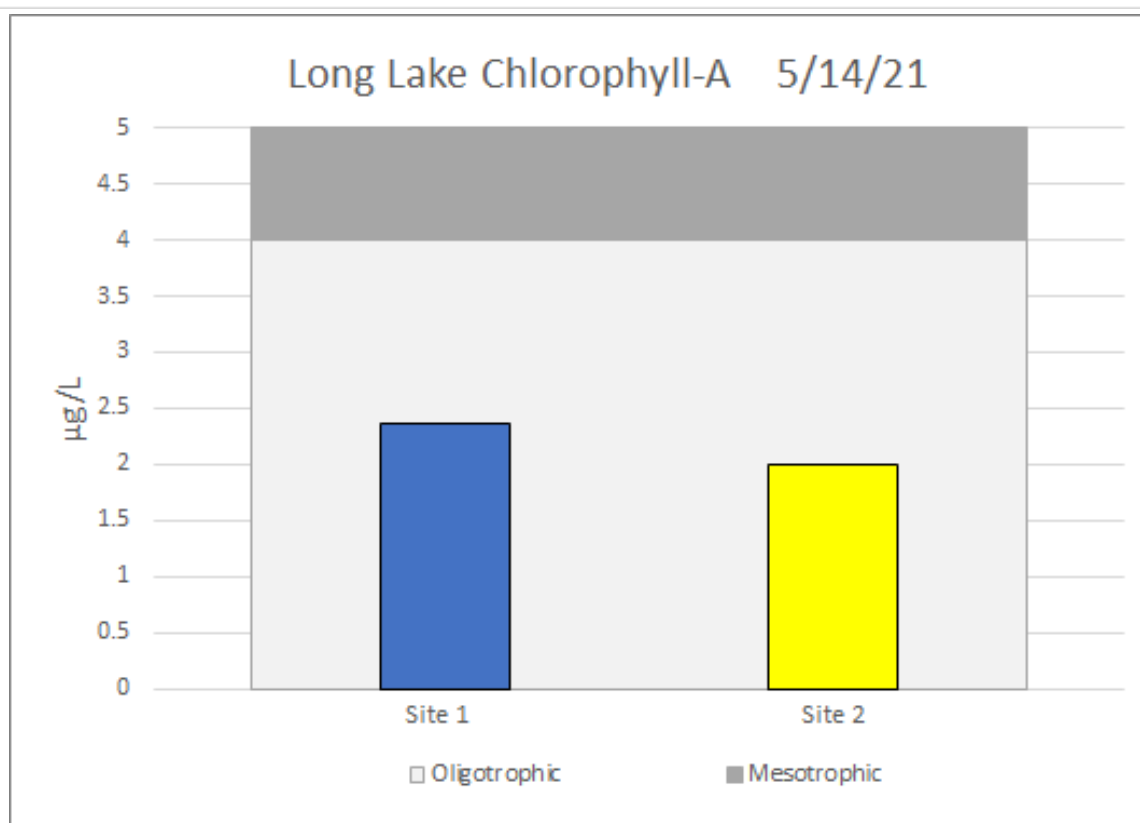
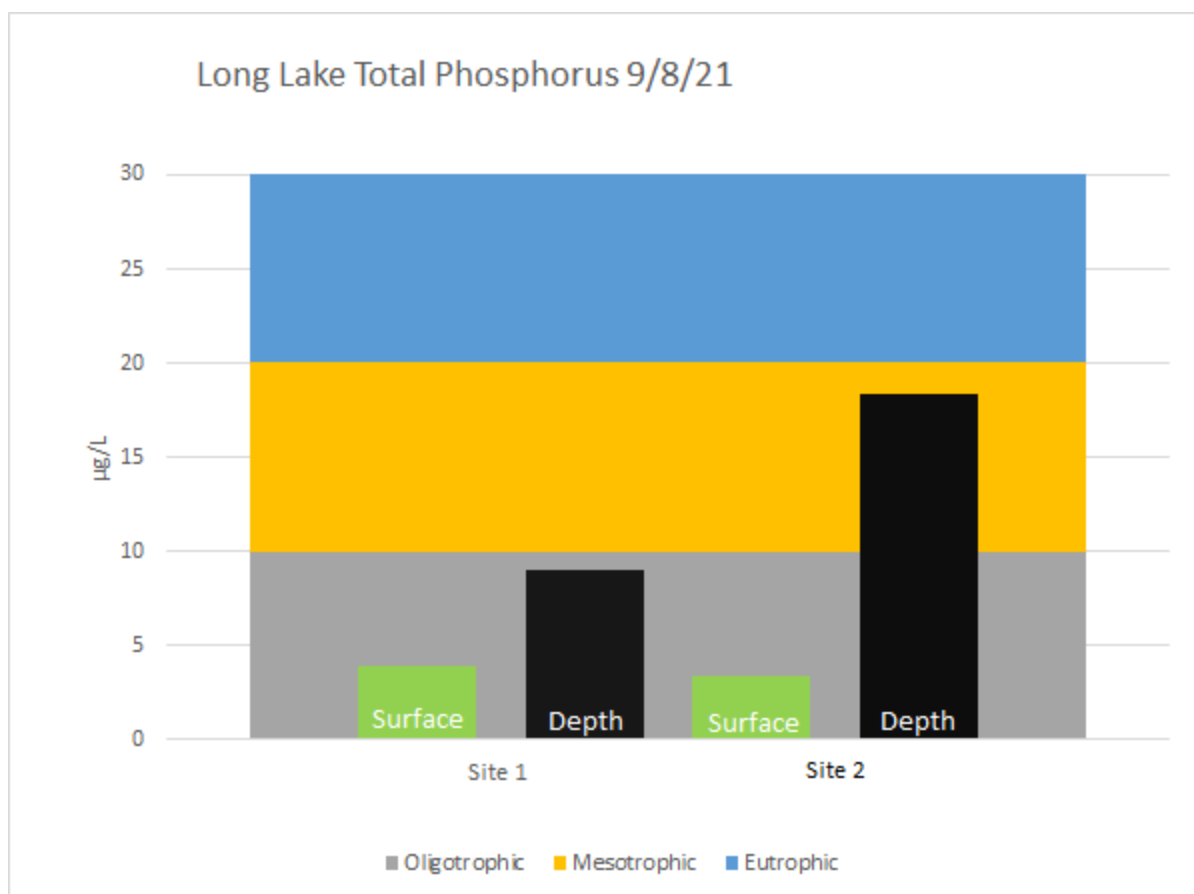
| | <i>May 14, 2021</i> | <i>September 8, 2021</i> |
|-----------------|---------------------|--------------------------|
| Location | Site 1 | Site 1 |
| | <0.004 | <0.004 |

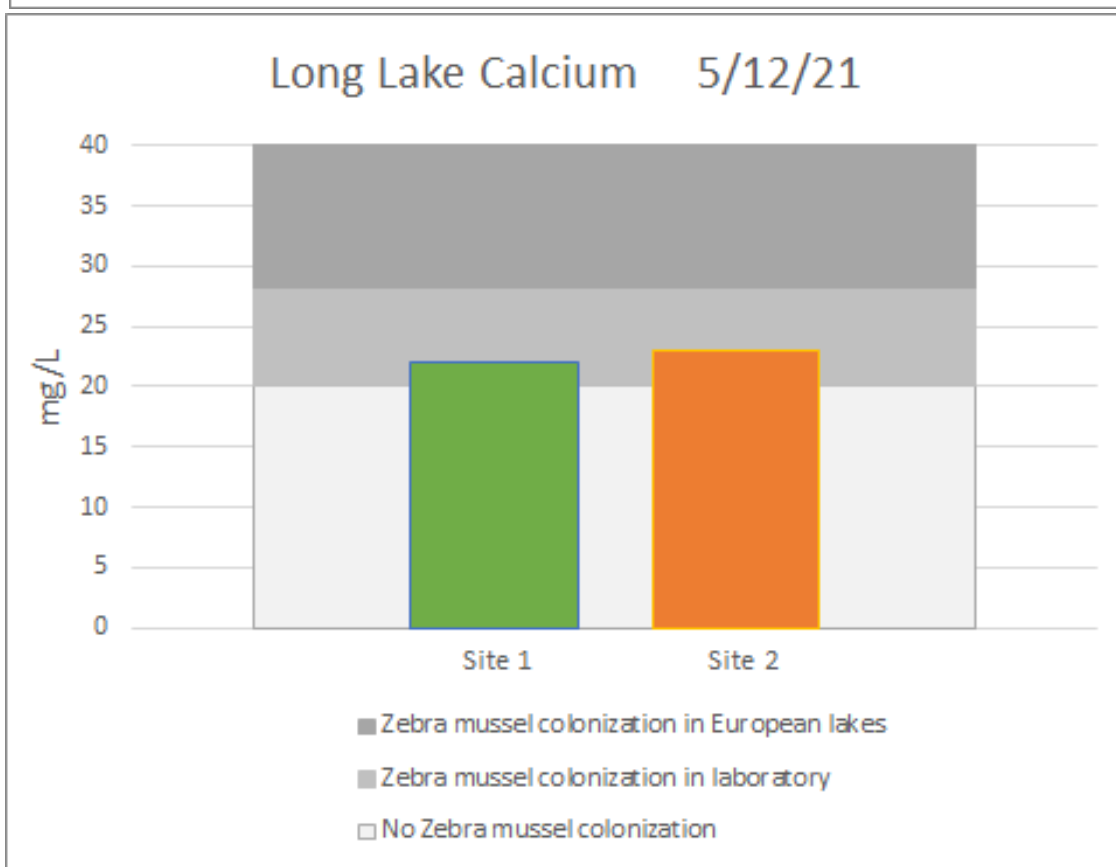
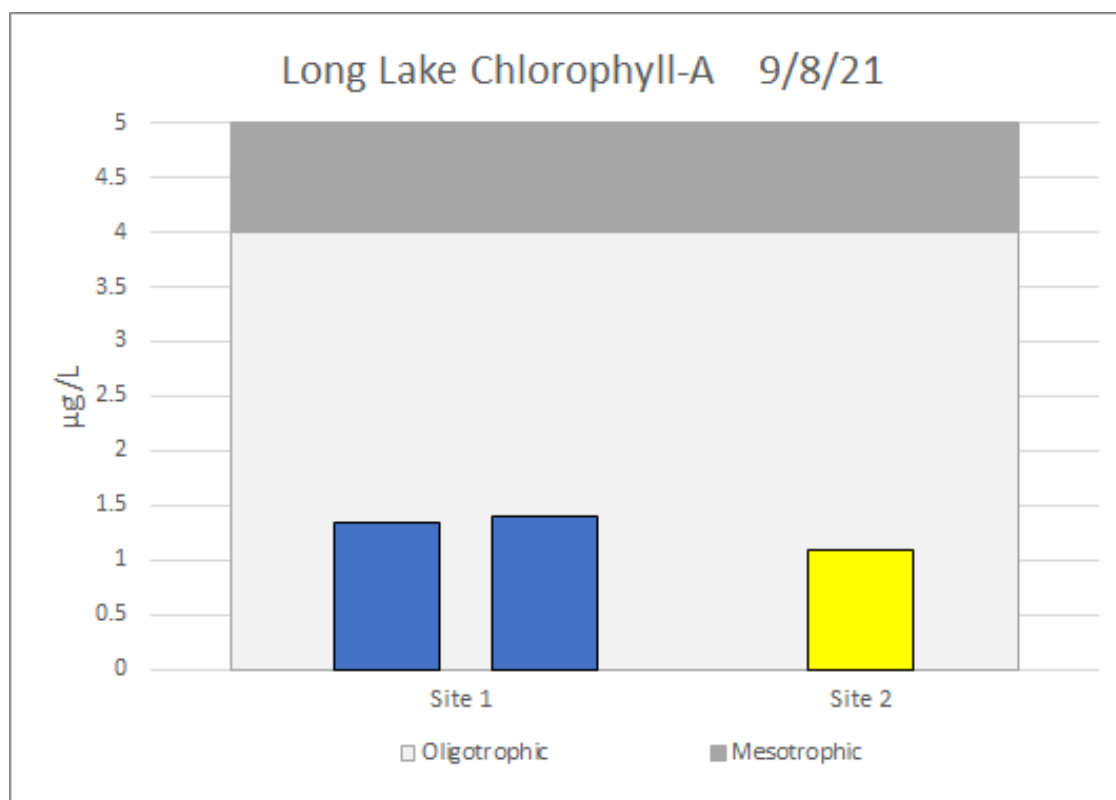
Average Secchi Depth (m)

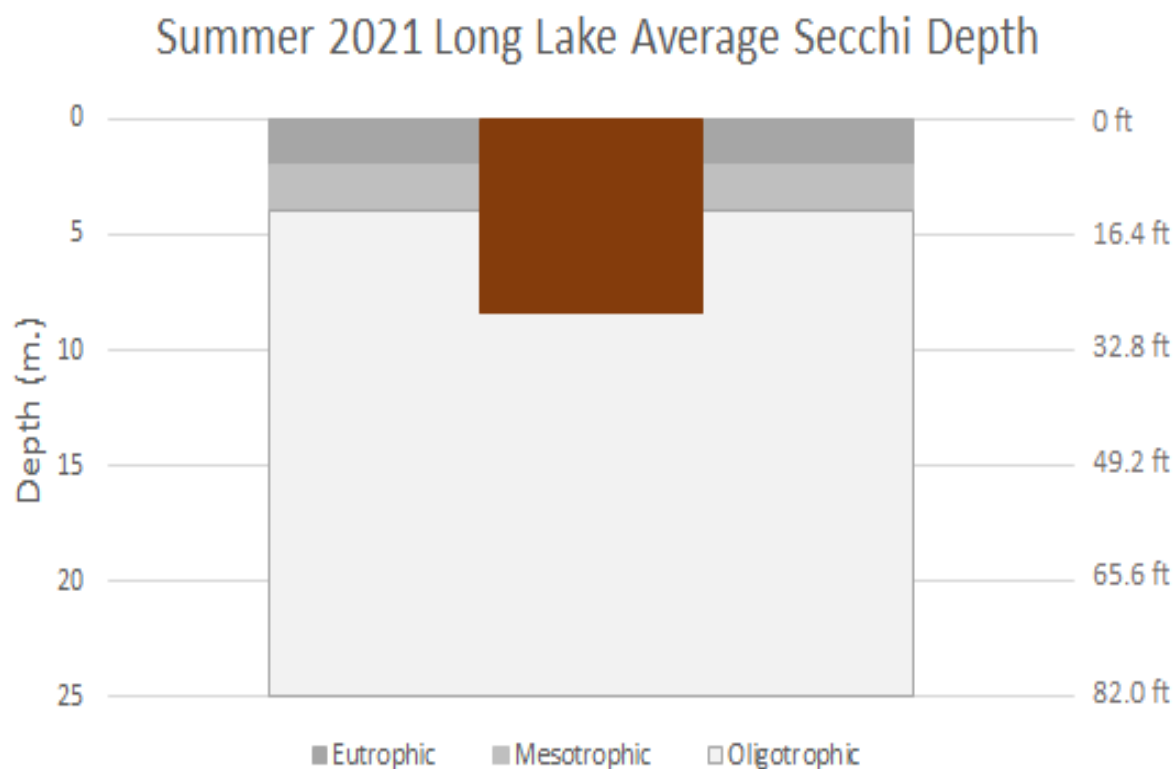
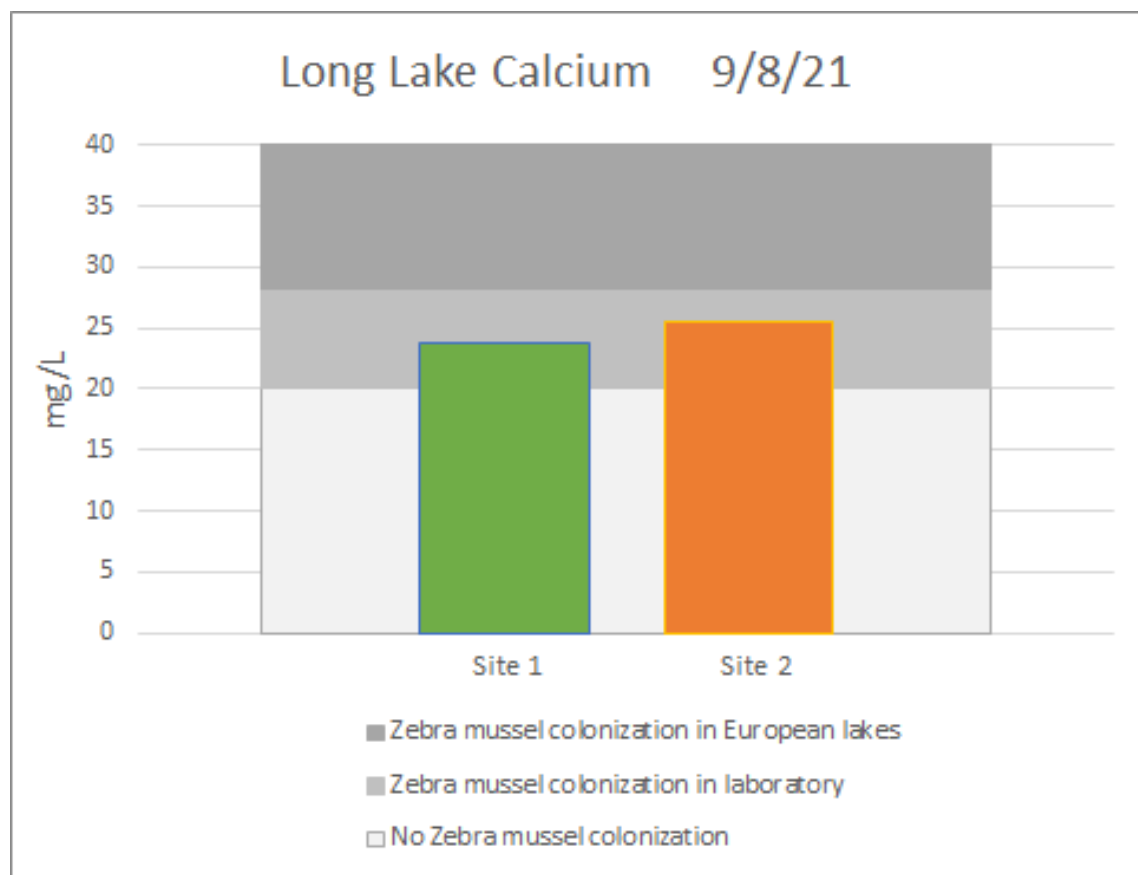
Ruth Lake Total Average: 0.92

Water Chemistry Data Graphs: Long Lake

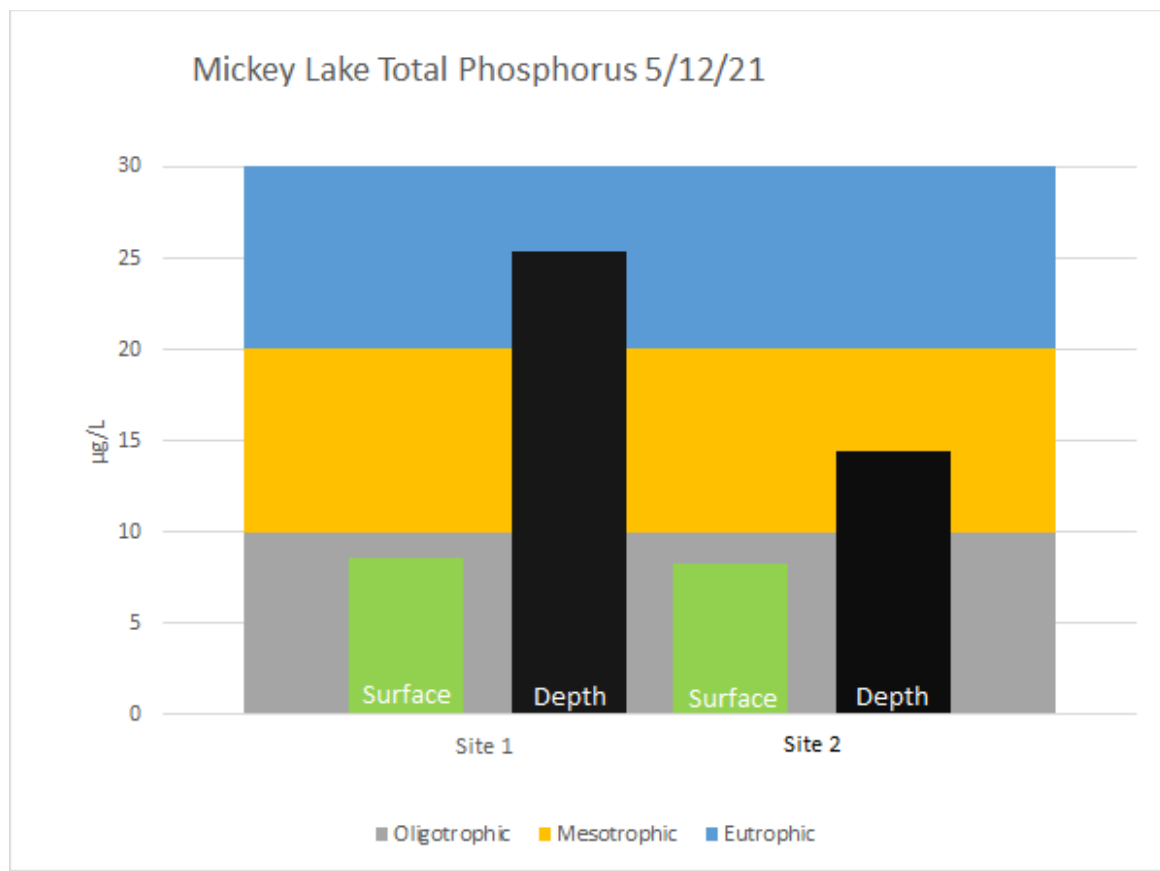




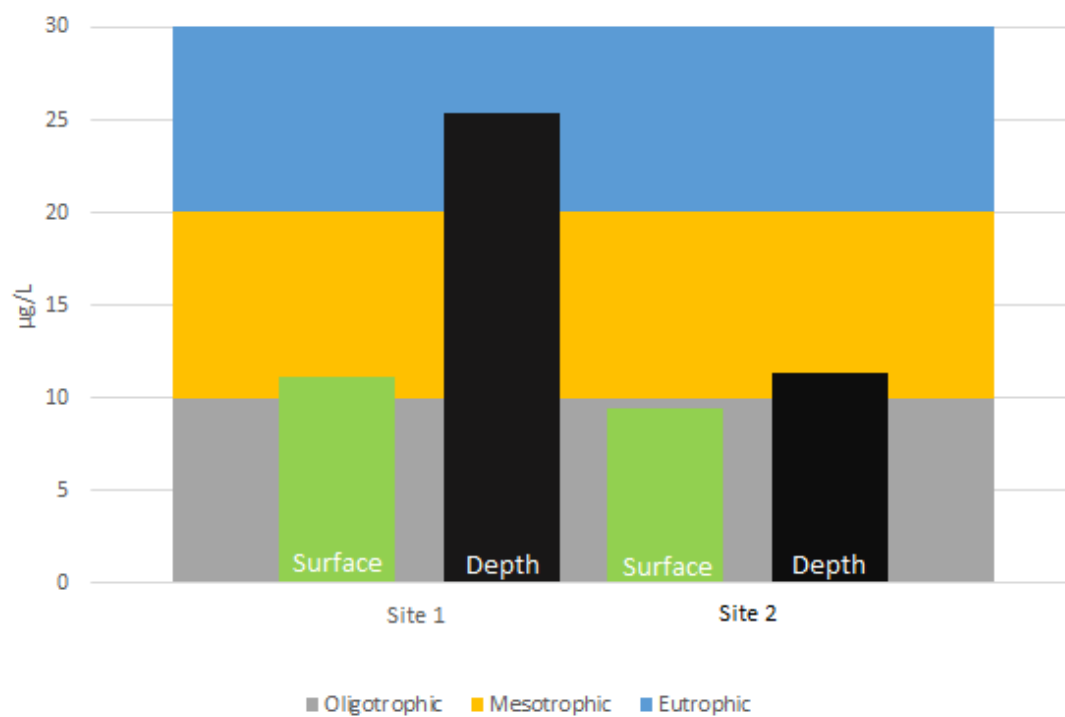




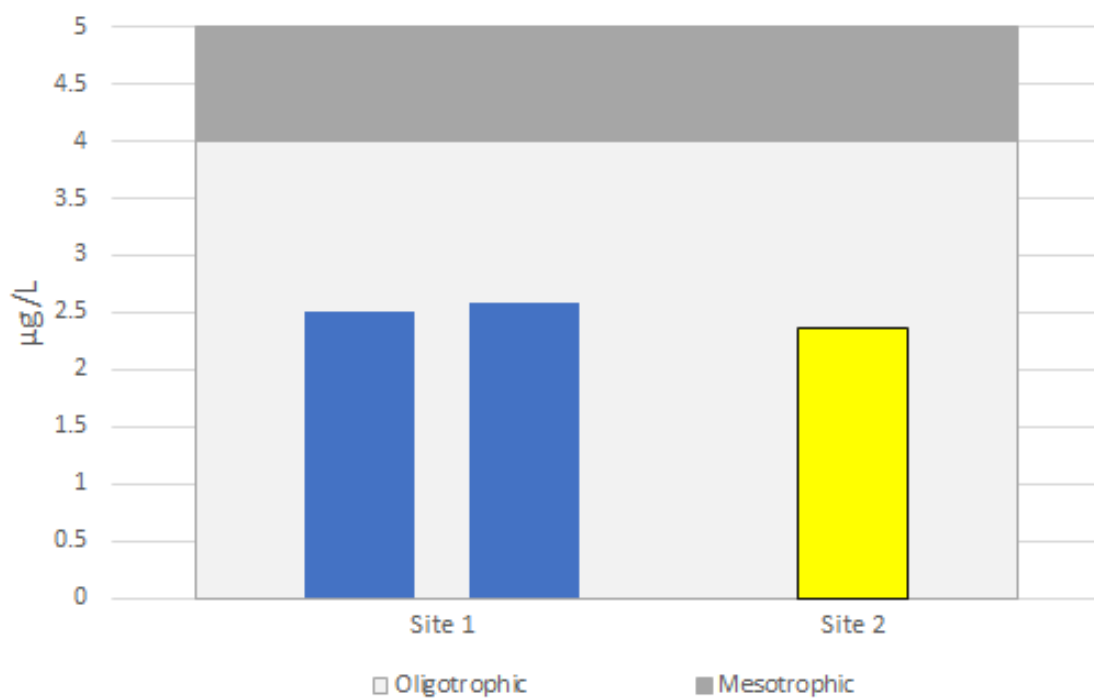
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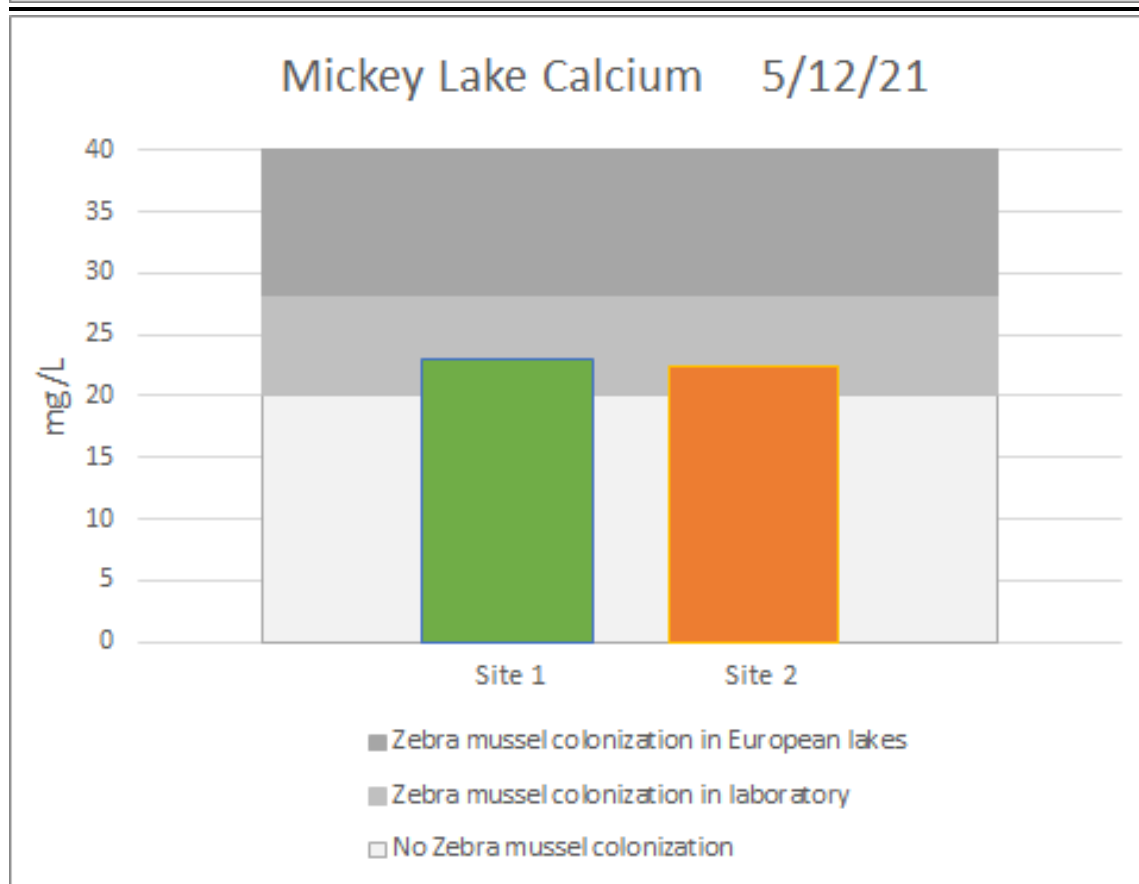
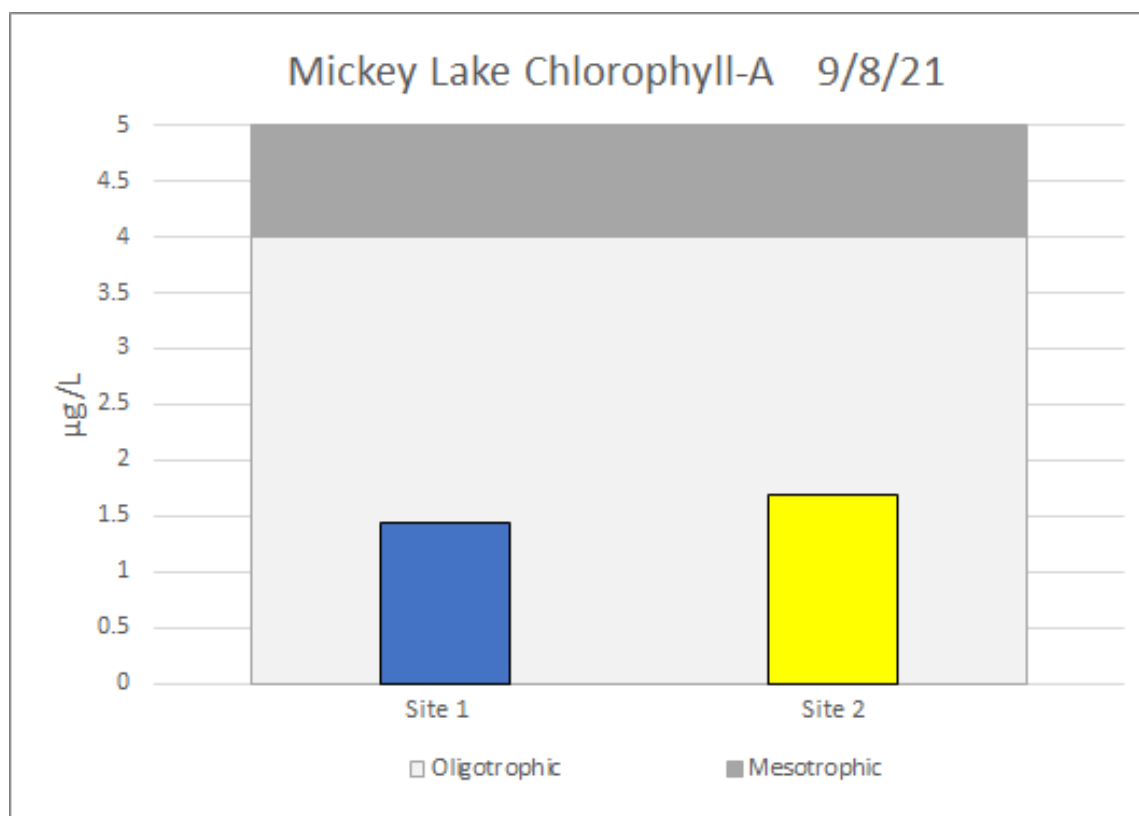


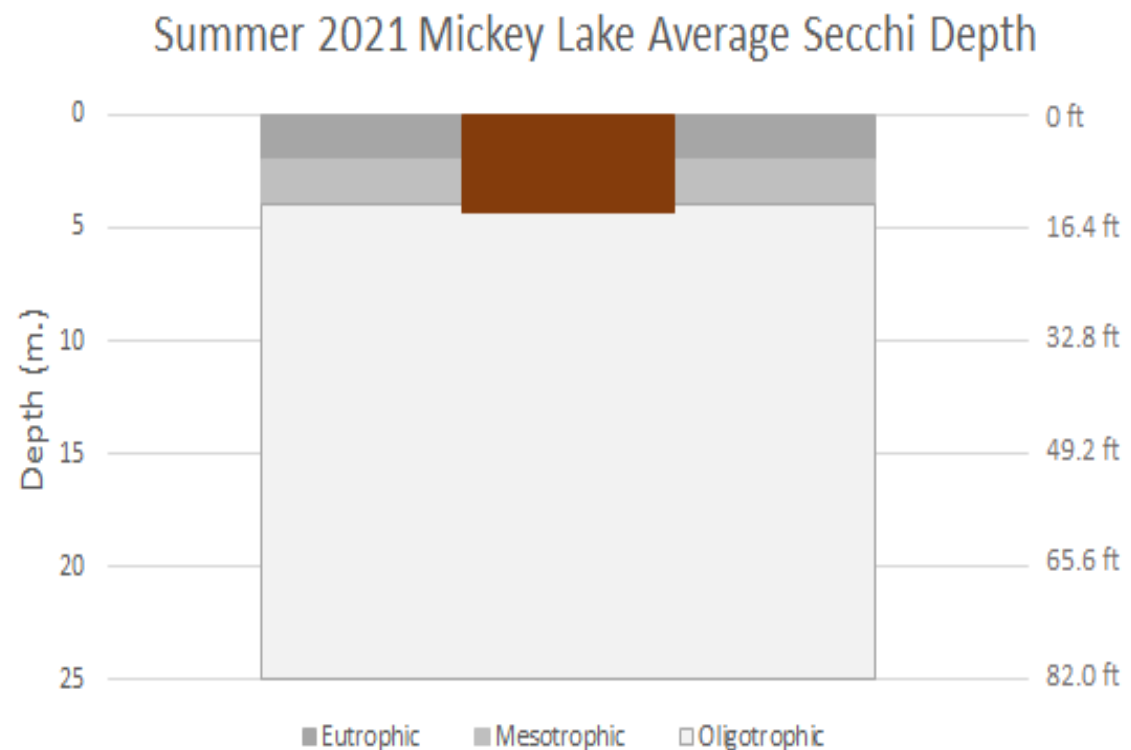
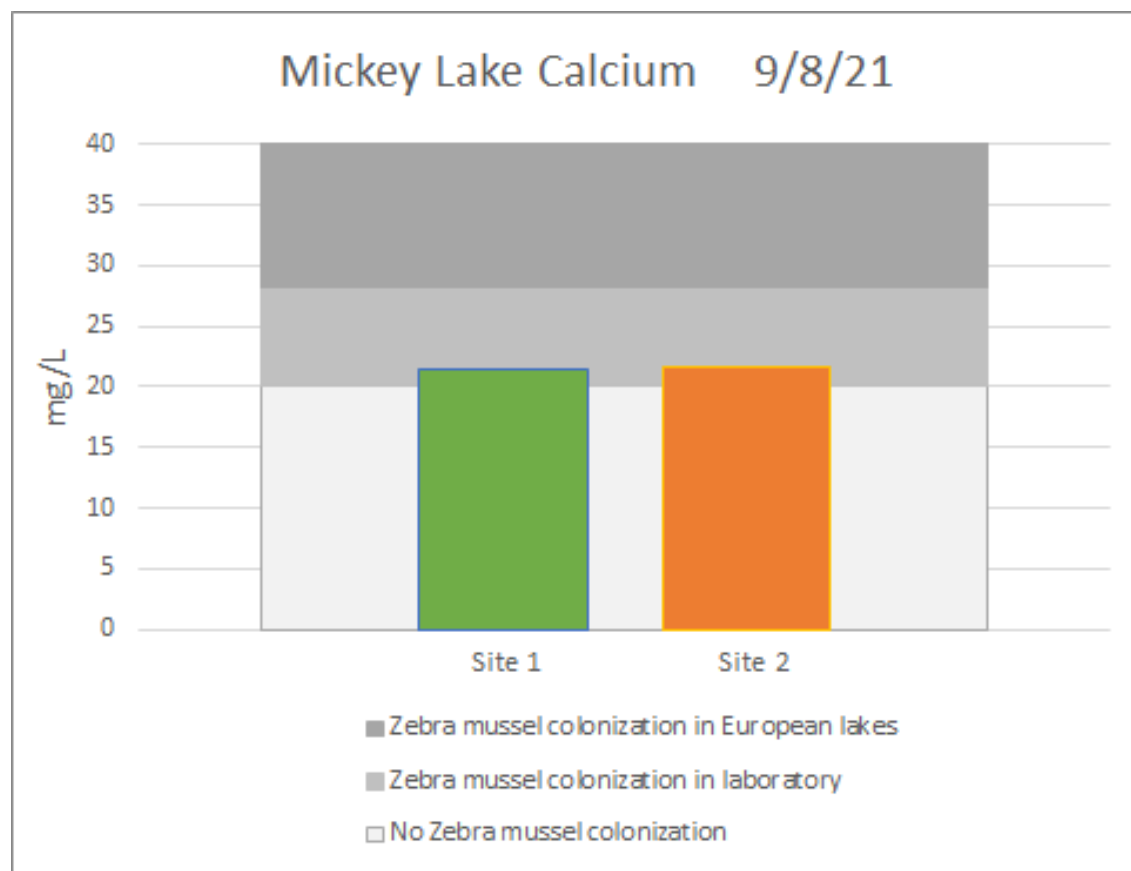
Mickey Lake Total Phosphorus 9/8/21



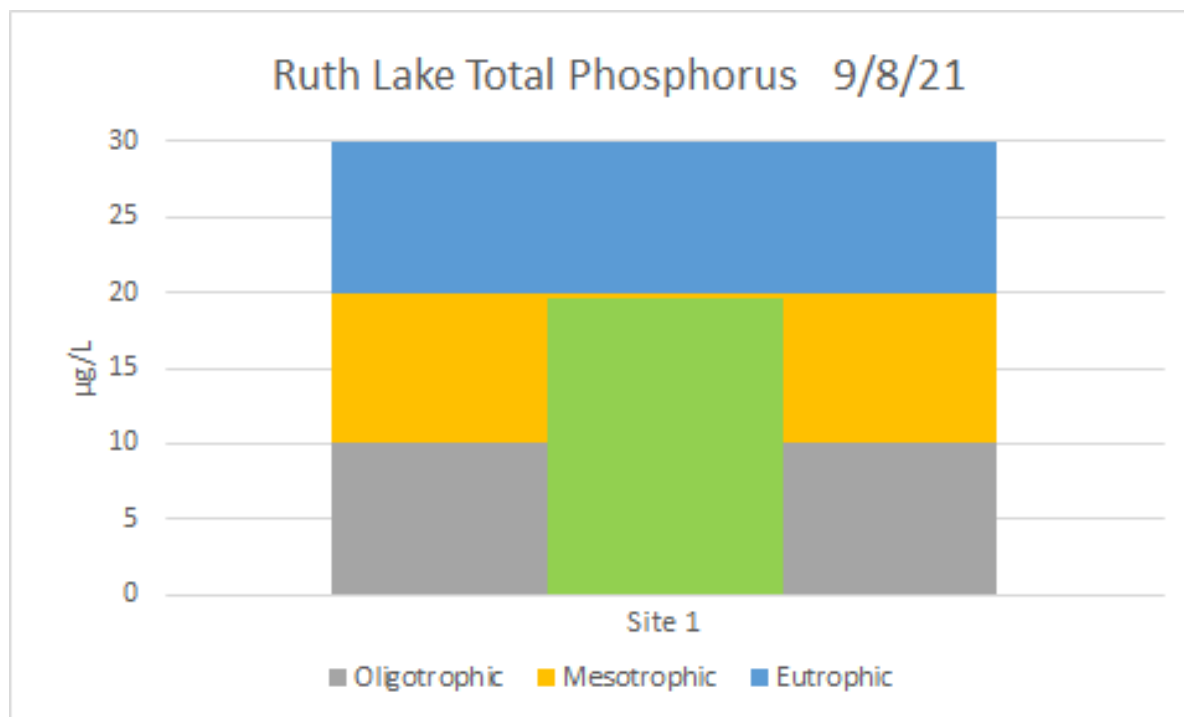
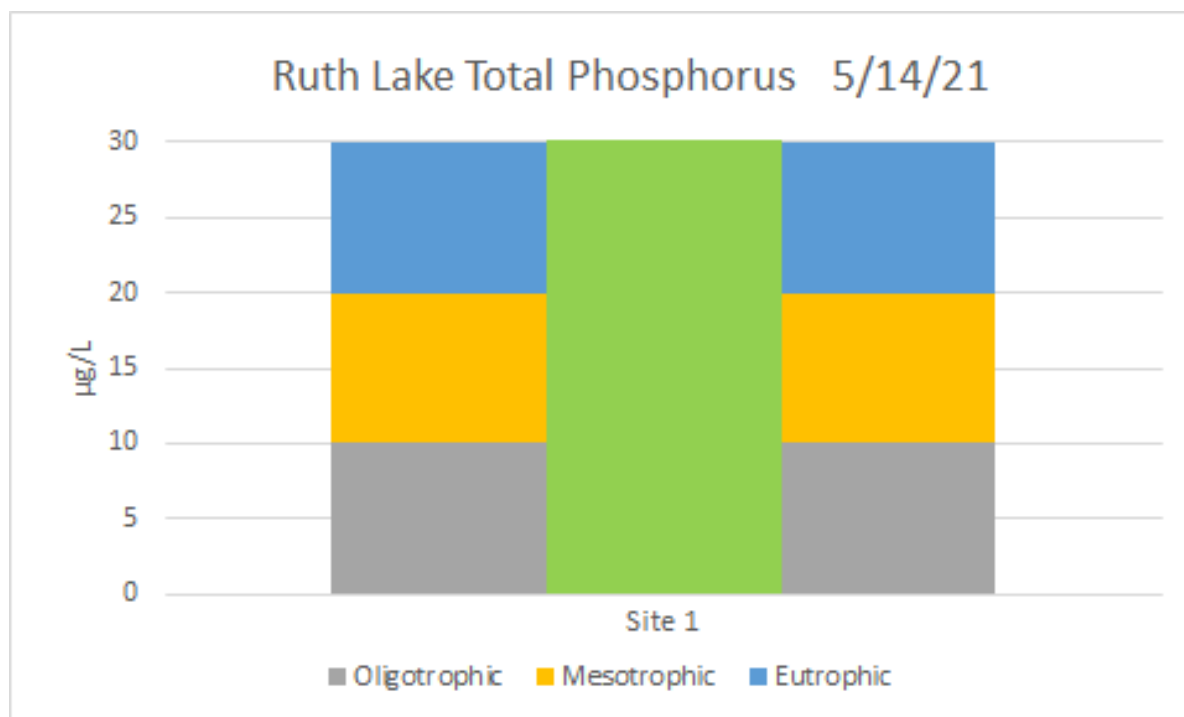
Mickey Lake Chlorophyll-A 5/14/21

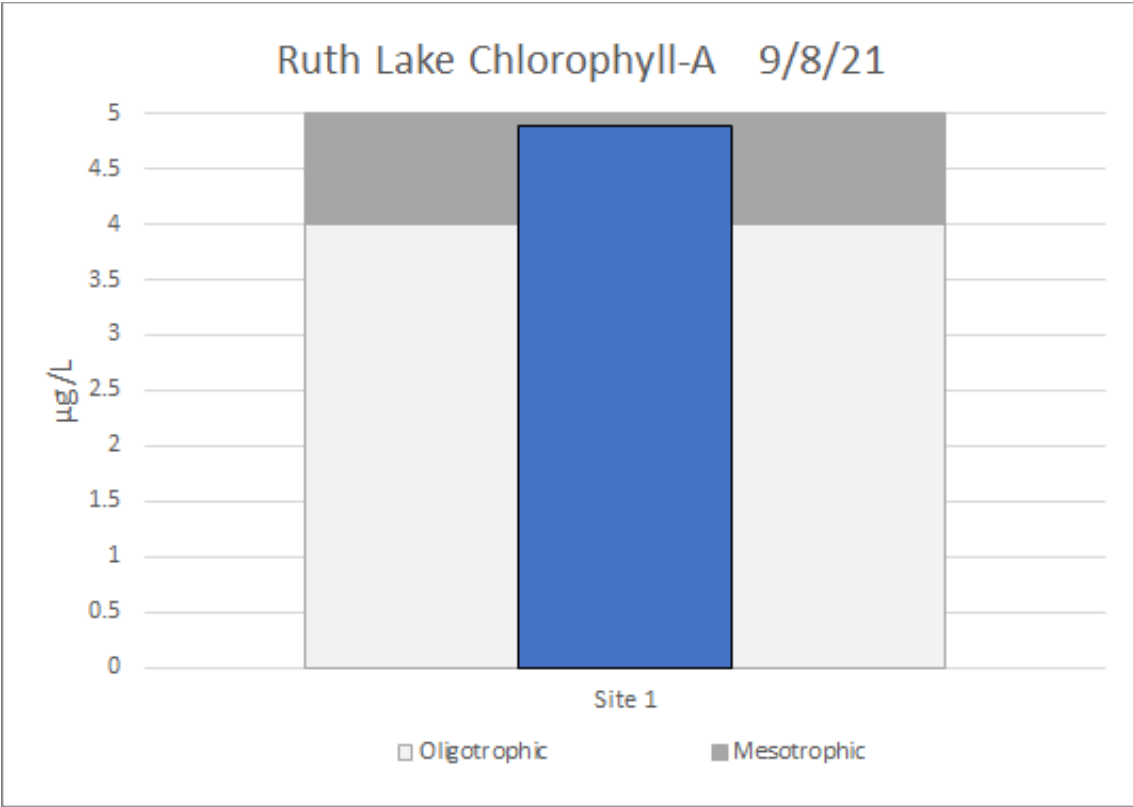
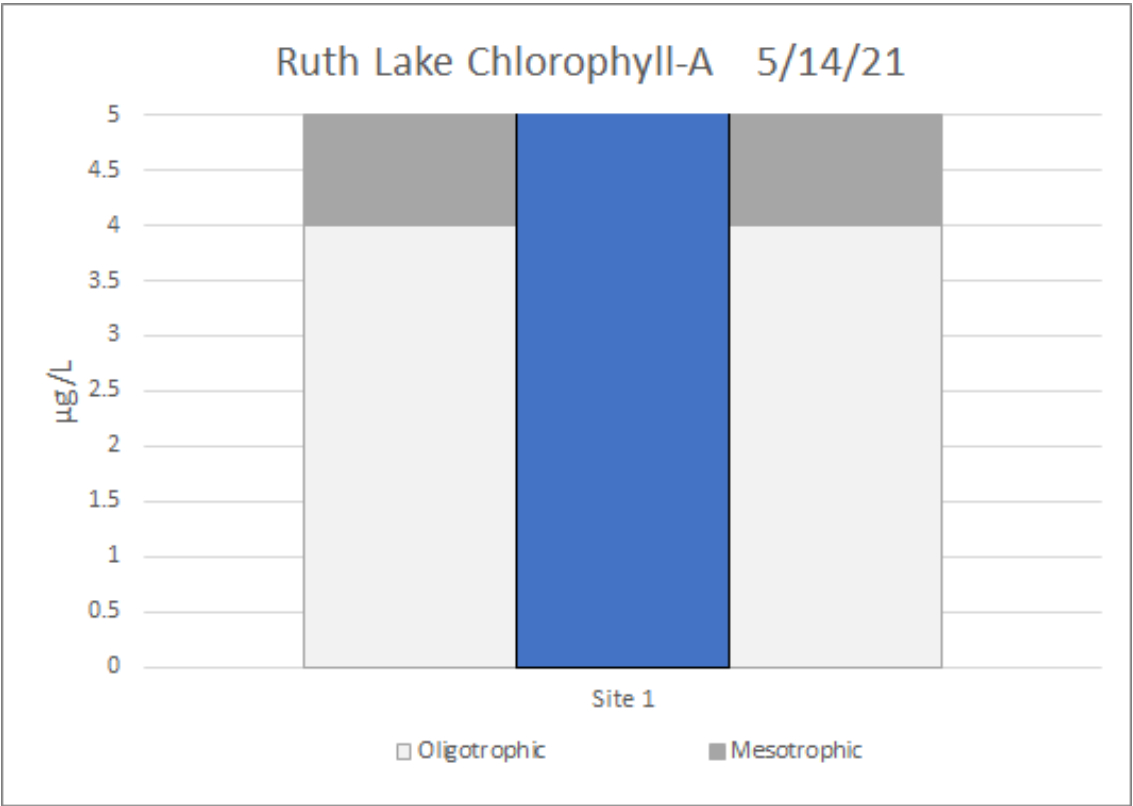


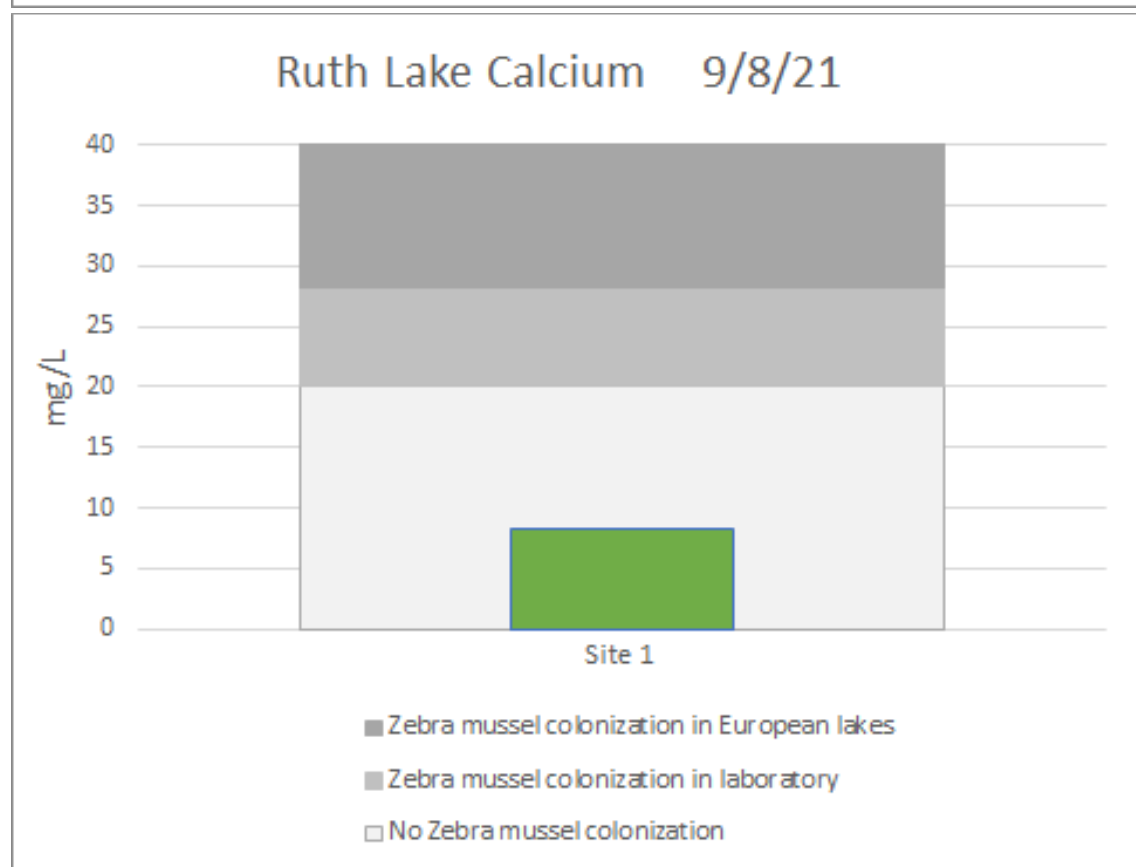
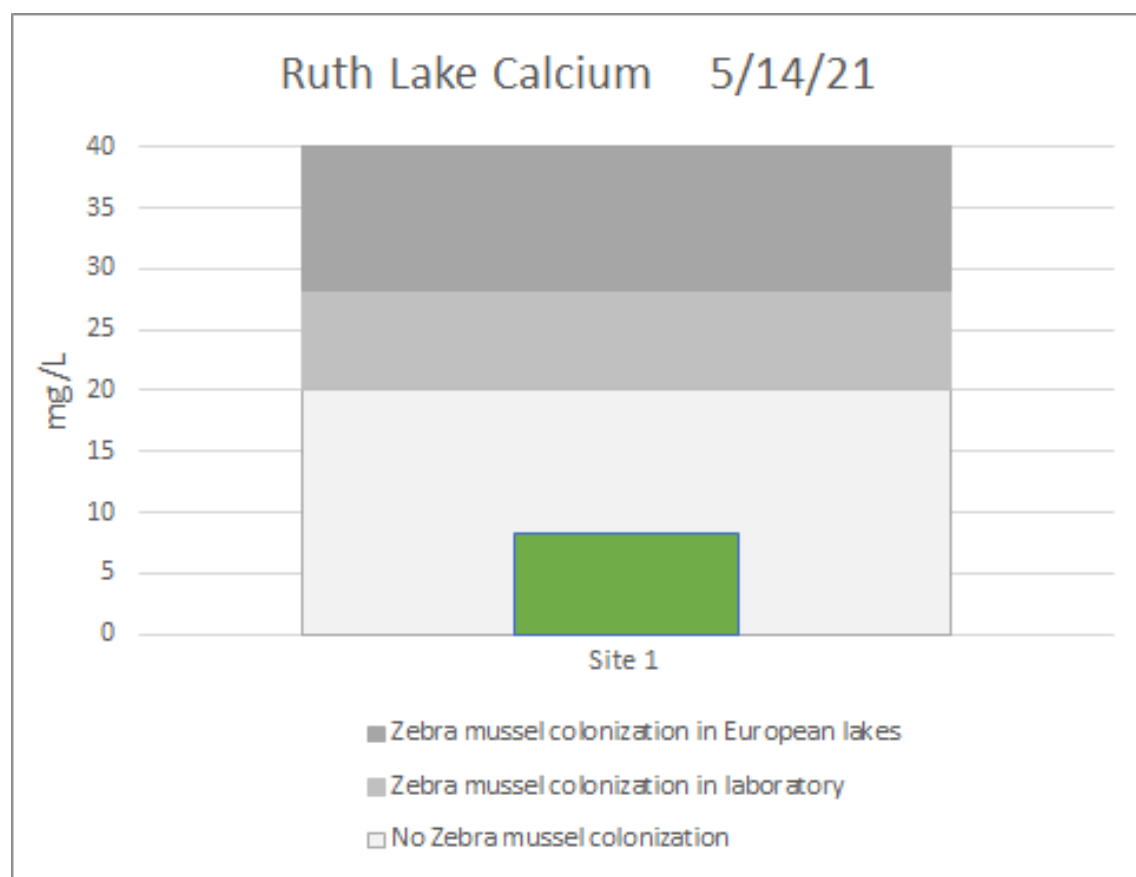


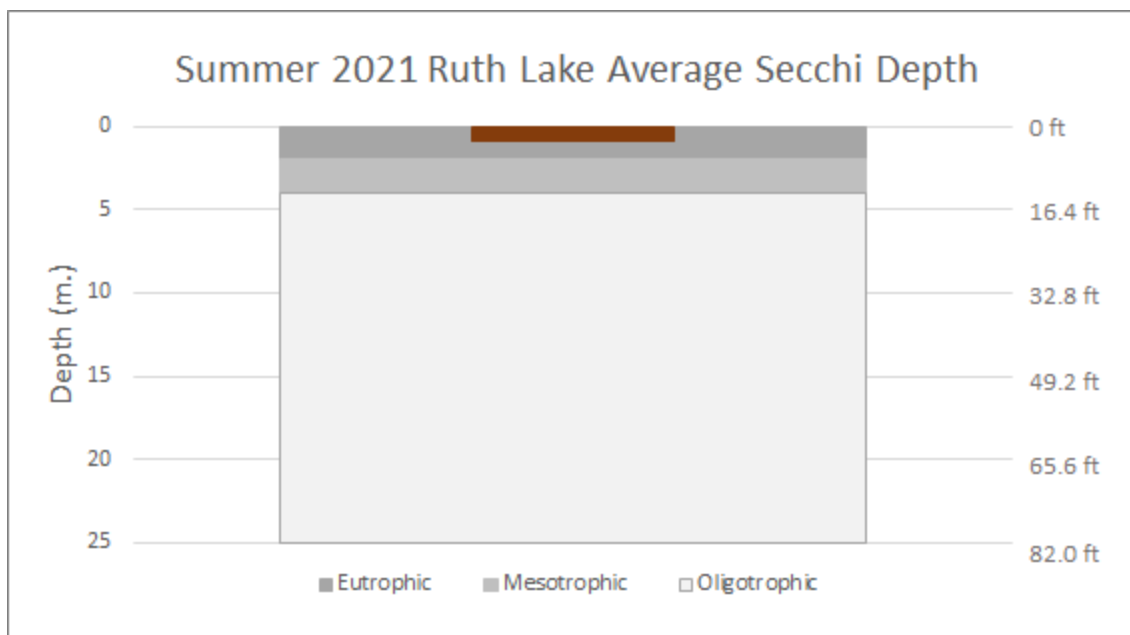


Water Chemistry Data Graphs: Ruth Lake

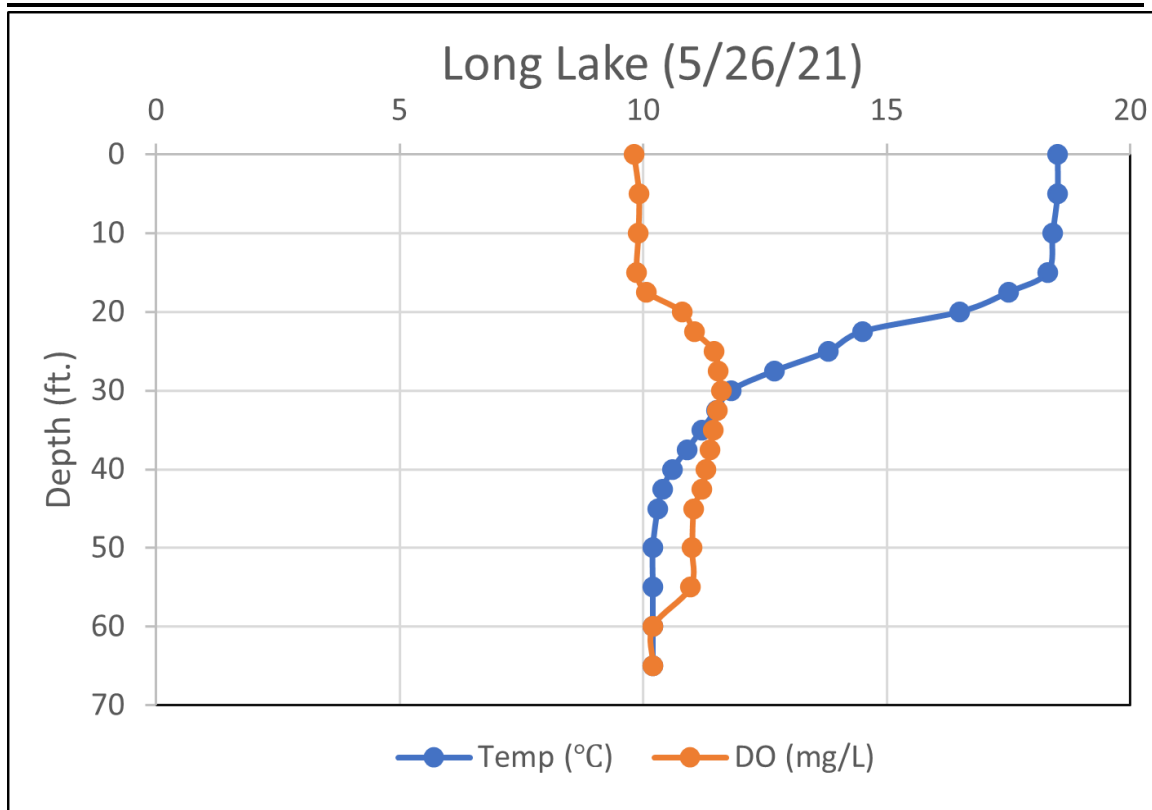
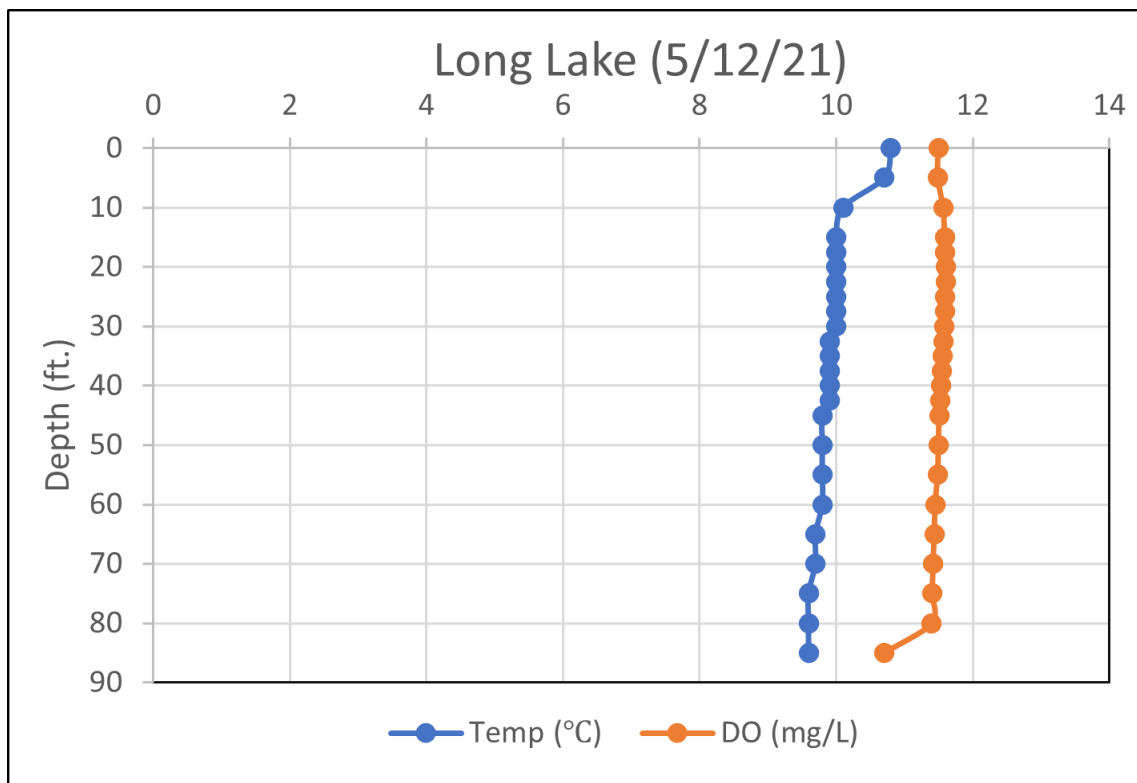


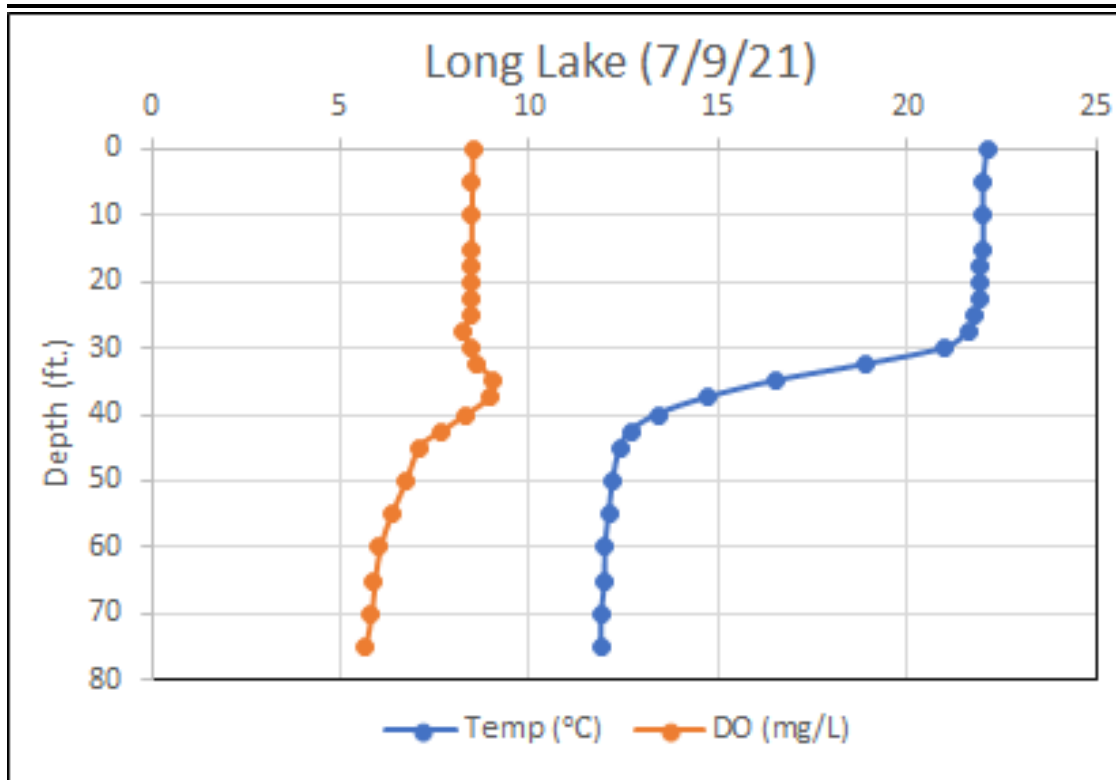
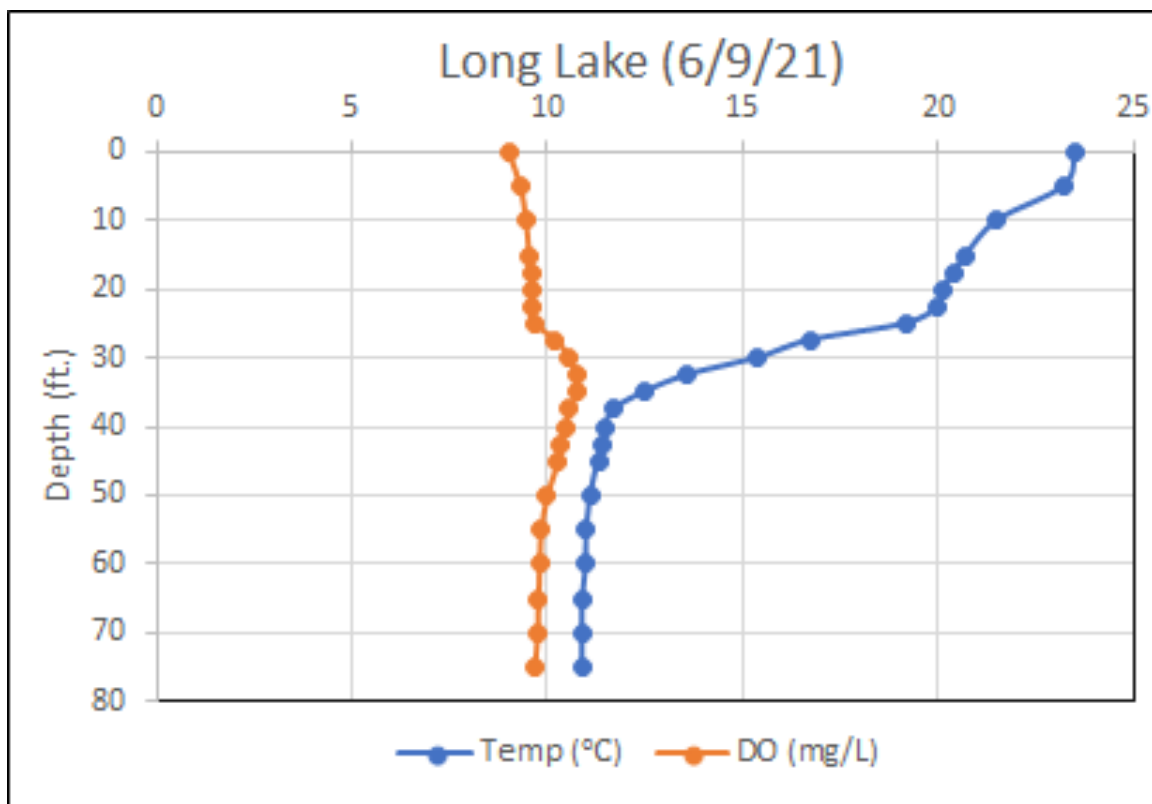


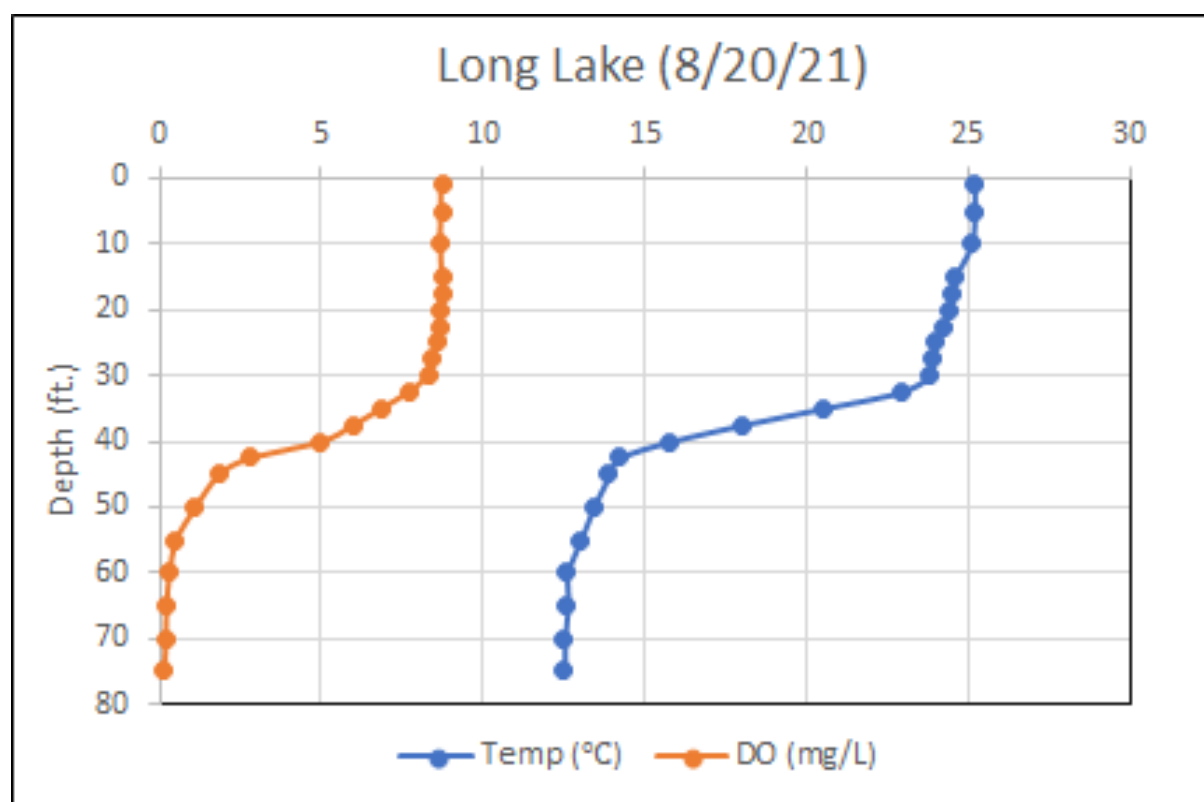
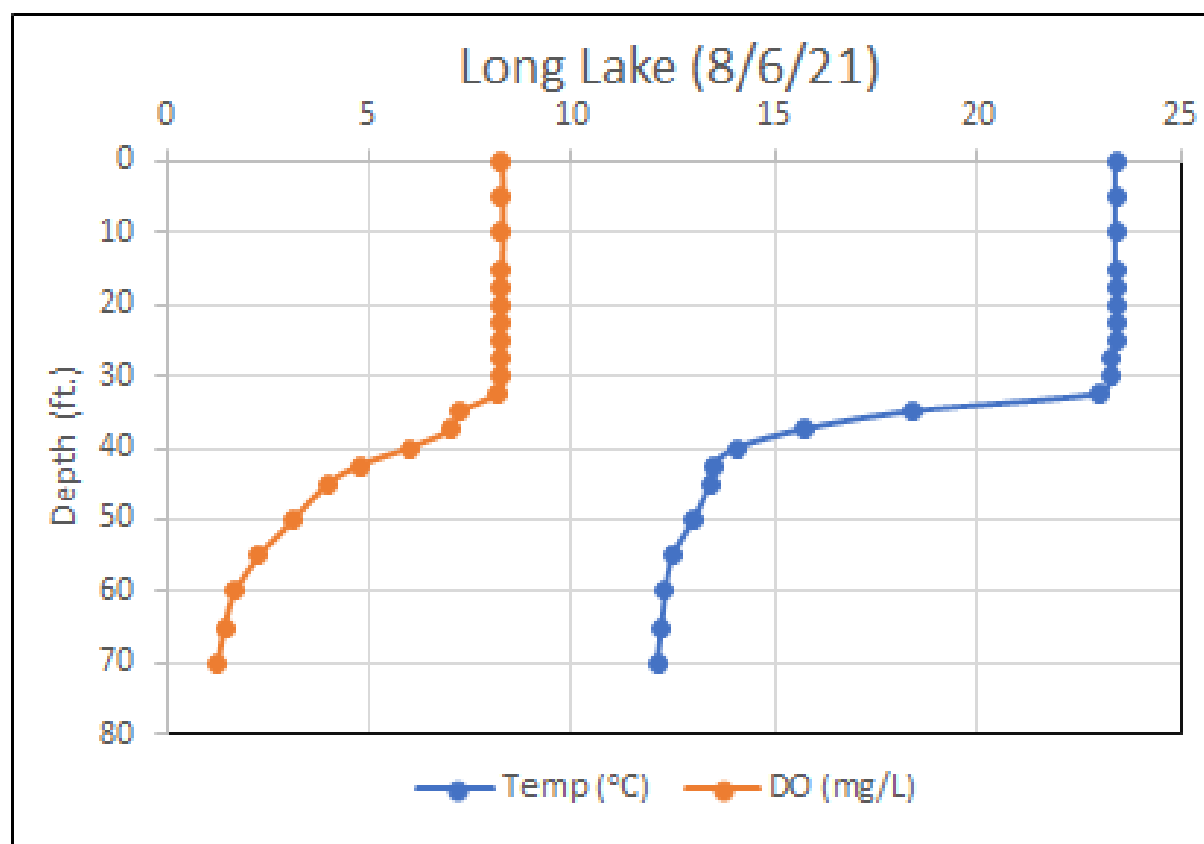


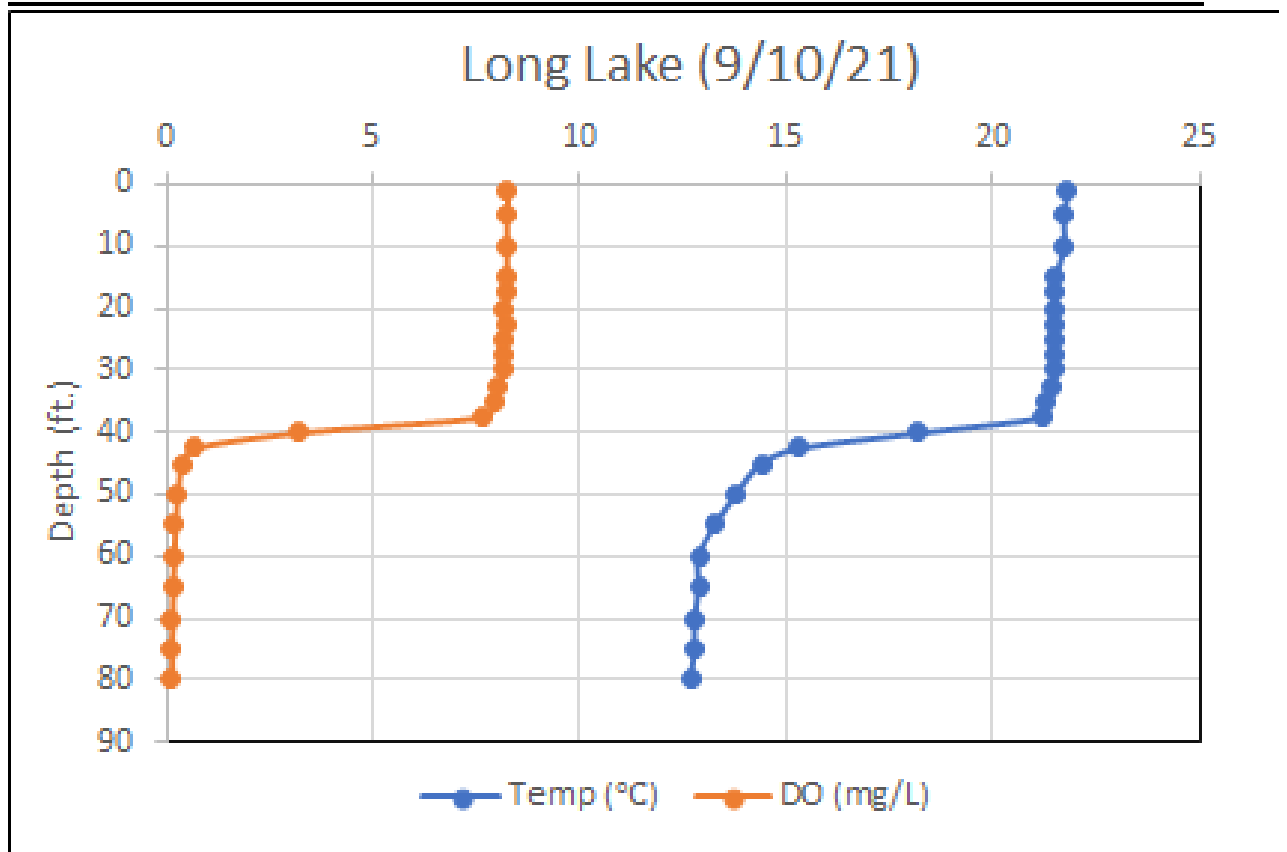
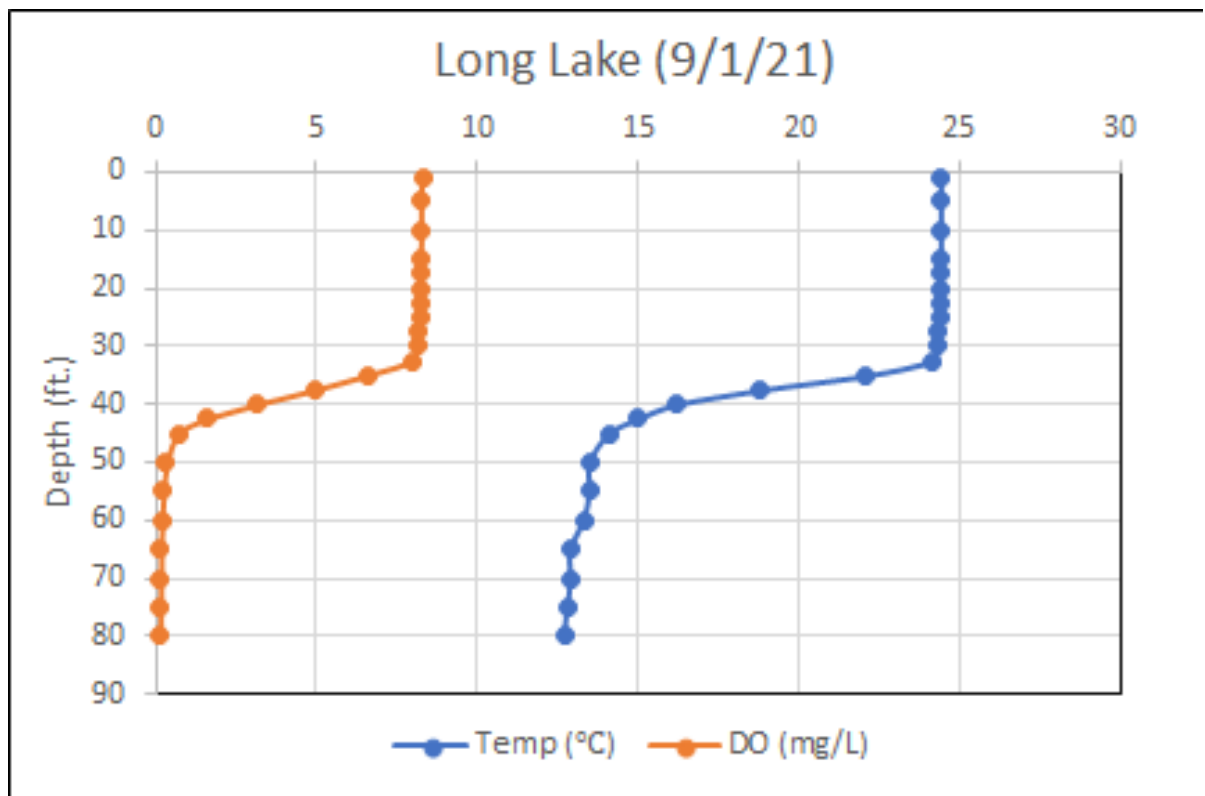


Dissolved Oxygen/Temperature Depth Profiles: Long Lake

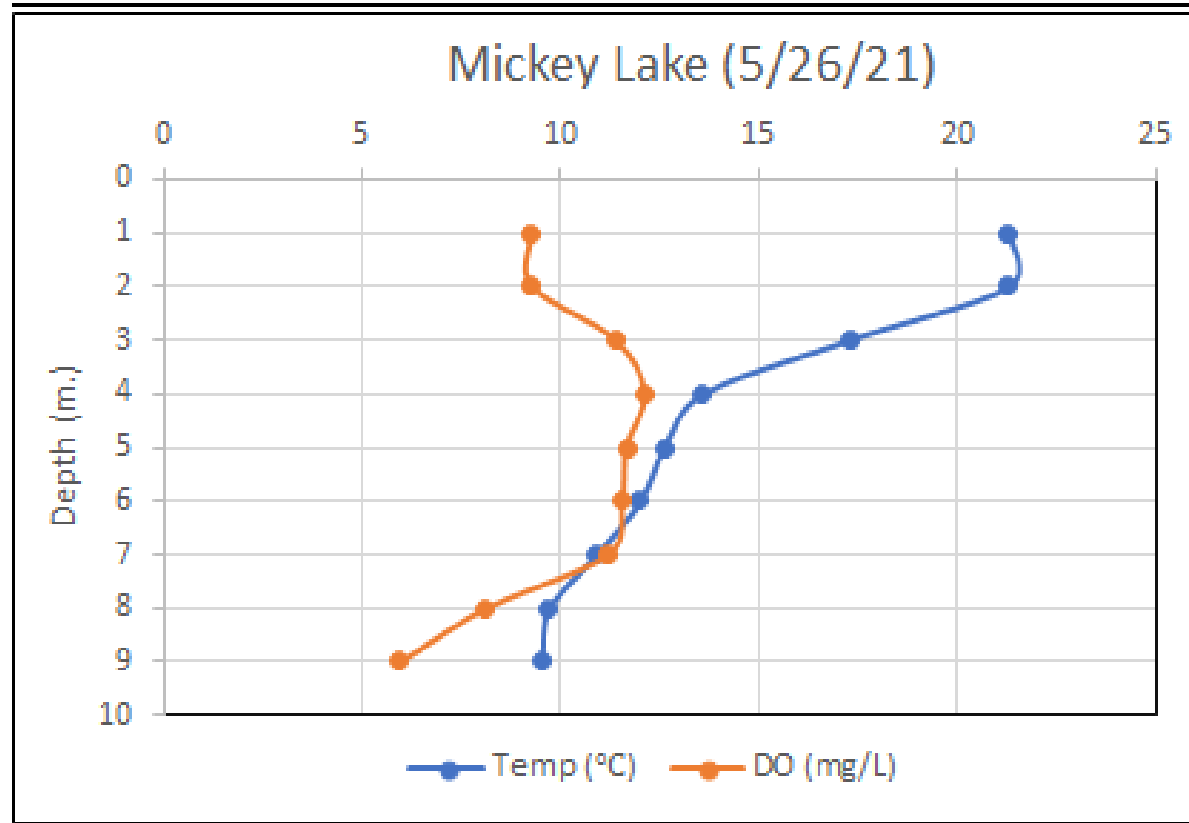
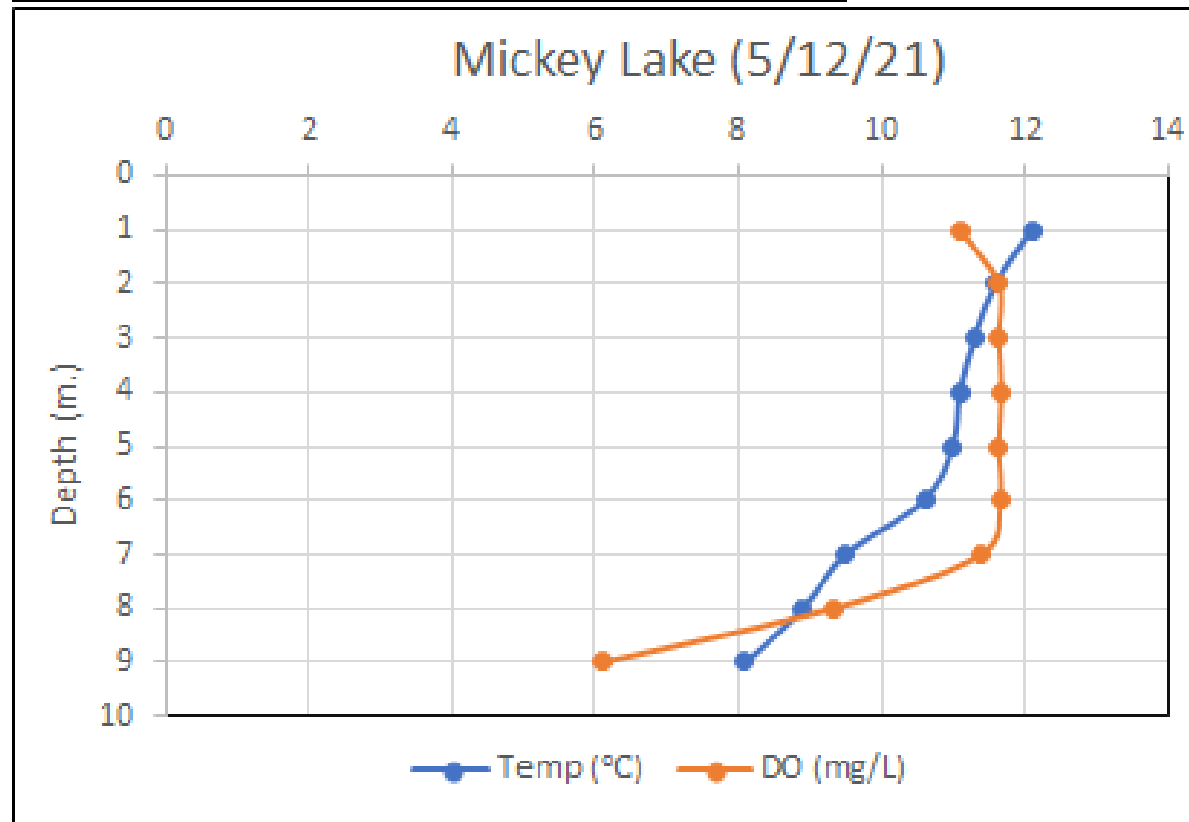


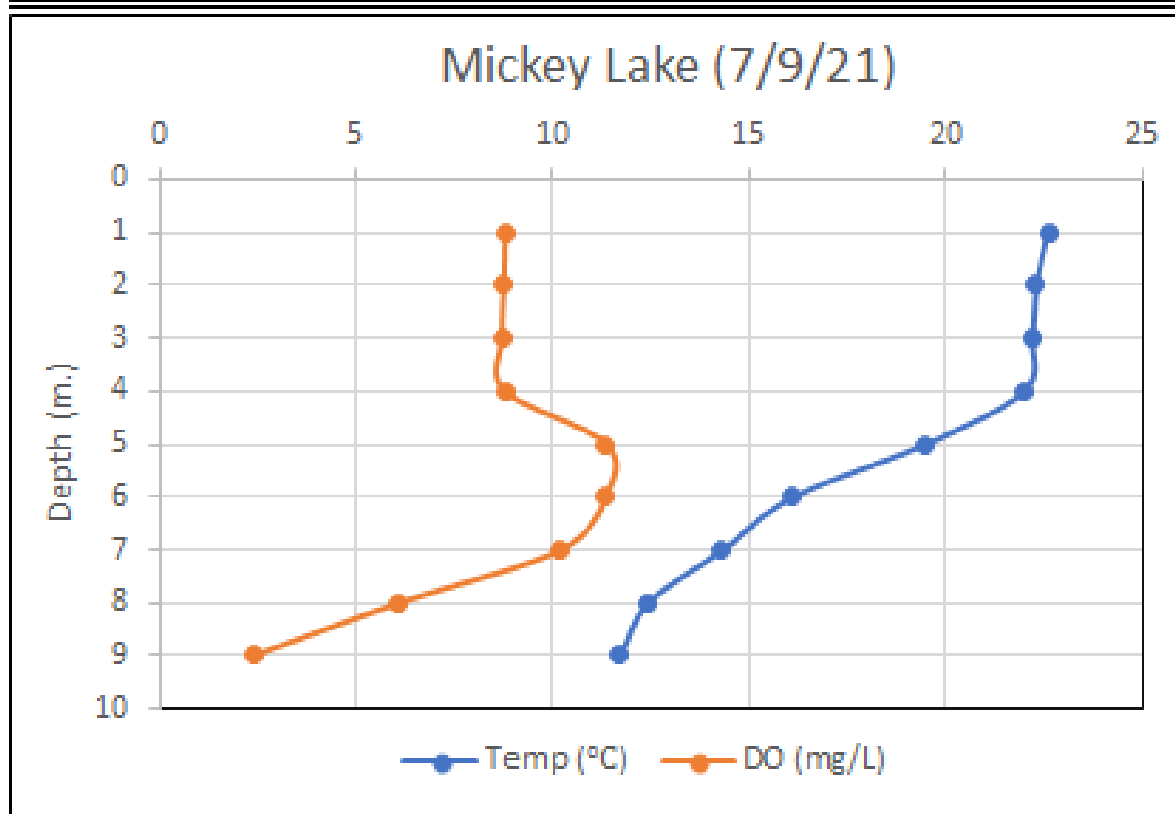
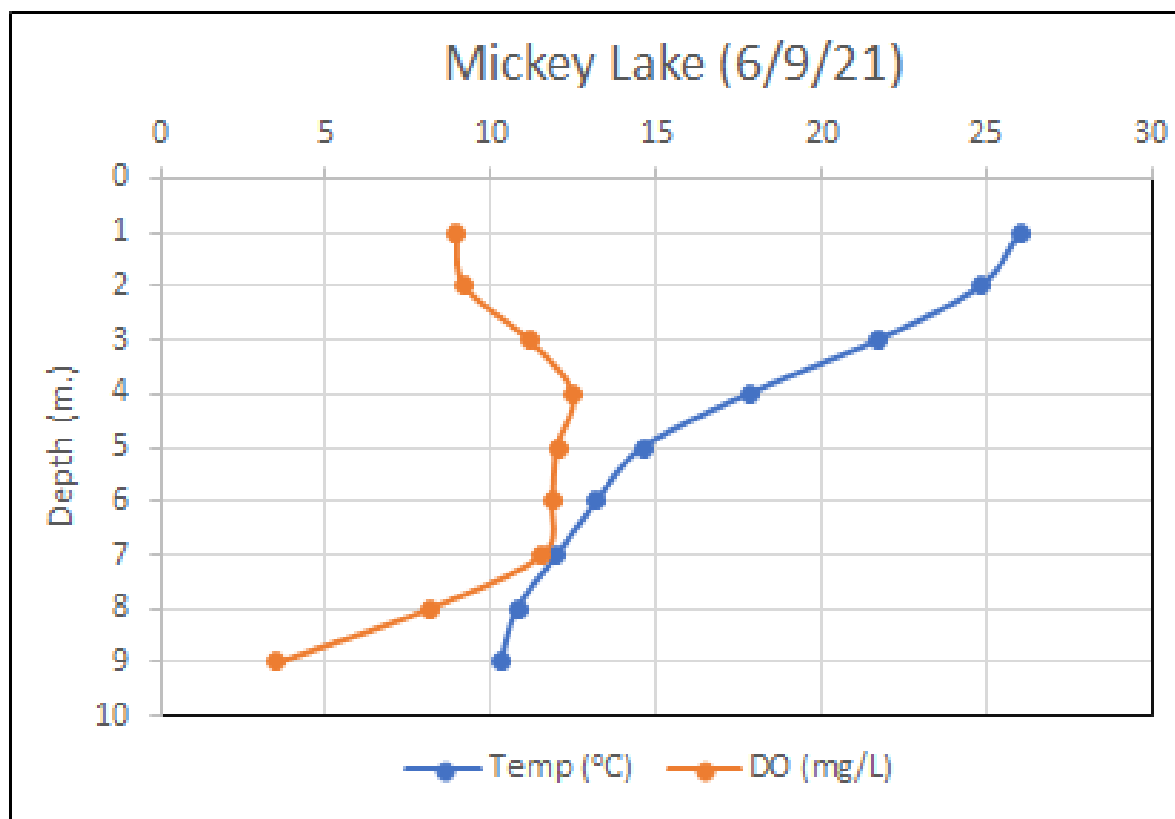


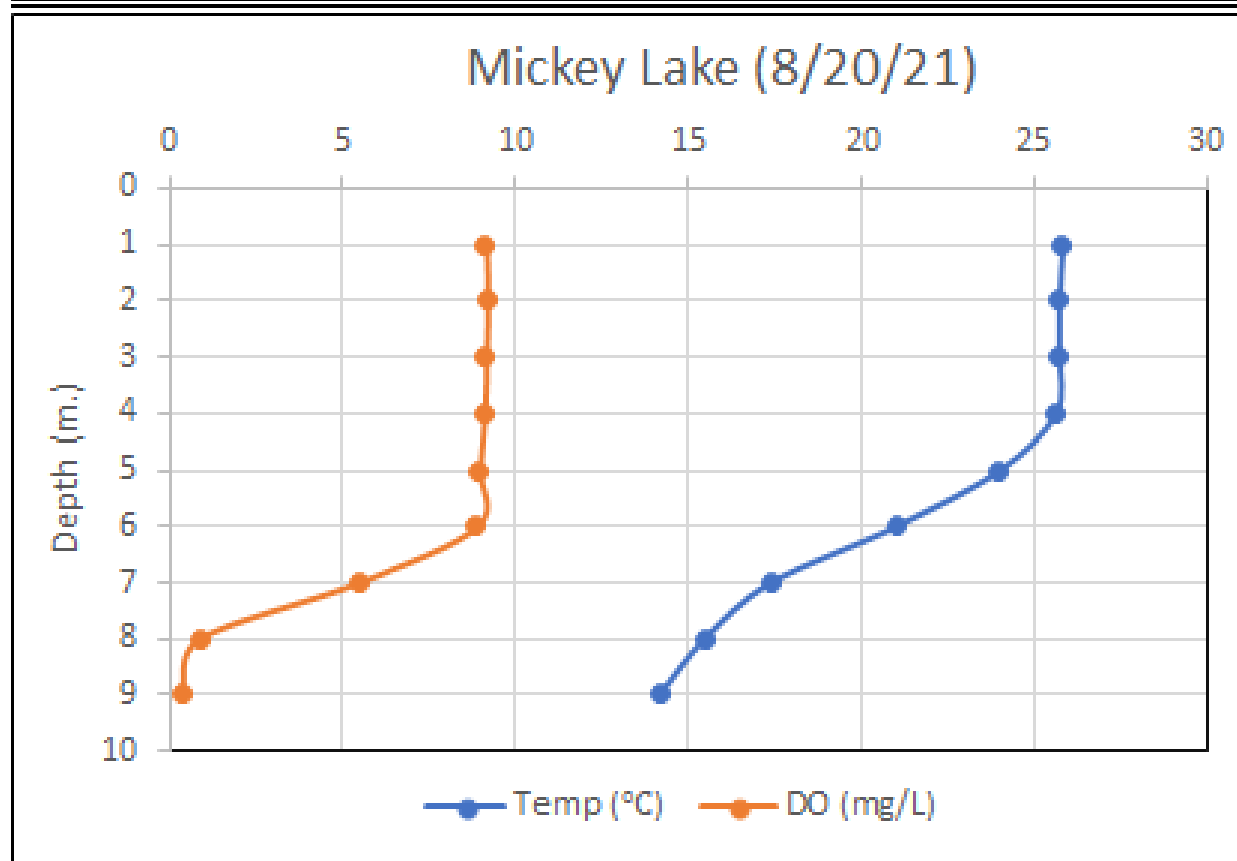
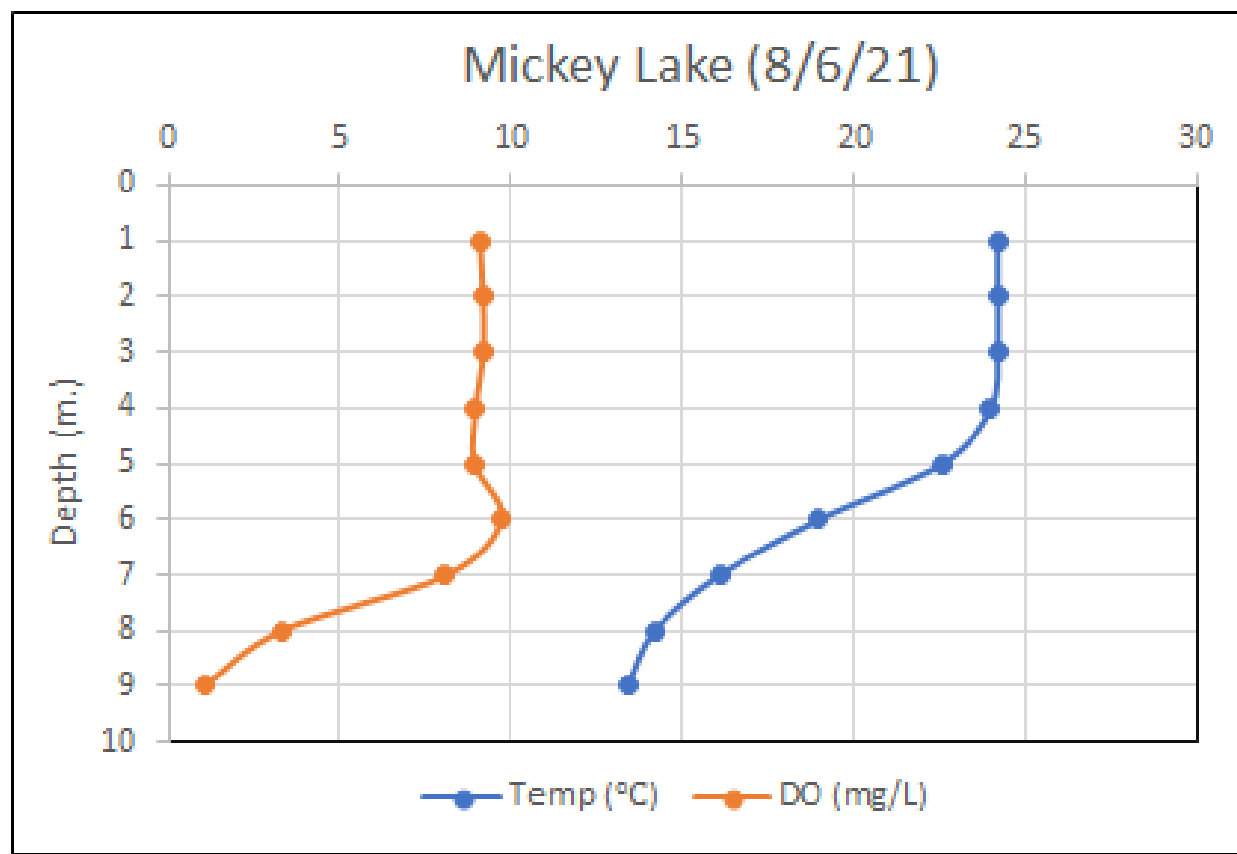


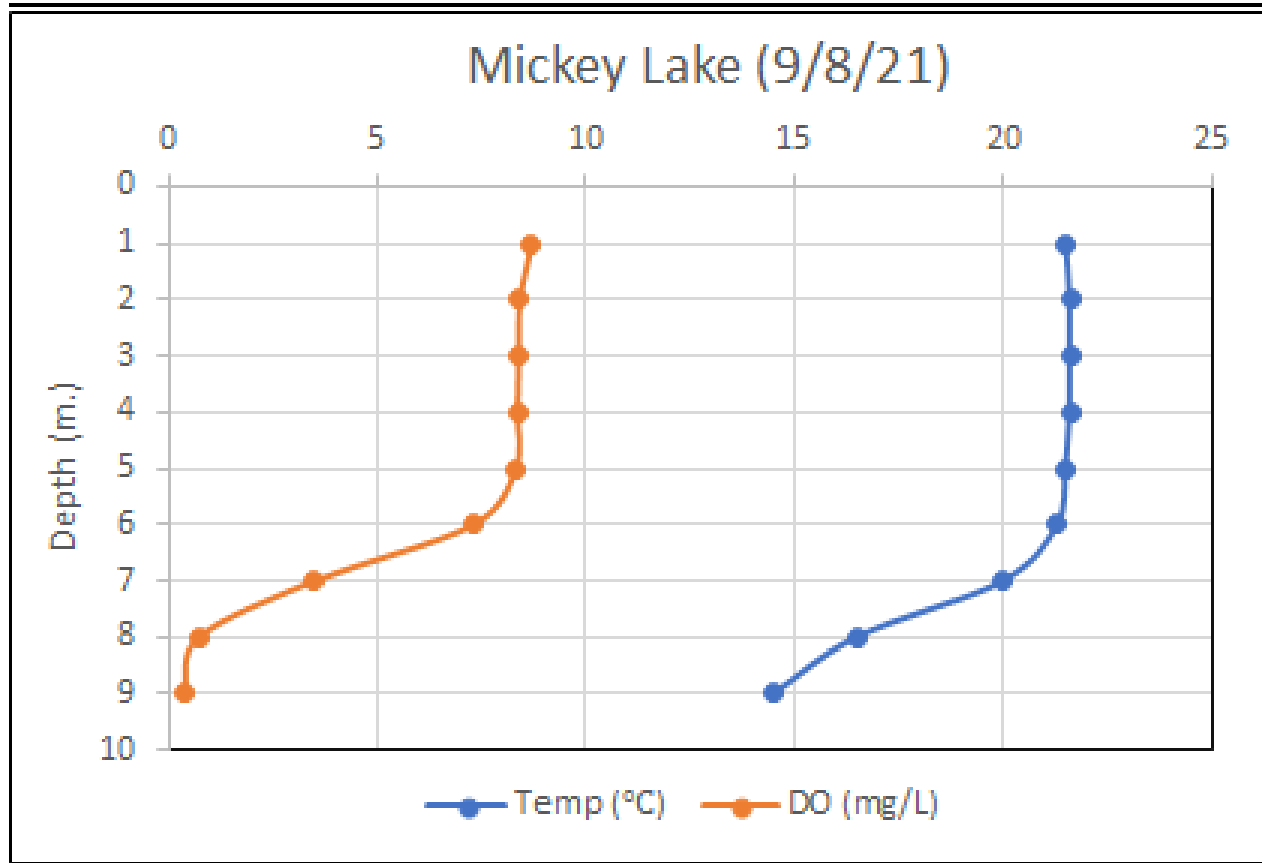
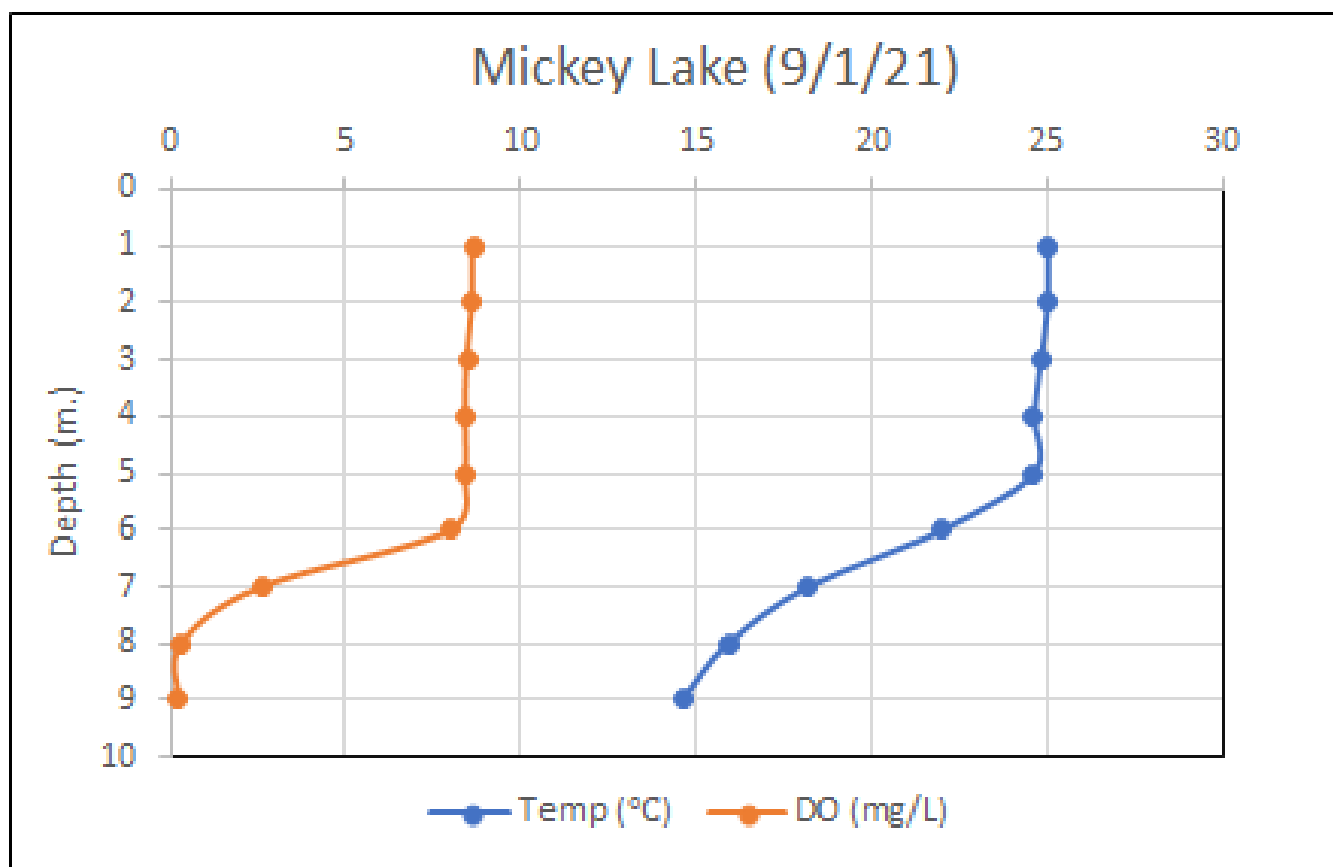


Dissolved Oxygen/Temperature Depth Profiles: Mickey Lake

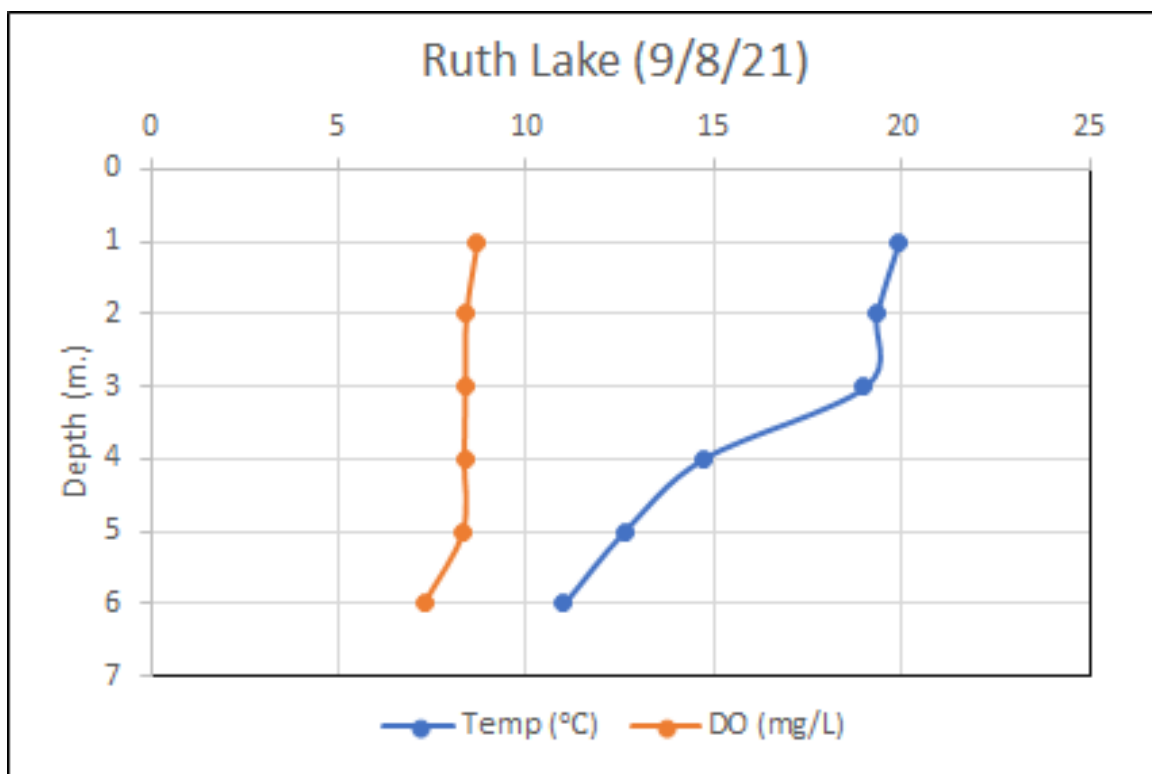
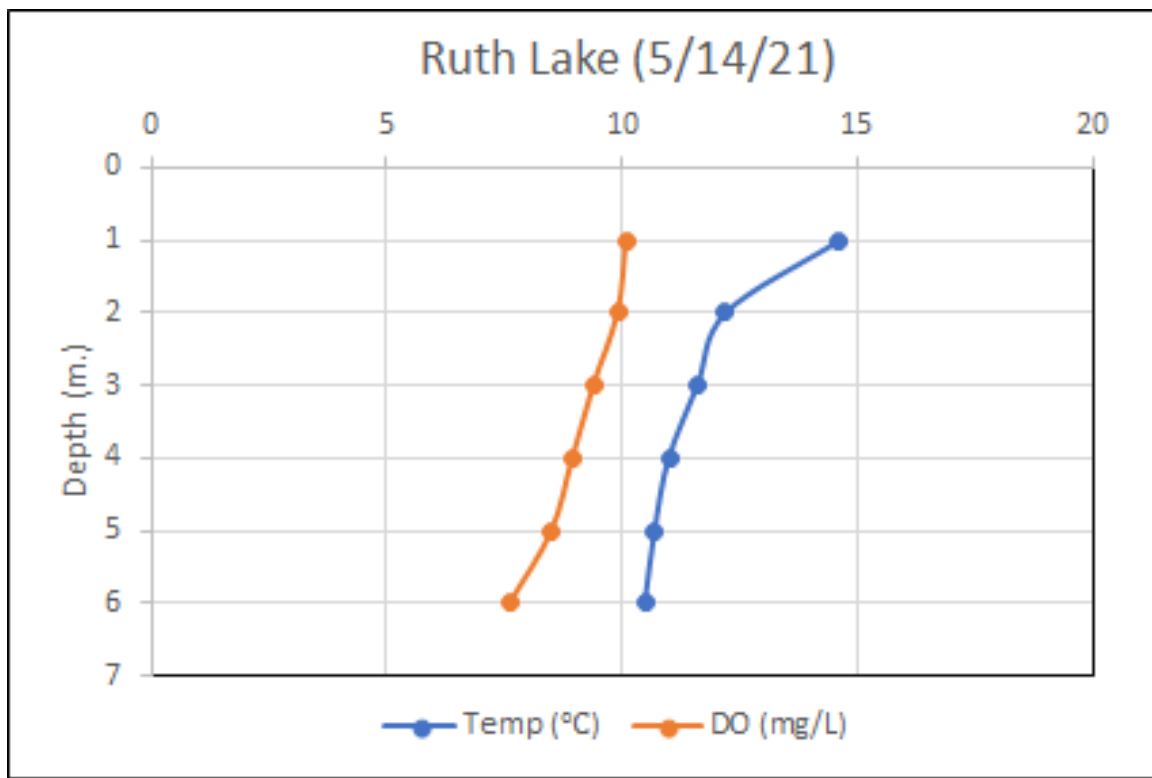








Dissolved Oxygen/Temperature Depth Profiles: Ruth Lake



Plankton of Long Lake

Written December 2018,

Dr. Richard A Roeper Professor Emeritus of Biology , Alma College

Introduction and Methods for 2018-2021

Besides using chemical and physical data to analyze the trophic status and health of an inland lake, it is practical to study the biota of the lake. This report looks at one part of the biota consisting of analysis of plankton of Long Lake in Grand Traverse County, Michigan. Plankton is defined as the microscopic algal phytoplankton and the animal zooplankton suspended in the lake's water.

The method involved that samples were collected with a plankton net drawn at a slow speed off a platoon boat. Samples were not fixed, but were chilled and examined within a day of collection. Microscopic mounts consisted of drops of the plankton sample covered by a cover slip and then examined at 100X and 450X of a binocular compound microscope. The observations were made determining the genus of the plankton using several identification sources listed in the bibliography.

Observations were made until no new genera of plankton were observed. Quantitative estimates of observed plankton genera by indicating frequency of observation each genus with a range from one 'x' to three 'xxx'.

From EPA sources and other web sources the trophic level (eutrophic- polluted and oligotrophic-clean) of the plankton were determined.

Results:

| 2021 Plankton Data- Long Lake | | | | | | |
|-------------------------------|-----------|----------|----------|-----------|----------|----------|
| Dates Sampled | | | | | | |
| | 5/26/2021 | 6/9/2021 | 7/9/2021 | 7/26/2021 | 9/1/2021 | 9/8/2021 |
| Phytoplankton | | | | | | |
| Blue Green Algae | | | | | | |
| Gleotrichia | | | | X | | X |
| Coelosphaerium | | | | | | |
| Merismopedia | X | | | X | X | X |
| Microcystis | | | | | XXX | |
| Anacystis | | | | | | X |
| Anabaena | | X | | | | |
| Diatoms | | | | | | |
| Melosira | | | | | | |
| Asterionella | X | | | | | |
| Fragillaria | X | | | XXX | X | |
| Dinoflagellates | | | | | | |
| Ceratium | X | | | | | XXX |
| Chrysophyta | | | | | | |
| Dinophyton | | | | XXX | XX | X |
| Green Algae | | | | | | |
| Desmid | | | | | | |
| Cosmarium | | X | | | | X |
| Zooplankton | | | | | | |
| Rotifers | | | | | | |
| Keratella | | XX | | XX | XX | XX |
| Kellicottia | | XX | | | XX | |
| Cladocera | | | | | | |
| Bosmina | | | | X | | |
| Nauplius | | X | | XX | | |
| Coepodia | | X | | X | XXX | XX |

| 2021 Plankton Data- Mickey Lake | | | | | |
|---------------------------------|-----------|----------|----------|-----------|--------|
| Dates Sampled | | | | | |
| | 5/26/2021 | 6/9/2021 | 7/9/2021 | 7/26/2021 | 9/1/21 |
| Phytoplankton | | | | | |
| Blue Green Algae | | | | | |
| Gleotrichia | x | x | x | x | x |
| Coelosphaerium | x | | | | |
| Merismopedia | | | x | | |
| Anacystis | | | | x | x |
| Diatoms | | | | | |
| Melosira | x | | | | |
| Asterionella | | | | | |
| Fragillaria | | | | | x |
| Dinoflagellates | | | | | |
| Ceratium | x | | x | | |
| Chrysophyta | | | | | |
| Dinophyton | xx | x | x | x | |
| Green Algae | | | | | |
| Pediastrum | | | x | | |
| Cosmarium | x | x | | | |
| Zooplankton | | | | | |
| Rotifers | | | | | |
| Keratella | xxx | x | xxx | xx | x |
| Kellicottia | xxx | x | x | | |
| Cladocera | | | | | |
| Bosmina | | | x | x | |
| Nauplius | x | x | x | xx | |
| Coepodia | xx | xxx | x | x | xx |

| 2020 Plankton Data- Ruth Lake | | |
|-------------------------------|-----------|-----|
| Dates Sampled | | |
| | 9/24/2021 | N/A |
| Phytoplankton | | |
| Blue Green Algae | | |
| Gleotrichia | | |
| Coelosphaerium | x | |
| Microcystis | | |
| Diatoms | | |
| Asterionella | | |
| Fragillaria | | |
| Dinoflagellates | | |
| Ceratium | xxx | |
| Chrysophyta | | |
| Dinophyton | | |
| Hydrus | | |
| Green Algae | | |
| Desmid | | |
| Penium | x | |
| Zooplankton | | |
| Rotifers | | |
| Kellicotta | x | |
| Keratella | xxx | |
| Protozoa | | |
| Ciliates | | |
| Cladocera | | |
| Nauplius | xx | |
| Bosima | | |
| Other | | |
| Coepodia | x | |

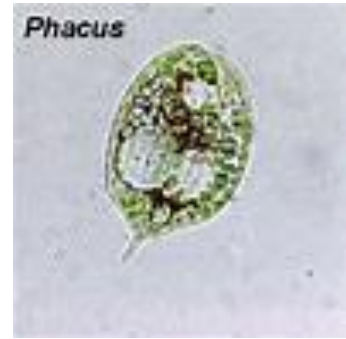
Representative Algae



Oscillatoria



Gloeotrichia



Phacus

Discussion:

Gloeotrichia is a concern. It is considered a meroplankton. Filaments of Gloeotrichia develop as a ball of cells visible to the naked eye. They start in the sediment of the lake. As the summer progresses, gas vesicles will cause the colony to rise in a late summer bloom. In several lakes in Maine blooms have been observed. Gloeotrichia produces a toxin called microcystin which can cause liver damage if ingested. A swimmers-itch like symptoms have been reported during these late summer blooms.

The presence of Oscillatoria, Phormidium, and Phacus indicate enrichment in Mickey Lake. Desmids may also bloom.

In general, one would conclude the plankton of Long Lake does not represent a eutrophic condition.

Bibliography

Bold, H.C. and M. L. Wynne. 1985 Introduction to the Algae. 2nd Edition . Prentice Hall. 720pp.

Needham, J.G. 1962 Guide to the Study of Fresh Water Biology.

Prescott, G.W. 1970. How to Know the Freshwater Algae 2nd edition 348pp.

Section II:

Historical Data Trends

Data from Dr. Wallace Fusilier's 1993-2005 reports, as well as GLEC's 2005, '08, '11, and '14 reports were used to analyze historical trends for Long Lake, Ruth Lake and Mickey Lake. Water quality data spanning from 2016 to 2021 has been collected by the Long Lake Association's water quality monitoring interns with the support of mentors and local organizations (with the exception of the year 2020 as no interns were hired that year due to pandemic precautions).

Historical analysis can bring to light trends in water quality parameters, both positive and negative. Understanding how the lakes change over time, whether because of a normal eutrophication process or cultural eutrophication, is important for both property owners and lake health specialists. Further analysis can help determine proper treatment plans based on whether the issue is a long term, or sudden development.

Water quality parameters that are included in the historical analysis are total phosphorus (surface and bottom), sediment phosphorus, nitrate and nitrite, secchi depth, chlorophyll a, and calcium. Data collected during the 2021 sampling season is assumed to be accurate unless noted otherwise.

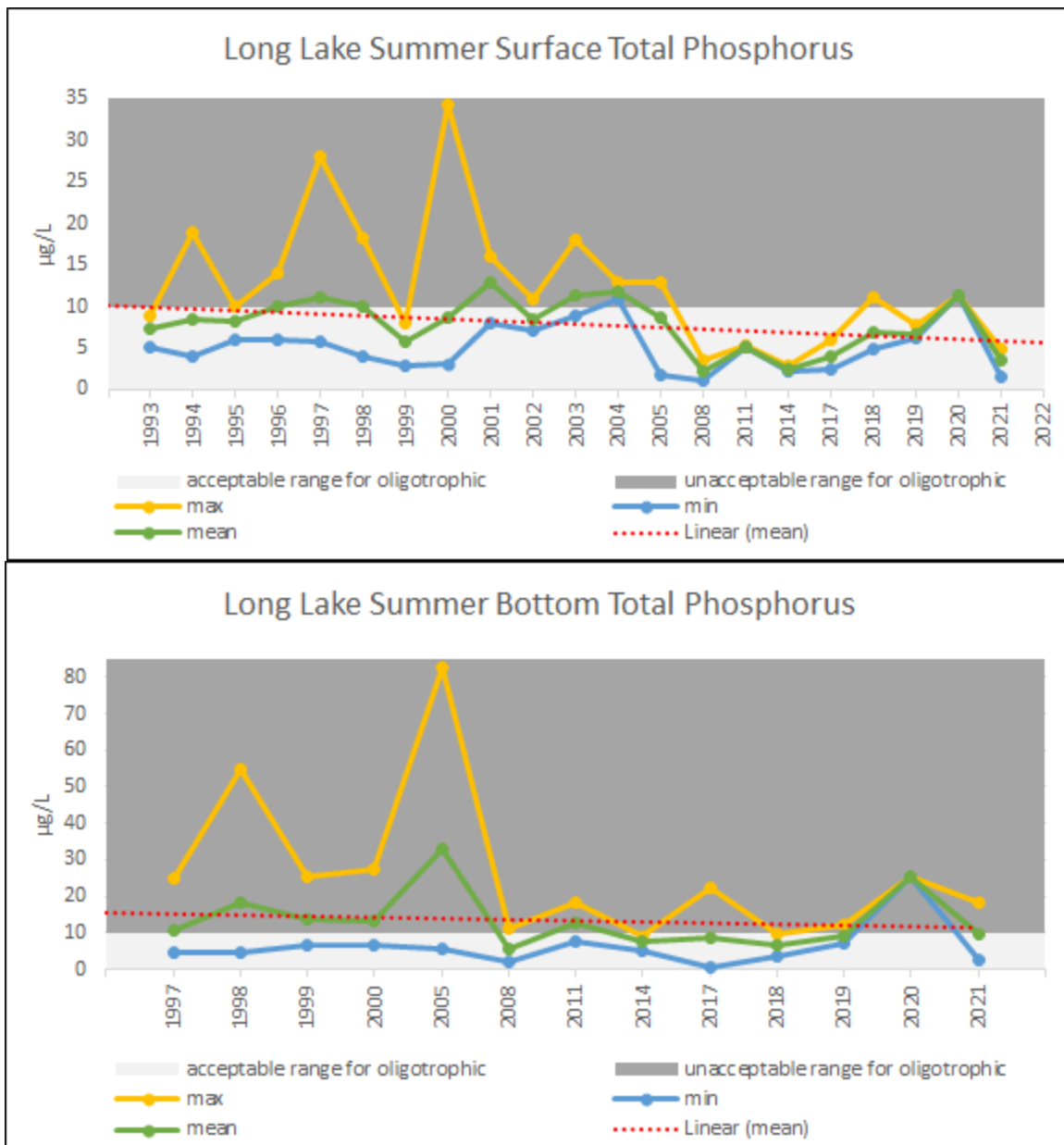
Note: data from the 2020 season will be quite different than surrounding years. This is due to a much lower sample size. 2020 sampling only occurred in late June and mid-September, rather than starting in early spring. Because of the increased level of plant growth that would be present as the summer develops (as well as the smaller overall sample size), the data collected will be skewed.

Historical Charts

Long Lake

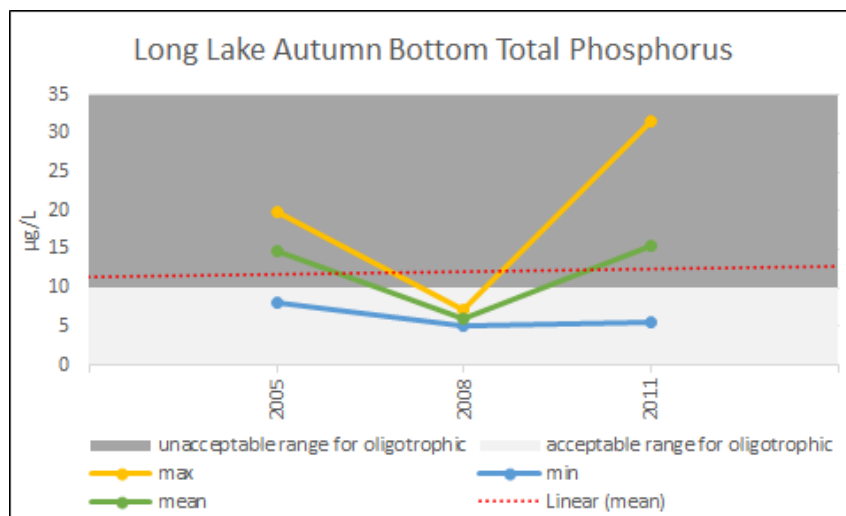
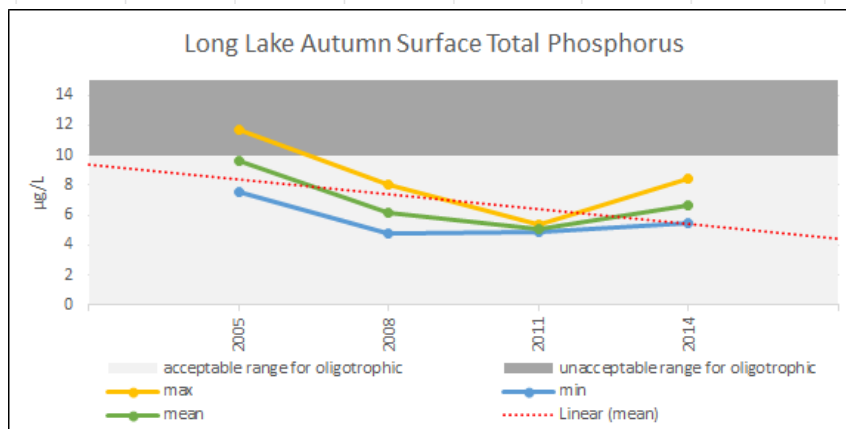
| Long Lake | | | | | | | | | | | | | | | | |
|---------------------------------------|-----------|--------|--------------------|---------------------|---------|--------|--------------------|---------------------|---------|--------|--------------------|---------------------|---------|--------|--------------------|---------------------|
| Total Phosphorus (µg/L) SPRING/SUMMER | | | | | | | | | | | | | | | | |
| Year | # samples | | | | min | | | | max | | | | mean | | | |
| | Surface | Bottom | Mid-Epi limnion | Mid-Hypo limnion | Surface | Bottom | Mid-Epi limnion | Mid-Hypo limnion | Surface | Bottom | Mid-Epi limnion | Mid-Hypo limnion | Surface | Bottom | Mid-Epi limnion | Mid-Hypo limnion |
| 1993 | 4 | --- | --- | --- | 5 | --- | --- | --- | 9 | --- | --- | --- | 7.25 | --- | --- | --- |
| 1994 | 6 | --- | --- | --- | 4 | --- | --- | --- | 19 | --- | --- | --- | 8.50 | --- | --- | --- |
| 1995 | 4 | --- | --- | --- | 6 | --- | --- | --- | 10 | --- | --- | --- | 8.25 | --- | --- | --- |
| 1996 | 4 | --- | --- | --- | 6 | --- | --- | --- | 14 | --- | --- | --- | 10.00 | --- | --- | --- |
| 1997 | 19 | 6 | --- | --- | 5.8 | 4.7 | --- | --- | 28 | 24.9 | --- | --- | 11.09 | 10.87 | --- | --- |
| 1998 | 9 | 6 | --- | --- | 4 | 4.7 | --- | --- | 18.2 | 55 | --- | --- | 9.99 | 18.1 | --- | --- |
| 1999 | 6 | 6 | --- | --- | 2.8 | 6.8 | --- | --- | 7.9 | 25.4 | --- | --- | 5.67 | 13.47 | --- | --- |
| 2000 | 33 | 27 | 22 | 18 | 3.1 | 6.4 | 3.3 | 4.2 | 34.4 | 27.4 | 10.6 | 21 | 8.77 | 13.25 | 7.37 | 9.92 |
| 2001 | 6 | --- | --- | --- | 8 | --- | --- | --- | 16 | --- | --- | --- | 12.83 | --- | --- | --- |
| 2002 | 6 | --- | --- | --- | 7 | --- | --- | --- | 11 | --- | --- | --- | 8.50 | --- | --- | --- |
| 2003 | 15 | --- | --- | --- | 9 | --- | --- | --- | 18 | --- | --- | --- | 11.27 | --- | --- | --- |
| 2004 | 6 | --- | --- | --- | 11 | --- | --- | --- | 13 | --- | --- | --- | 11.83 | --- | --- | --- |
| 2005 | 6 | 3 | --- | --- | 1.8 | 5.7 | --- | --- | 12.9 | 82.5* | --- | --- | 8.65 | 33.17 | --- | --- |
| 2008 | 3 | 3 | --- | --- | 1.2 | 1.9 | --- | --- | 3.6 | 11.3 | --- | --- | 2.20 | 5.77 | --- | --- |
| 2011 | 2 | 2 | --- | --- | 5 | 7.5 | --- | --- | 5.4 | 18.4 | --- | --- | 5.20 | 12.95 | --- | --- |
| 2014 | 3 | 3 | --- | --- | 2.2 | 4.9 | --- | --- | 2.8 | 9.1 | --- | --- | 2.47 | 7.63 | --- | --- |
| 2017 | 6 | 7 | --- | --- | 2.5 | 0.3 | --- | --- | 6.1 | 22.3 | --- | --- | 3.95 | 8.53 | --- | --- |
| 2018 | 6 | 6 | --- | --- | 4.9 | 3.7 | --- | --- | 11.2 | 9.9 | --- | --- | 6.97 | 6.62 | --- | --- |
| 2019 | 6 | 6 | --- | --- | 6.3 | 6.9 | --- | --- | 7.7 | 12.1 | --- | --- | 6.68 | 9.18 | --- | --- |
| 2020 [^] | 1 | 1 | --- | --- | 11.3 | 25.2 | --- | --- | 11.3 | 25.2 | --- | --- | 11.30 | 25.20 | --- | --- |
| 2021 | 5 | 4 | --- | --- | <1.6 | 2.7 | --- | --- | 4.9 | 18.4 | --- | --- | 3.64 | 9.78 | --- | --- |

*Possible contamination from bottom sediment [^]only one sample date in Sept. due to COVID-19

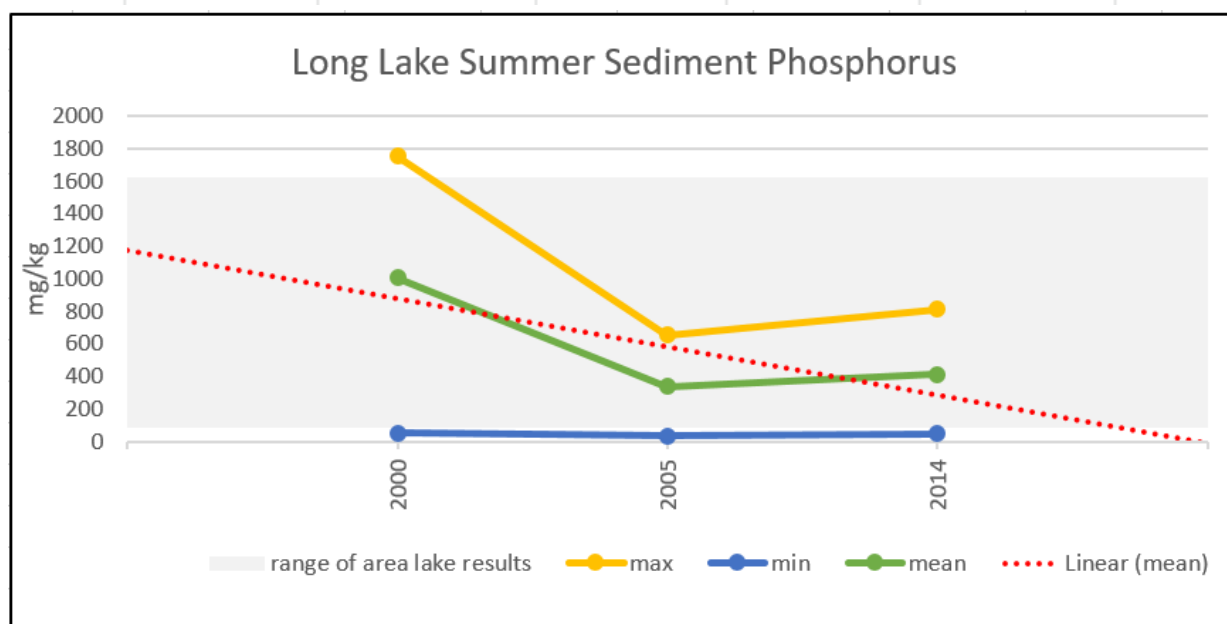


Summary: (see table 1 and 3) * In 2005 there was possible sediment contamination in a sample. This sample was included in the graph, but the overall trend downward is still consistent with what we see in the spring/summer samples. This trend could be slightly more significant if not considering this sample. In 2020 there was only one sampling date which shows high amounts of phosphorus. This is most likely due to the small sample size but it should be watched in the future.

| Total Phosphorus (µg/L) AUTUMN | | | | | | | | |
|--------------------------------|-----------|--------|---------|--------|---------|--------|---------|--------|
| Year | # samples | | min | | max | | mean | |
| | Surface | Bottom | Surface | Bottom | Surface | Bottom | Surface | Bottom |
| 1993 | --- | --- | --- | --- | --- | --- | --- | --- |
| 1994 | --- | --- | --- | --- | --- | --- | --- | --- |
| 1995 | --- | --- | --- | --- | --- | --- | --- | --- |
| 1996 | --- | --- | --- | --- | --- | --- | --- | --- |
| 1997 | --- | --- | --- | --- | --- | --- | --- | --- |
| 1998 | --- | --- | --- | --- | --- | --- | --- | --- |
| 1999 | --- | --- | --- | --- | --- | --- | --- | --- |
| 2000 | --- | --- | --- | --- | --- | --- | --- | --- |
| 2001 | --- | --- | --- | --- | --- | --- | --- | --- |
| 2002 | --- | --- | --- | --- | --- | --- | --- | --- |
| 2003 | --- | --- | --- | --- | --- | --- | --- | --- |
| 2004 | --- | --- | --- | --- | --- | --- | --- | --- |
| 2005 | 3 | 3 | 7.5 | 8.1 | 11.7 | 19.9 | 9.63 | 14.83 |
| 2008 | 3 | 3 | 4.8 | 5.1 | 8 | 7.2 | 6.13 | 6.03 |
| 2011 | 3 | 3 | 4.9 | 5.5 | 5.4 | 31.7 | 5.10 | 15.43 |
| 2014 | 3 | 3 | 5.5 | 6.5 | 8.4 | 14.2 | 6.70 | 9.10 |
| 2017 | --- | --- | --- | --- | --- | --- | --- | --- |
| 2018 | --- | --- | --- | --- | --- | --- | --- | --- |
| 2019 | --- | --- | --- | --- | --- | --- | --- | --- |
| 2020 | --- | --- | --- | --- | --- | --- | --- | --- |
| 2021 | --- | --- | --- | --- | --- | --- | --- | --- |



| Sediment Phosphorus (mg/kg) SPRING/SUMMER | | | | |
|---|-----------|------|------|---------|
| Year | # samples | min | max | mean |
| 2000 | 3 | 50.6 | 1754 | 1005.30 |
| 2005 | 3 | 33 | 654 | 336.33 |
| 2008 | --- | --- | --- | --- |
| 2011 | --- | --- | --- | --- |
| 2014 | 3 | 48 | 811 | 412.67 |
| 2017 | --- | --- | --- | --- |
| 2018 | --- | --- | --- | --- |
| 2019 | --- | --- | --- | --- |
| 2020 | --- | --- | --- | --- |

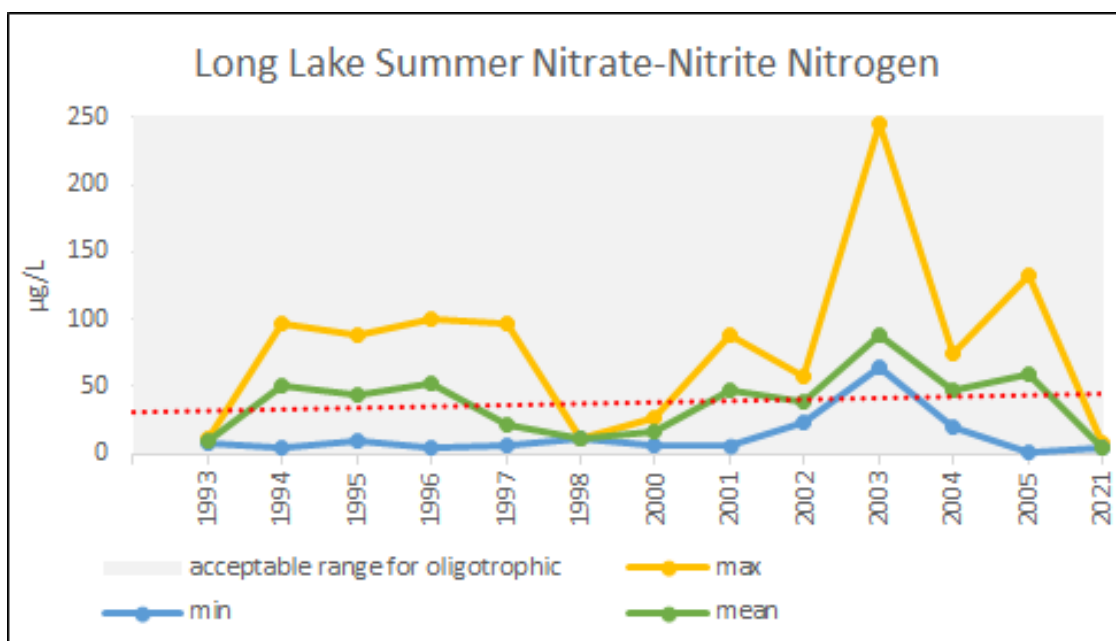


| Nitrate-Nitrite Nitrogen (µg/L) SPRING/SUMMER | | | | | | | | |
|---|-----------|--------|---------|--------|---------|--------|---------|--------|
| Year | # samples | | min | | max | | mean | |
| | Surface | Bottom | Surface | Bottom | Surface | Bottom | Surface | Bottom |
| 1993 | 4 | --- | 8 | --- | 12 | --- | 10.00 | --- |
| 1994 | 6 | --- | 5 | --- | 97 | --- | 51.50 | --- |
| 1995 | 4 | --- | 9 | --- | 89 | --- | 44.25 | --- |
| 1996 | 4 | --- | 4 | --- | 101 | --- | 52.75 | --- |
| 1997 | 13 | --- | 6 | --- | 96 | --- | 22.15 | --- |
| 1998 | 3 | --- | 11 | --- | 12 | --- | 11.33 | --- |
| 1999 | --- | --- | --- | --- | --- | --- | --- | --- |
| 2000 | 6 | --- | 6 | --- | 26 | --- | 16.17 | --- |
| 2001 | 6 | --- | 7 | --- | 88 | --- | 47.50 | --- |
| 2002 | 6 | --- | 24 | --- | 57 | --- | 39.33 | --- |
| 2003 | 15 | --- | 65 | --- | 245 | --- | 87.87 | --- |
| 2004 | 6 | --- | 20 | --- | 75 | --- | 47.17 | --- |
| 2005 | 6 | 3 | <1.4 | <1.4 | 133 | 34.1 | 59.27 | 16.97 |
| 2021 | 4 | 4 | <4.0 | <4.0 | 7.4 | 8.2 | 5.10 | 5.68 |

| Nitrate-Nitrite Nitrogen (µg/L) AUTUMN | | | | | | | | |
|--|-----------|--------|---------|--------|---------|--------|---------|--------|
| Year | # samples | | min | | max | | mean | |
| | Surface | Bottom | Surface | Bottom | Surface | Bottom | Surface | Bottom |
| 1993 | --- | --- | --- | --- | --- | --- | --- | --- |
| 1994 | --- | --- | --- | --- | --- | --- | --- | --- |
| 1995 | --- | --- | --- | --- | --- | --- | --- | --- |
| 1996 | --- | --- | --- | --- | --- | --- | --- | --- |
| 1997 | --- | --- | --- | --- | --- | --- | --- | --- |
| 1998 | --- | --- | --- | --- | --- | --- | --- | --- |
| 1999 | --- | --- | --- | --- | --- | --- | --- | --- |
| 2000 | --- | --- | --- | --- | --- | --- | --- | --- |
| 2001 | --- | --- | --- | --- | --- | --- | --- | --- |
| 2002 | --- | --- | --- | --- | --- | --- | --- | --- |
| 2003 | --- | --- | --- | --- | --- | --- | --- | --- |
| 2004 | --- | --- | --- | --- | --- | --- | --- | --- |
| 2005 | 3 | 3 | 1.5 | 5.1 | 6.1 | 8 | 4.1 | 6.6 |

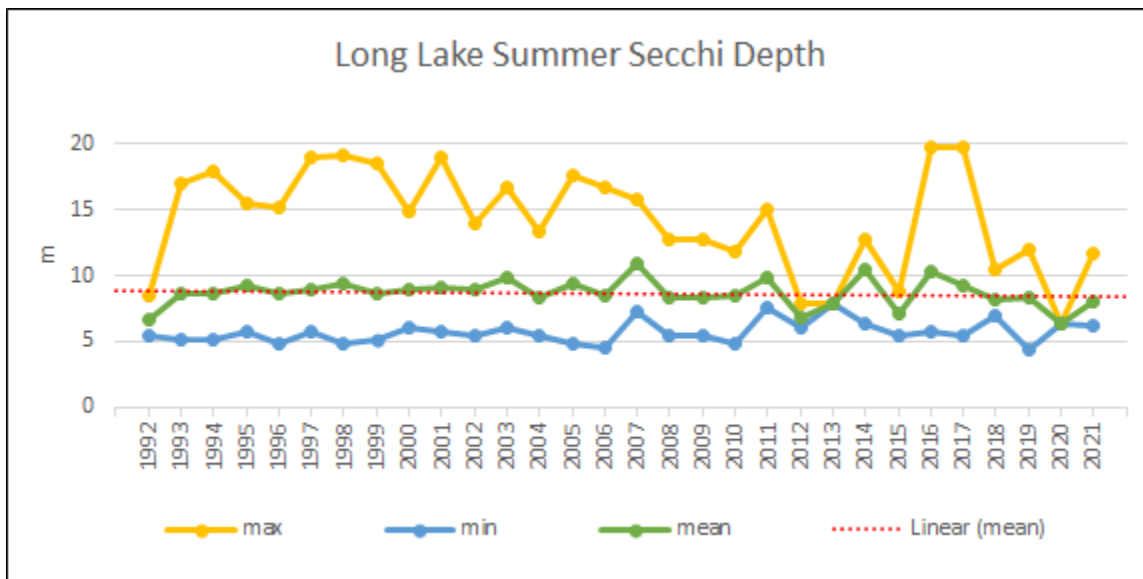
| Nitrogen: Nitrate (µg/L) SPRING/SUMMER | | | | | | | | |
|--|-----------|--------|---------|--------|---------|--------|---------|--------|
| Year | # samples | | min | | max | | mean | |
| | Surface | Bottom | Surface | Bottom | Surface | Bottom | Surface | Bottom |
| 2018 | 3 | --- | <1000 | --- | <1000 | --- | <1000 | --- |
| 2019 | 6 | --- | <1000 | --- | <1000 | --- | <1000 | --- |
| 2020 | 1 | --- | <1000 | --- | <1000 | --- | <1000 | --- |

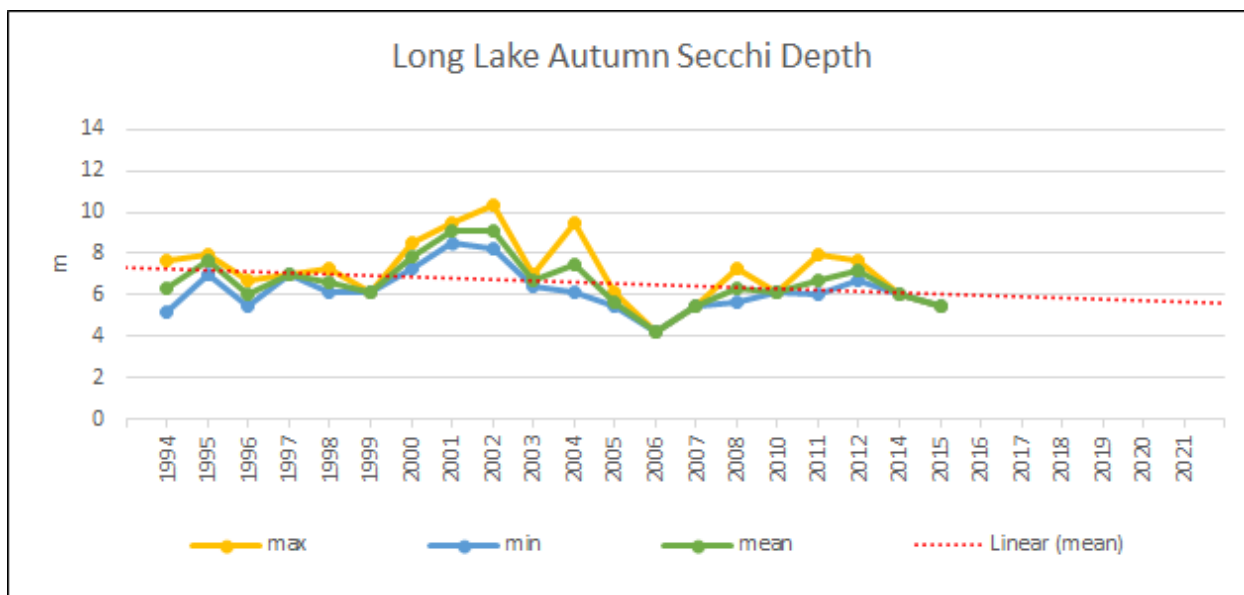
| Nitrogen: Nitrite (µg/L) SPRING/SUMMER | | | | | | | | |
|--|-----------|--------|---------|--------|---------|--------|---------|--------|
| Year | # samples | | min | | max | | mean | |
| | Surface | Bottom | Surface | Bottom | Surface | Bottom | Surface | Bottom |
| 2018 | 3 | --- | <50 | --- | <50 | --- | <50 | --- |
| 2019 | 6 | --- | <50 | --- | <50 | --- | <50 | --- |
| 2020 | 1 | --- | <50 | --- | <50 | --- | <50 | --- |



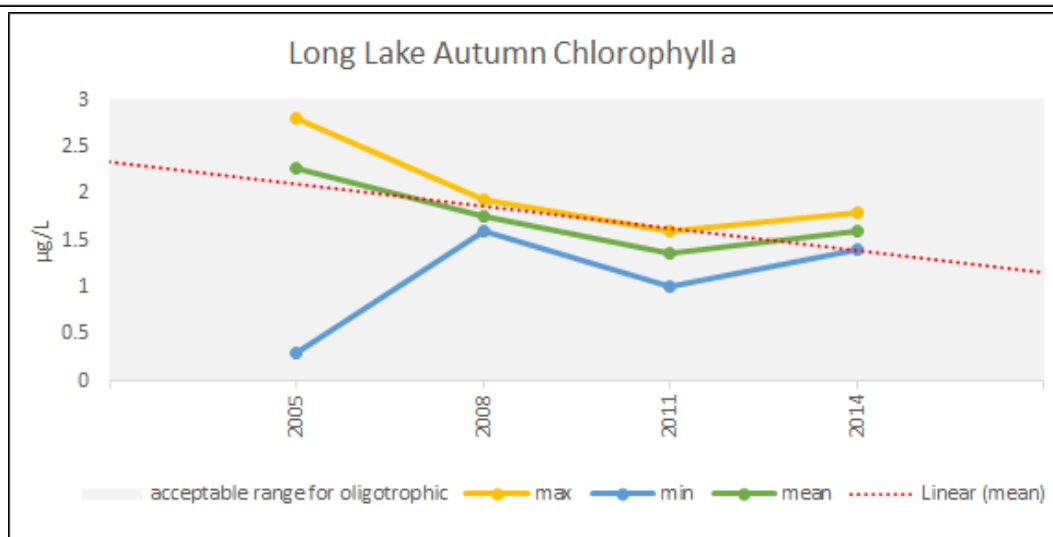
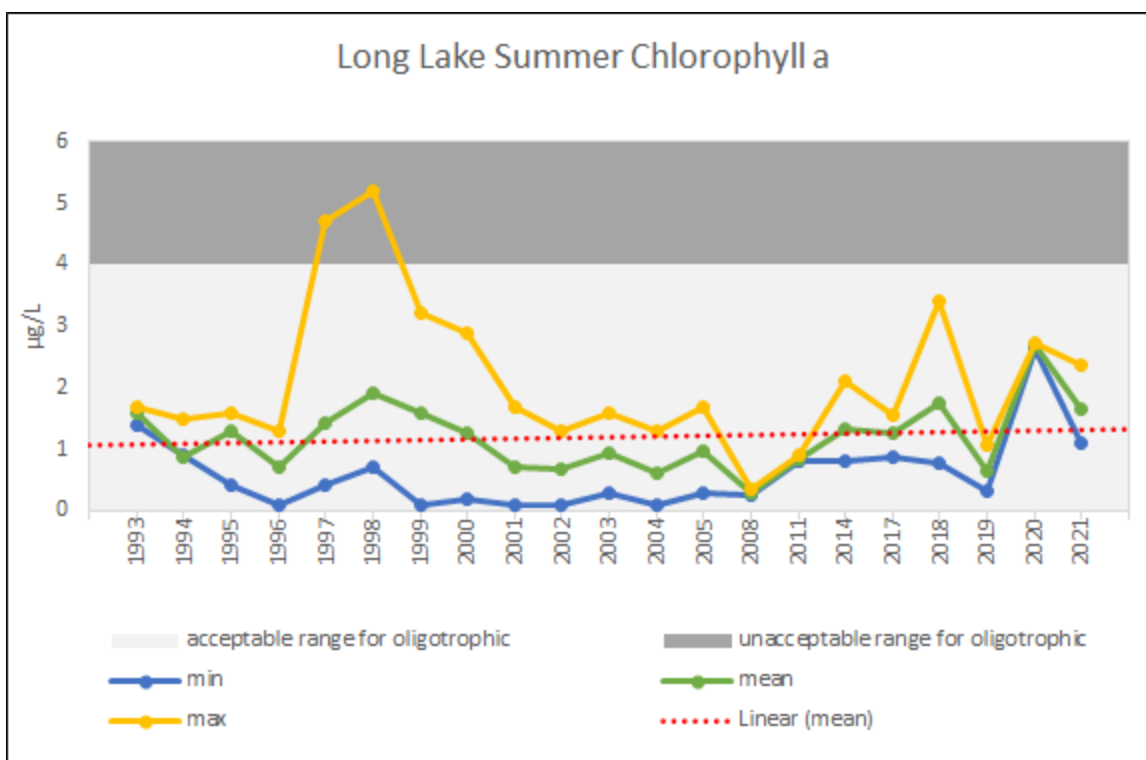
Summary: (see table 2) * There was only 1 bottom sample taken in 2005, so it is not included in the graph. It would have decreased the slope of the trend slightly, but not significantly. The one autumn sample year, 2005, is also not included since no trend could be established. Different nitrogen testing methods were used in both 2018 and 2019, so we are not yet able to compare this data with any historical data.

| Secchi Disk (m.) SPRING/SUMMER | | | | | Secchi Disk (m.) AUTUMN | | | | |
|--------------------------------|-----------|------|-------|-------|-------------------------|-----------|------|-------|------|
| Year | # samples | min | max | mean | Year | # samples | min | max | mean |
| 1992 | 14 | 5.49 | 8.53 | 6.58 | 1992 | --- | --- | --- | --- |
| 1993 | 25 | 5.18 | 17.07 | 8.56 | 1993 | --- | --- | --- | --- |
| 1994 | 27 | 5.18 | 17.98 | 8.69 | 1994 | 4 | 5.18 | 7.62 | 6.33 |
| 1995 | 28 | 5.79 | 15.54 | 9.30 | 1995 | 4 | 7.01 | 7.92 | 7.62 |
| 1996 | 25 | 4.88 | 15.24 | 8.66 | 1996 | 4 | 5.49 | 6.71 | 6.02 |
| 1997 | 33 | 5.79 | 18.9 | 8.87 | 1997 | 1 | 7.01 | 7.01 | 7.01 |
| 1998 | 61 | 4.88 | 19.2 | 9.45 | 1998 | 4 | 6.1 | 7.32 | 6.63 |
| 1999 | 24 | 5.18 | 18.59 | 8.65 | 1999 | 3 | 6.1 | 6.1 | 6.10 |
| 2000 | 38 | 6.1 | 14.94 | 8.90 | 2000 | 3 | 7.32 | 8.53 | 7.82 |
| 2001 | 30 | 5.79 | 18.9 | 9.08 | 2001 | 3 | 8.53 | 9.45 | 9.14 |
| 2002 | 30 | 5.49 | 14.02 | 8.86 | 2002 | 4 | 8.23 | 10.36 | 9.14 |
| 2003 | 32 | 6.1 | 16.76 | 9.88 | 2003 | 2 | 6.4 | 7.01 | 6.71 |
| 2004 | 30 | 5.49 | 13.41 | 8.30 | 2004 | 5 | 6.1 | 9.45 | 7.44 |
| 2005 | 27 | 4.88 | 17.68 | 9.42 | 2005 | 5 | 5.49 | 6.1 | 5.70 |
| 2006 | 24 | 4.57 | 16.76 | 8.55 | 2006 | 1 | 4.27 | 4.27 | 4.27 |
| 2007 | 6 | 7.32 | 15.85 | 10.87 | 2007 | 1 | 5.49 | 5.49 | 5.49 |
| 2008 | 10 | 5.49 | 12.74 | 8.37 | 2008 | 4 | 5.64 | 7.32 | 6.31 |
| 2009 | 7 | 5.49 | 12.8 | 8.40 | 2009 | --- | --- | --- | --- |
| 2010 | 7 | 4.88 | 11.89 | 8.45 | 2010 | 1 | 6.1 | 6.1 | 6.10 |
| 2011 | 4 | 7.5 | 15 | 9.79 | 2011 | 4 | 6 | 7.92 | 6.73 |
| 2012 | 3 | 6.1 | 7.92 | 6.81 | 2012 | 2 | 6.71 | 7.62 | 7.17 |
| 2013 | 1 | 7.92 | 7.92 | 7.92 | 2013 | --- | --- | --- | --- |
| 2014 | 5 | 6.4 | 12.74 | 10.51 | 2014 | 3 | 6 | 6 | 6.00 |
| 2015 | 2 | 5.49 | 8.84 | 7.17 | 2015 | 1 | 5.49 | 5.49 | 5.49 |
| 2016 | 10 | 5.79 | 19.81 | 10.30 | 2016 | --- | --- | --- | --- |
| 2017 | 8 | 5.5 | 19.81 | 9.29 | 2017 | --- | --- | --- | --- |
| 2018 | 7 | 7 | 10.5 | 8.24 | 2018 | --- | --- | --- | --- |
| 2019 | 25 | 4.42 | 12.04 | 8.32 | 2019 | --- | --- | --- | --- |
| 2020 | 5 | 5.75 | 18.9 | 9.00 | 2020 | --- | --- | --- | --- |
| 2021 | 17 | 6.25 | 11.6 | 7.98 | 2021 | --- | --- | --- | --- |



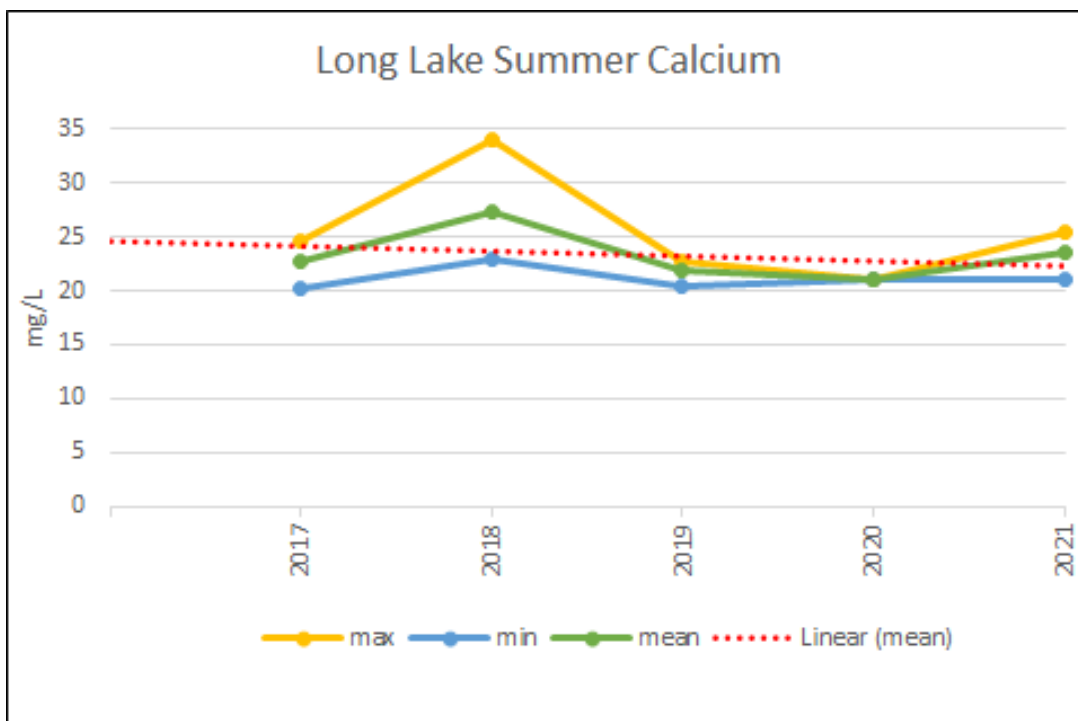


| Chlorophyll a (µg/L) SPRING/SUMMER | | | | | Chlorophyll a (µg/L) AUTUMN | | | | |
|------------------------------------|-----------|------|------|-------|-----------------------------|-----------|------|------|------|
| Year | # samples | min | max | mean | Year | # samples | min | max | mean |
| 1993 | 4 | 1.4 | 1.7 | 1.58 | 1993 | --- | --- | --- | --- |
| 1994 | 6 | 0.9 | 1.5 | 0.88 | 1994 | --- | --- | --- | --- |
| 1995 | 4 | 0.4 | 1.6 | 1.28 | 1995 | --- | --- | --- | --- |
| 1996 | 4 | 0.1 | 1.3 | 0.70 | 1996 | --- | --- | --- | --- |
| 1997 | 6 | 0.4 | 4.7 | 1.43 | 1997 | --- | --- | --- | --- |
| 1998 | 5 | 0.7 | 5.2 | 1.92 | 1998 | --- | --- | --- | --- |
| 1999 | 6 | 0.1 | 3.2 | 1.60 | 1999 | --- | --- | --- | --- |
| 2000 | 12 | 0.2 | 2.9 | 1.26 | 2000 | --- | --- | --- | --- |
| 2001 | 6 | 0.1 | 1.7 | 0.72 | 2001 | --- | --- | --- | --- |
| 2002 | 6 | 0.1 | 1.3 | 0.68 | 2002 | --- | --- | --- | --- |
| 2003 | 6 | 0.3 | 1.6 | 0.92 | 2003 | --- | --- | --- | --- |
| 2004 | 6 | 0.1 | 1.3 | 0.60 | 2004 | --- | --- | --- | --- |
| 2005 | 6 | 0.3 | 1.7 | 0.97 | 2005 | 3 | 0.3 | 2.8 | 2.27 |
| 2008 | 3 | 0.25 | 0.35 | 0.30 | 2008 | 3 | 1.61 | 1.93 | 1.75 |
| 2011 | 2 | 0.8 | 0.9 | 0.85 | 2011 | 3 | 1 | 1.6 | 1.37 |
| 2014 | 3 | 0.8 | 2.1 | 1.33 | 2014 | 3 | 1.4 | 1.8 | 1.60 |
| 2017 | 7 | 0.86 | 1.57 | 1.25 | | | | | |
| 2018 | 8 | 0.78 | 3.4 | 1.76 | | | | | |
| 2019 | 8 | 0.33 | 1.05 | 0.65 | | | | | |
| 2020 | 2 | 2.64 | 2.74 | 2.69 | | | | | |
| 2021 | 5 | 1.09 | 2.36 | 1.636 | | | | | |



Calcium (mg/L) SPRING/SUMMER

| Year | # samples | min | max | mean |
|------|-----------|------|------|-------|
| 2017 | 6 | 20.2 | 24.6 | 22.70 |
| 2018 | 6 | 22.9 | 34 | 27.32 |
| 2019 | 6 | 20.5 | 22.7 | 21.85 |
| 2020 | 1 | 21 | 21 | 21 |
| 2021 | 4 | 22.1 | 25.5 | 23.6 |



| Bacterial Testing (per 100mL) Summer | | | |
|--------------------------------------|--------------|----------------|---------|
| Year | Beach | Total Coliform | E. coli |
| 2018 | Taylor Park | 307.6 | 3.1 |
| 2018 | Gilbert Park | 770.1 | 8.6 |

| Recommended Safe Body Contact | E. coli count per 100 milliliters |
|-----------------------------------|-----------------------------------|
| Full body contact | 0-299 |
| Partial body contact (waist down) | 300-999 |
| No body contact | 1,000+ |

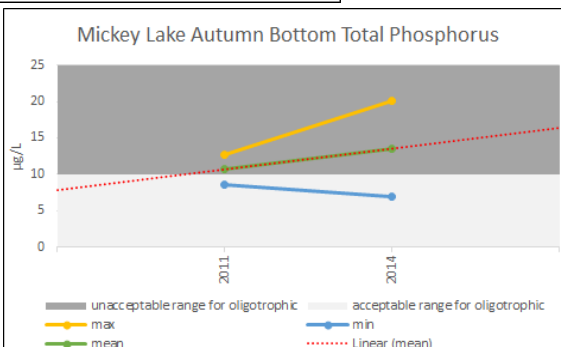
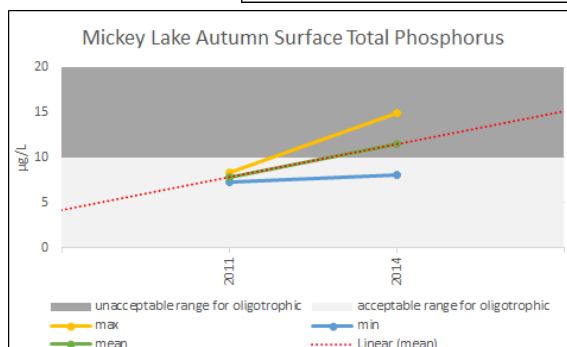
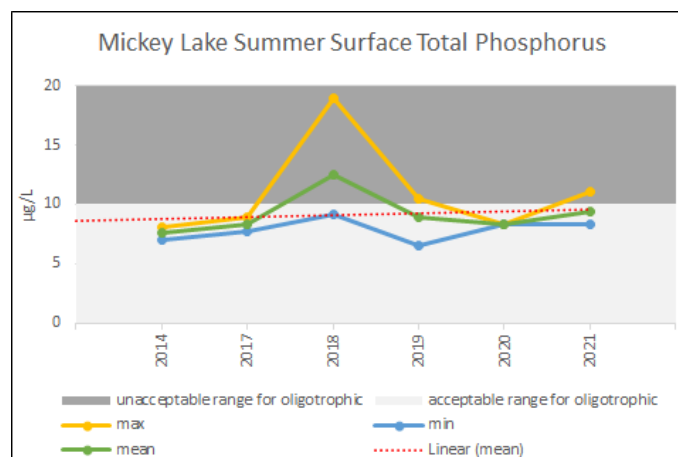
*Michigan EGLE standards (Michigan Department of Environment, Great Lakes, and Energy, 2019)

Mickey Lake

| Total Phosphorus (µg/L) SPRING/SUMMER | | | | | | | | |
|---------------------------------------|-----------|--------|---------|--------|---------|--------|---------|--------|
| Year | # samples | | min | | max | | mean | |
| | Surface | Bottom | Surface | Bottom | Surface | Bottom | Surface | Bottom |
| 2011 | --- | --- | --- | --- | --- | --- | --- | --- |
| 2014 | 2 | 2 | 7 | 7.6 | 8.1 | 18 | 7.55 | 12.80 |
| 2017 | 5 | 4 | 7.71 | 6.5 | 8.9 | 28.1* | 8.30 | 14.43 |
| 2018 | 3 | 2 | 9.1 | 10.4 | 18.9 | 15.4 | 12.50 | 12.90 |
| 2019 | 4 | 4 | 6.5 | 7.5 | 10.5 | 17.6 | 8.88 | 12.70 |
| 2020 | 1 | 1 | 8.3 | 21.8 | 8.3 | 21.8 | 8.30 | 21.80 |
| 2021 | 4 | 4 | 8.3 | 11.3 | 11.1 | 25.4 | 9.43 | 18.88 |

*Possible contamination from bottom sediment

| Total Phosphorus (µg/L) AUTUMN | | | | | | | | |
|--------------------------------|-----------|--------|---------|--------|---------|--------|---------|--------|
| Year | # samples | | min | | max | | mean | |
| | Surface | Bottom | Surface | Bottom | Surface | Bottom | Surface | Bottom |
| 2011 | 2 | 2 | 7.3 | 8.6 | 8.4 | 12.7 | 7.85 | 10.65 |
| 2014 | 2 | 2 | 8.1 | 6.9 | 14.9 | 20.1 | 11.50 | 13.50 |



| Sediment Phosphorus (mg/kg) SPRING/SUMMER | | | | |
|---|-----------|-----|------|------|
| Year | # samples | min | max | mean |
| 2014 | 2 | 879 | 1625 | 1252 |

Summary: There is only one sample year, so no trend could be established.

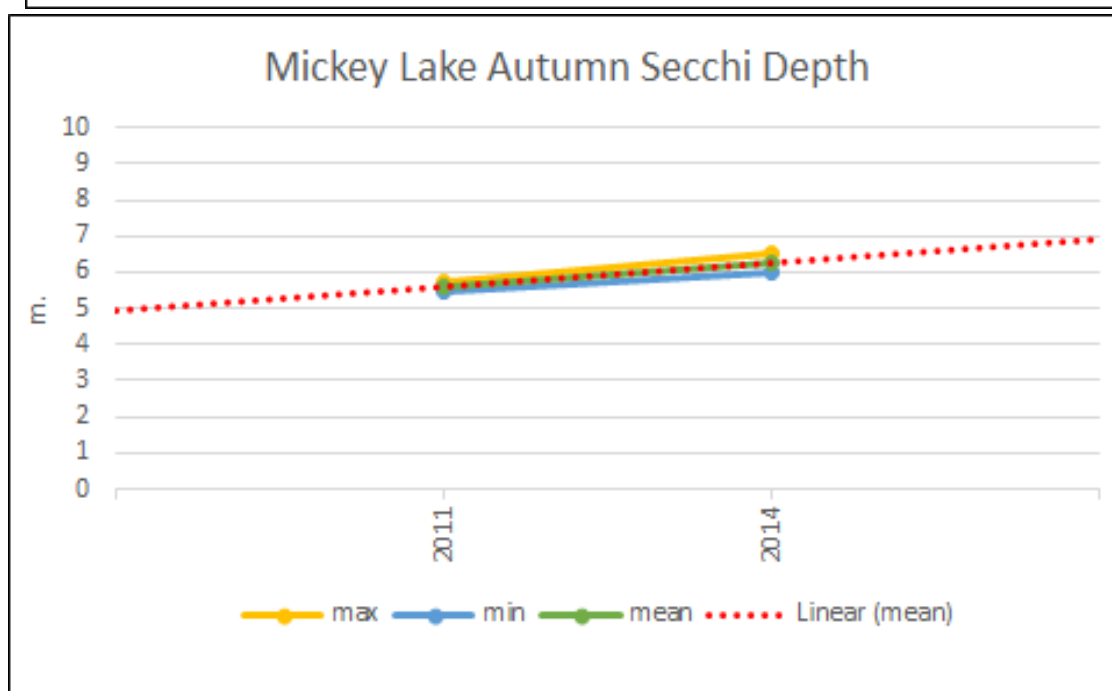
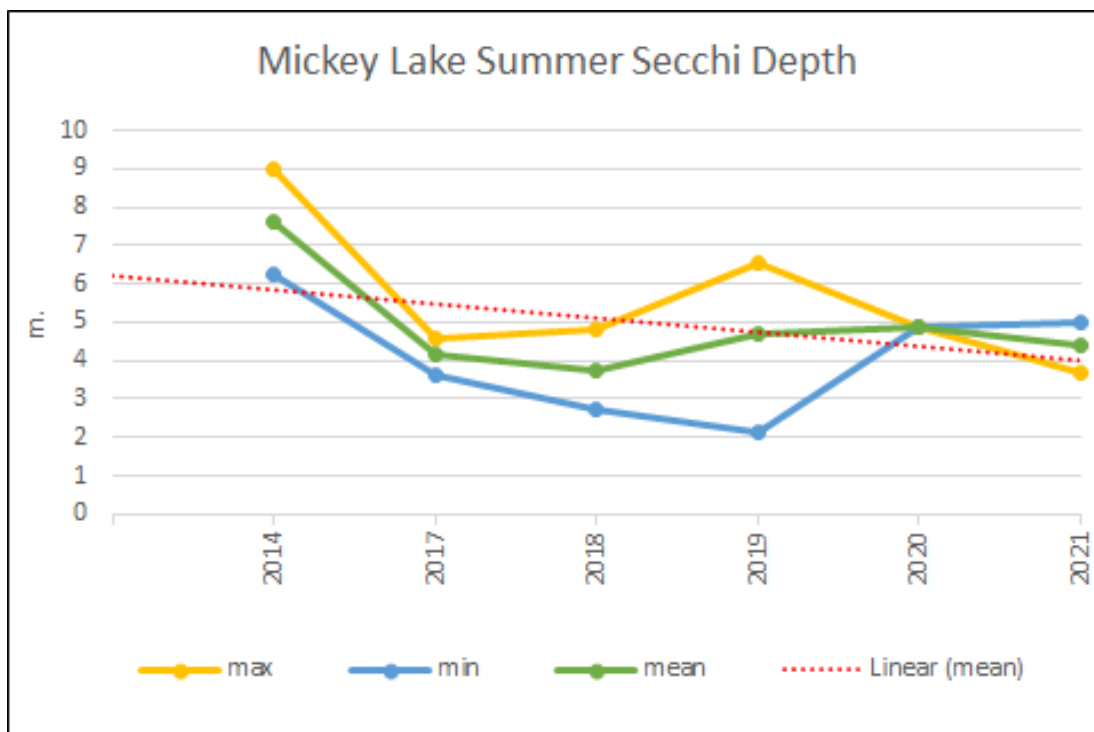
| Nitrogen: Nitrate (µg/L) SPRING/SUMMER | | | | | | | | |
|--|-----------|--------|---------|--------|---------|--------|---------|--------|
| Year | # samples | | min | | max | | mean | |
| | Surface | Bottom | Surface | Bottom | Surface | Bottom | Surface | Bottom |
| 2018 | 1 | --- | <1000 | --- | <1000 | --- | <1000 | --- |
| 2019 | 4 | --- | <1000 | --- | <1000 | --- | <1000 | --- |

| Nitrogen: Nitrite (µg/L) SPRING/SUMMER | | | | | | | | |
|--|-----------|--------|---------|--------|---------|--------|---------|--------|
| Year | # samples | | min | | max | | mean | |
| | Surface | Bottom | Surface | Bottom | Surface | Bottom | Surface | Bottom |
| 2018 | 1 | --- | <50 | --- | <50 | --- | <50 | --- |
| 2019 | 4 | --- | <50 | --- | <50 | --- | <50 | --- |

Summary: 2018 and 2019 used two different measuring techniques so a trend cannot yet be established as they are not comparable. Samples were not taken in 2020. For 2021, Nitrates and Nitrites were calculated together, so we do not know the values separately.

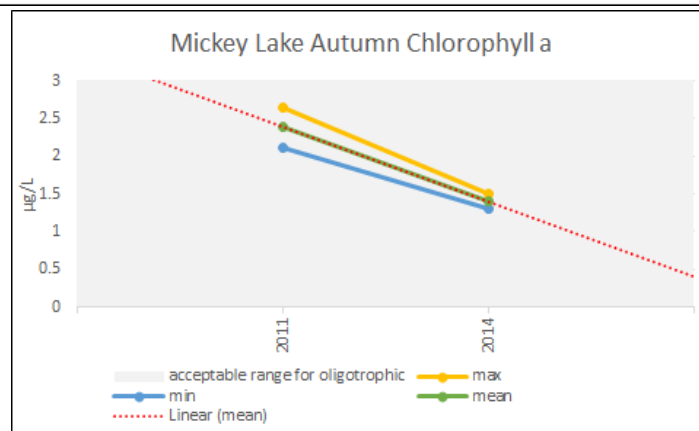
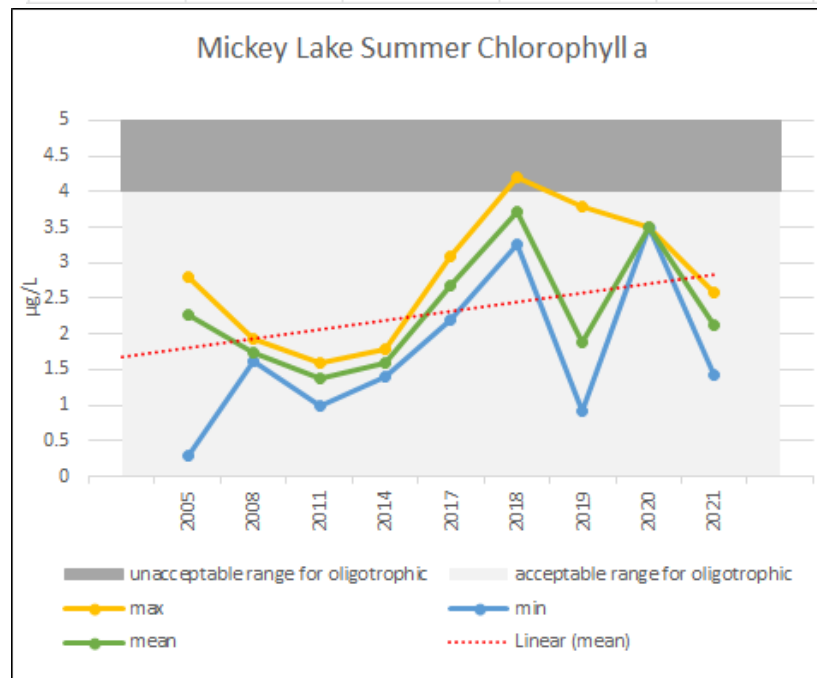
| Secchi Disk (m.) SPRING/SUMMER | | | | |
|--------------------------------|-----------|------|------|------|
| Year | # samples | min | max | mean |
| 2011 | --- | --- | --- | --- |
| 2014 | 2 | 6.25 | 8.99 | 7.62 |
| 2017 | 4 | 3.6 | 4.6 | 4.15 |
| 2018 | 4 | 2.7 | 4.8 | 3.74 |
| 2019 | 6 | 2.13 | 6.55 | 4.72 |
| 2020 | 1 | 4.9 | 4.9 | 4.90 |
| 2021 | 9 | 3.7 | 5 | 4.38 |

| Secchi Disk (m.) AUTUMN | | | | |
|-------------------------|-----------|------|------|------|
| Year | # samples | min | max | mean |
| 2011 | 2 | 5.49 | 5.7 | 5.60 |
| 2014 | 2 | 6 | 6.49 | 6.25 |



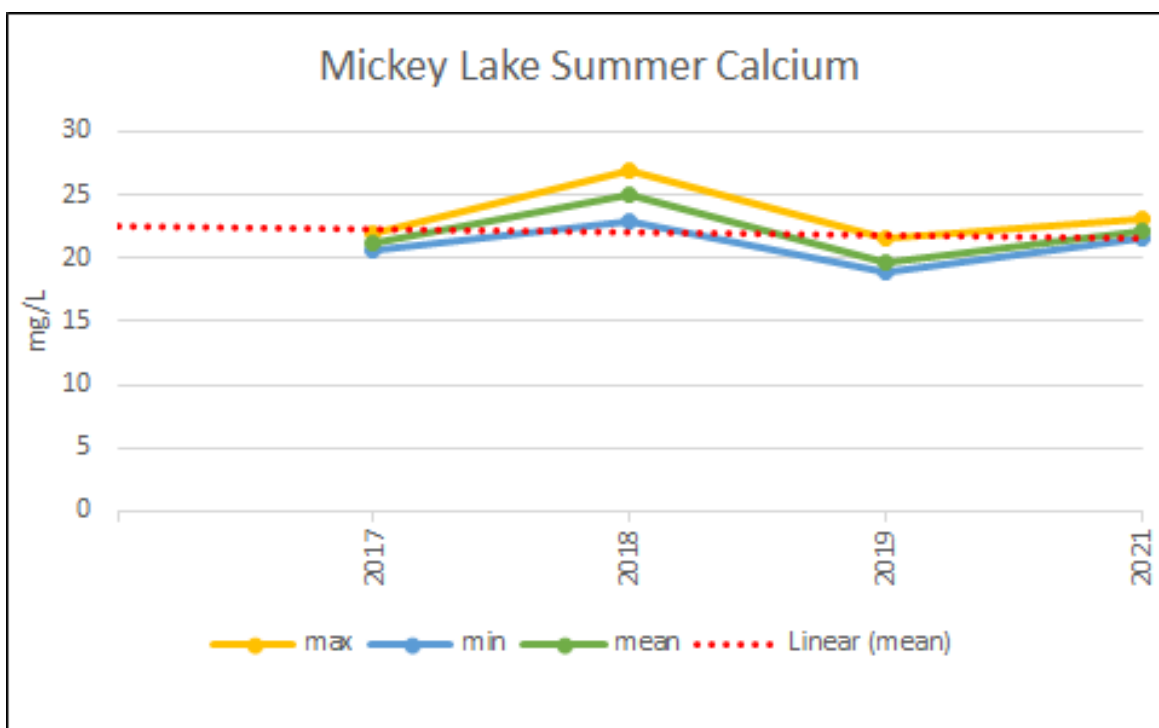
| Chlorophyll a (µg/L) SPRING/SUMMER | | | | |
|------------------------------------|-----------|------|------|-------|
| Year | # samples | min | max | mean |
| 2011 | --- | --- | --- | --- |
| 2014 | 2 | 2 | 5.2 | 3.6 |
| 2017 | 2 | 2.2 | 3.1 | 2.69 |
| 2018 | 2 | 3.27 | 4.19 | 3.73 |
| 2019 | 3 | 0.92 | 3.78 | 1.873 |
| 2020 | 1 | 3.5 | 3.5 | 3.50 |
| 2021 | 5 | 1.43 | 2.59 | 2.116 |

| Chlorophyll a (µg/L) AUTUMN | | | | |
|-----------------------------|-----------|------|------|------|
| Year | # samples | min | max | mean |
| 2011 | 2 | 2.12 | 2.65 | 2.39 |
| 2014 | 2 | 1.3 | 1.5 | 1.4 |



| Calcium (mg/L) SPRING/SUMMER | | | | |
|------------------------------|-----------|------|------|--------|
| Year | # samples | min | max | mean |
| 2017 | 3 | 20.6 | 21.9 | 21.17 |
| 2018 | 3 | 22.9 | 27 | 24.95 |
| 2019 | 4 | 18.8 | 21.6 | 19.575 |
| 2020 | --- | --- | --- | --- |
| 2021 | 4 | 21.5 | 23 | 22.175 |

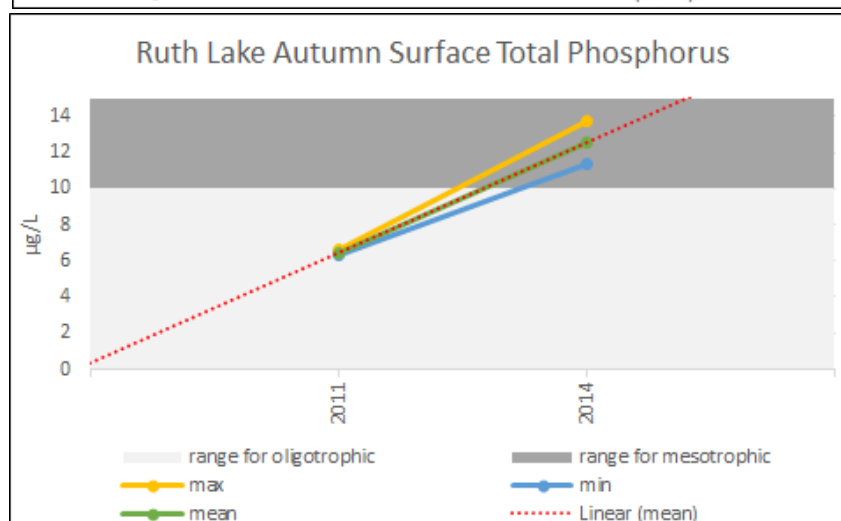
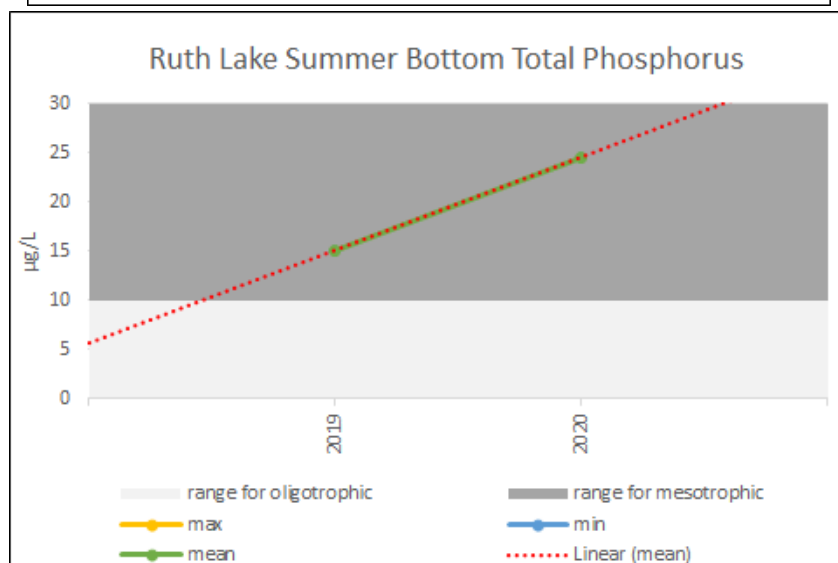
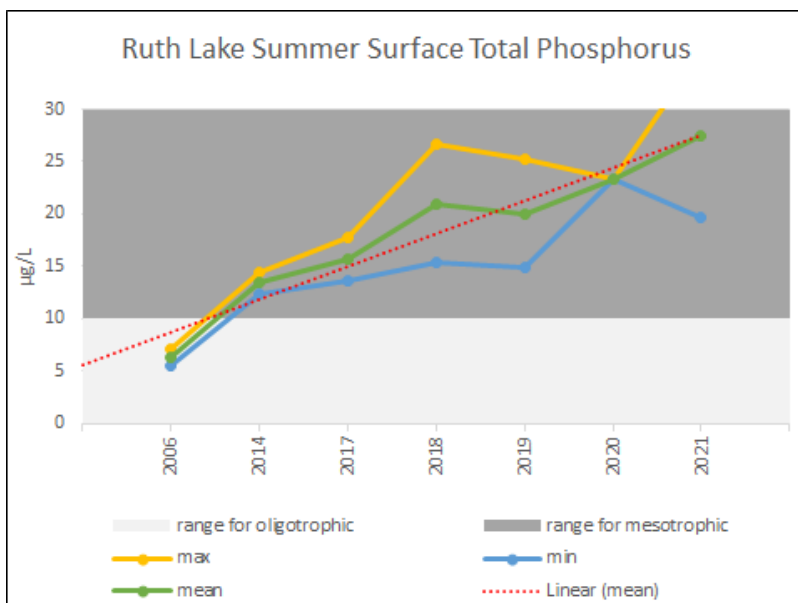
*Calcium was not tested in 2020



Ruth Lake

| Total Phosphorus (µg/L) SPRING/SUMMER | | | | | | | | |
|---------------------------------------|-----------|--------|---------|--------|---------|--------|---------|--------|
| Year | # samples | | min | | max | | mean | |
| | Surface | Bottom | Surface | Bottom | Surface | Bottom | Surface | Bottom |
| 2006 | 2 | --- | 5.5 | --- | 7.1 | --- | 6.30 | --- |
| 2011 | --- | --- | --- | --- | --- | --- | --- | --- |
| 2014 | 2 | --- | 12.4 | --- | 14.4 | --- | 13.40 | --- |
| 2017 | 2 | --- | 13.7 | --- | 17.8 | --- | 15.75 | --- |
| 2018 | 2 | --- | 15.4 | --- | 26.6 | --- | 21.00 | --- |
| 2019 | 2 | 1 | 14.9 | 15.1 | 25.2 | 15.1 | 20.05 | 15.10 |
| 2020 | 1 | 1 | 23.4 | 24.6 | 23.4 | 24.6 | 23.40 | 24.60 |
| 2021 | 2 | --- | 19.6 | --- | 35.4 | --- | 27.50 | --- |

| Total Phosphorus (µg/L) AUTUMN | | | | | | | | |
|--------------------------------|-----------|--------|---------|--------|---------|--------|---------|--------|
| Year | # samples | | min | | max | | mean | |
| | Surface | Bottom | Surface | Bottom | Surface | Bottom | Surface | Bottom |
| 2006 | --- | --- | --- | --- | --- | --- | --- | --- |
| 2011 | 2 | --- | 6.3 | --- | 6.6 | --- | 6.45 | --- |
| 2014 | 2 | --- | 11.4 | --- | 13.7 | --- | 12.55 | --- |



| Sediment Phosphorus (mg/kg) SPRING/SUMMER | | | | |
|---|-----------|-----|-----|------|
| Year | # samples | min | max | mean |
| 2014 | 2 | 445 | 461 | 451 |

Summary: There is only one sample year, so no trend could be established.

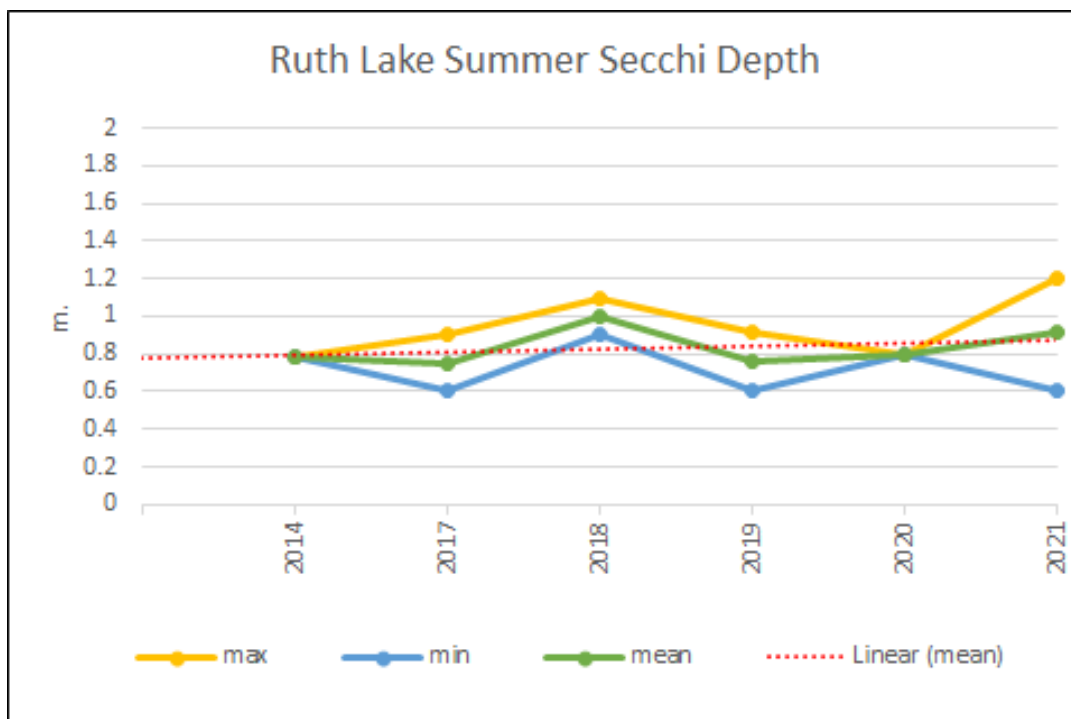
| Nitrogen: Nitrate (µg/L) SPRING/SUMMER | | | | | | | | |
|--|-----------|--------|---------|--------|---------|--------|---------|--------|
| Year | # samples | | min | | max | | mean | |
| | Surface | Bottom | Surface | Bottom | Surface | Bottom | Surface | Bottom |
| 2018 | 1 | --- | <1000 | --- | <1000 | --- | <1000 | --- |
| 2019 | 2 | --- | <1000 | --- | <1000 | --- | <1000 | --- |

| Nitrogen: Nitrite (µg/L) SPRING/SUMMER | | | | | | | | |
|--|-----------|--------|---------|--------|---------|--------|---------|--------|
| Year | # samples | | min | | max | | mean | |
| | Surface | Bottom | Surface | Bottom | Surface | Bottom | Surface | Bottom |
| 2018 | 1 | --- | <50 | --- | <50 | --- | <50 | --- |
| 2019 | 2 | --- | <50 | --- | <100 | --- | <75 | --- |

Summary: 2018 and 2019 used two different measuring techniques so a trend cannot yet be established as they are not comparable. Samples were not taken in 2020. For 2021, Nitrates and Nitrites were calculated together, so we do not know the values separately.

| Secchi Disk (m.) SPRING/SUMMER | | | | |
|--------------------------------|-----------|------|------|------|
| Year | # samples | min | max | mean |
| 2014 | 2 | 0.79 | 0.79 | 0.79 |
| 2017 | 2 | 0.6 | 0.9 | 0.75 |
| 2018 | 2 | 0.9 | 1.1 | 1 |
| 2019 | 2 | 0.61 | 0.91 | 0.76 |
| 2020 | 1 | 0.8 | 0.8 | 0.8 |
| 2021 | 2 | 0.61 | 1.2 | 0.92 |

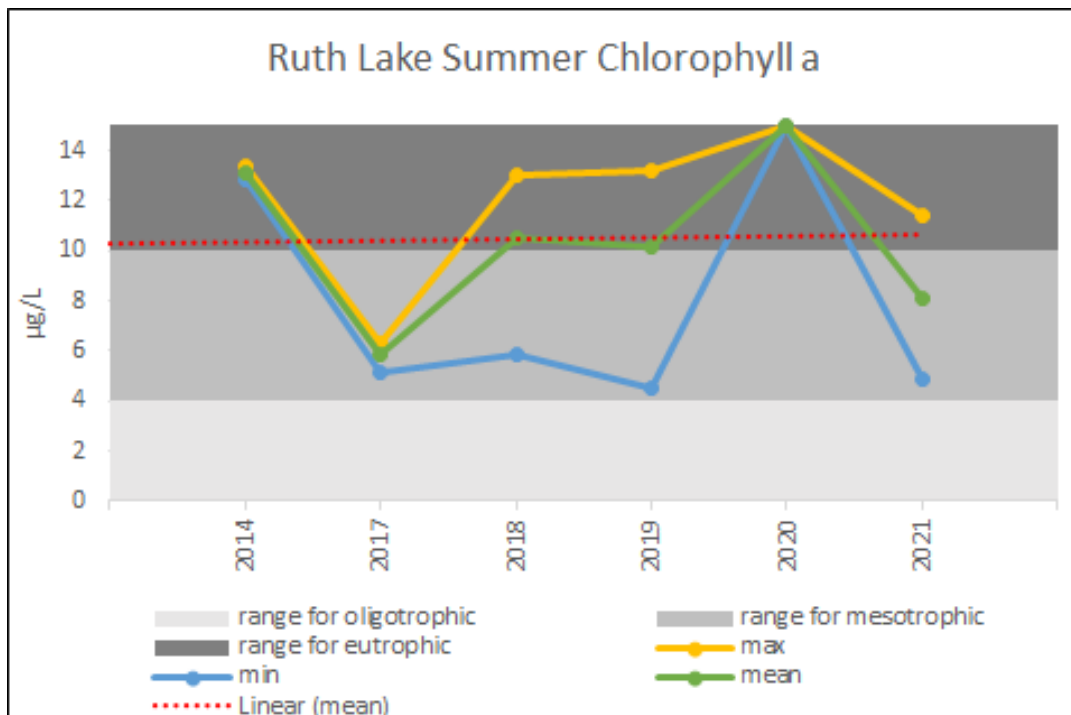
| Secchi Disk (m.) AUTUMN | | | | |
|-------------------------|-----------|------|------|------|
| Year | # samples | min | max | mean |
| 2014 | 2 | 1.01 | 1.01 | 1.01 |



Summary: There is only one sample year for Autumn, so no trend could be established.

| Chlorophyll a ($\mu\text{g/L}$) SPRING/SUMMER | | | | |
|---|-----------|-------|-------|--------|
| Year | # samples | min | max | mean |
| 2014 | 2 | 12.8 | 13.4 | 13.1 |
| 2017 | 3 | 5.17 | 6.27 | 5.86 |
| 2018 | 3 | 5.82 | 13 | 10.50 |
| 2019 | 3 | 4.51 | 13.15 | 10.183 |
| 2020 | 1 | 14.95 | 14.95 | 14.95 |
| 2021 | 2 | 4.88 | 11.37 | 8.125 |

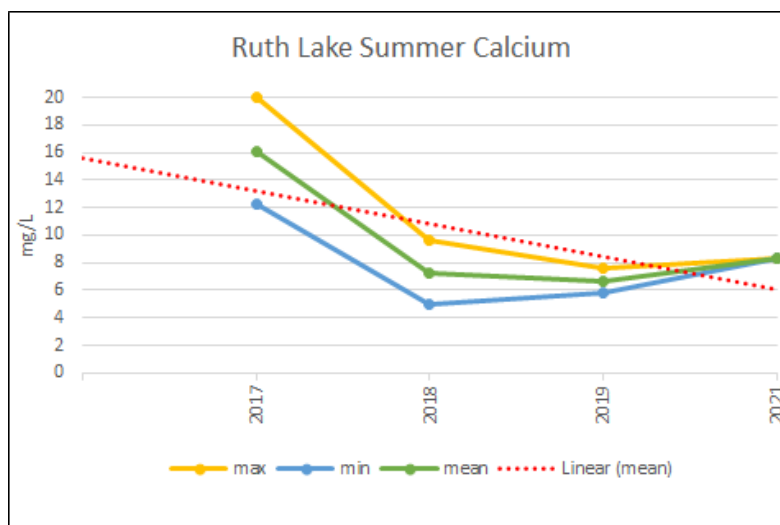
| Chlorophyll a ($\mu\text{g/L}$) AUTUMN | | | | |
|--|-----------|-----|------|------|
| Year | # samples | min | max | mean |
| 2014 | 2 | 3.7 | 10.7 | 7.2 |



Summary: There is only one sample year for Autumn, so no trend could be established.

| Calcium (mg/L) SPRING/SUMMER | | | | |
|------------------------------|-----------|------|-----|-------|
| Year | # samples | min | max | mean |
| 2017 | 2 | 12.2 | 20 | 16.10 |
| 2018 | 2 | 5 | 9.6 | 7.30 |
| 2019 | 2 | 5.8 | 7.6 | 6.7 |
| 2020 | --- | --- | --- | --- |
| 2021 | 2 | 8.3 | 8.3 | 8.3 |

*Calcium was not tested in 2020



Page Lake

| Total Phosphorus (µg/L) SPRING/SUMMER | | | | | | | | |
|---------------------------------------|-----------|--------|---------|--------|---------|--------|---------|--------|
| Year | # samples | | min | | max | | mean | |
| | Surface | Bottom | Surface | Bottom | Surface | Bottom | Surface | Bottom |
| 2016 | 1 | 1 | 20.8 | 63.7 | 20.8 | 63.7 | 20.8 | 63.7 |
| 2017 | --- | --- | --- | --- | --- | --- | --- | --- |

Summary: There is only one sample year, so no trend could be established.

| Sediment Phosphorus (mg/kg) SPRING/SUMMER | | | | |
|---|-----------|-----|-----|------|
| Year | # samples | min | max | mean |
| 2016 | 1 | 700 | 700 | 700 |
| 2017 | --- | --- | --- | --- |

Summary: There is only one sample year, so no trend could be established.

| Secchi Disk (m.) SPRING/SUMMER | | | | |
|--------------------------------|-----------|------|------|------|
| Year | # samples | min | max | mean |
| 2016 | 1 | 2.59 | 2.59 | 2.59 |
| 2017 | --- | --- | --- | --- |

Summary: There is only one sample year, so no trend could be established.

| Chlorophyll a (µg/L) SPRING/SUMMER | | | | |
|------------------------------------|-----------|------|------|------|
| Year | # samples | min | max | mean |
| 2016 | *1 | 12.7 | 12.7 | 12.7 |
| 2017 | --- | --- | --- | --- |

*Mean of two samples

Summary: There is only one sample year, so no trend could be established.

| Calcium (mg/L) SPRING/SUMMER | | | | |
|------------------------------|-----------|-----|-----|------|
| Year | # samples | min | max | mean |
| 2016 | 1 | 8.9 | 8.9 | 8.9 |

Summary: There is only one sample year, so no trend could be established.

Fern Lake

| Total Phosphorus (µg/L) SPRING/SUMMER | | | | | | | | |
|---------------------------------------|-----------|--------|---------|--------|---------|--------|---------|--------|
| Year | # samples | | min | | max | | mean | |
| | Surface | Bottom | Surface | Bottom | Surface | Bottom | Surface | Bottom |
| 2016 | 2 | 2 | 6.5 | 8.8 | 7 | 13.6 | 6.75 | 11.20 |
| 2017 | --- | --- | --- | --- | --- | --- | --- | --- |

Summary: There is only one sample year, so no trend could be established.

| Sediment Phosphorus (mg/kg) SPRING/SUMMER | | | | |
|---|-----------|-----|-----|-------|
| Year | # samples | min | max | mean |
| 2016 | 2 | 770 | 791 | 780.5 |
| 2017 | --- | --- | --- | --- |

Summary: There is only one sample year, so no trend could be established.

| Nitrate-Nitrite Nitrogen (µg/L) SPRING/SUMMER | | | | | | | | |
|---|-----------|--------|---------|--------|---------|--------|---------|--------|
| Year | # samples | | min | | max | | mean | |
| | Surface | Bottom | Surface | Bottom | Surface | Bottom | Surface | Bottom |
| 2016 | 2 | 2 | <1.1 | <1.1 | <1.1 | 5.4 | <1.1 | 3.25 |
| 2017 | --- | --- | --- | --- | --- | --- | --- | --- |

Summary: There is only one sample year, so no trend could be established.

| Secchi Disk (m.) SPRING/SUMMER | | | | |
|--------------------------------|-----------|------|------|------|
| Year | # samples | min | max | mean |
| 2016 | 2 | 4.39 | 4.45 | 4.42 |
| 2017 | --- | --- | --- | --- |

Summary: There is only one sample year, so no trend could be established.

| Chlorophyll a (µg/L) SPRING/SUMMER | | | | |
|------------------------------------|-----------|------|-----|------|
| Year | # samples | min | max | mean |
| 2016 | 3 | 5.3* | 5.8 | 5.55 |
| 2017 | --- | --- | --- | --- |

*Mean of two samples

Summary: There is only one sample year, so no trend could be established.

| Calcium (mg/L) SPRING/SUMMER | | | | |
|------------------------------|-----------|------|------|-------|
| Year | # samples | min | max | mean |
| 2016 | 2 | 30.9 | 32.2 | 31.55 |

Summary: There is only one sample year, so no trend could be established.

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Appendix A:

Indigenous Unionid Clam Refugia from Zebra Mussels in Michigan Inland Lakes

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Abstract

Zebra mussel *Dreissena polymorpha* Pallas, invasion into the Great Lakes region has resulted in high mortality or extirpation of native unionids from all or parts of Lake Erie, Lake St. Clair, and the Detroit River. Extirpation of native unionids has occurred primarily in open water, but small remnant populations occur in the Lake St. Clair delta and three areas of Lake Erie: Presque Isle Bay, Erie, PA; Metzger Marsh near Toledo, OH; and near the mouth of the Raisin River, Monroe, MI. In contrast, little is known about impacts of zebra mussels on native mussels in Michigan inland lakes although zebra mussels occur in at least 260 Michigan lakes. In laboratory studies, minimum calcium requirements for zebra mussel reproductive and establishment success has been reported as 20 mg/L, and in European lakes, minimum calcium requirements for colonization have been reported as 28.3 mg/L. Because some unionids (e.g. *Elliptio complanata* and *Pyganodon* (= *Anodonta*) *grandis*) occur at concentrations as low as 3 mg/L, it may be possible that soft water lakes, that is, lakes with calcium concentrations below 28.3 mg/L, might provide protection from zebra mussel induced mortality and/or extirpation of native unionids. This study identified Michigan inland lakes that have calcium concentrations less than 28.3 mg/L and have high potential for zebra mussel invasion (are heavily used by fishermen and have nearby lakes and/or streams where zebra mussels are established and could potentially serve as colonists). Five calcium poor lakes were identified that had 5 different unionid species present among them, where zebra mussel colonization had not occurred.

Introduction

Zebra mussel (*Dreissena polymorphas* Pallas) invasion into the Great Lakes region has resulted in high mortality or extirpation of native unionids from all or parts of Lake Erie, Lake St. Clair (Schloesser et al., 1998), and the Detroit River (Schloesser et al., 1998). Extirpation of native unionids has occurred primarily in open water, but small remnant populations occur in the Lake St. Clair delta (Zanatta et al., 2002) and three areas of Lake Erie: Presque Isle Bay, Erie, PA (Schloesser and Masteller, 1999), Metzger Marsh near Toledo, OH (Nichols and Amberg, 1999) and near the mouth of the Raisin River, Monroe, MI (Schloesser et al., 1997). In contrast, little is known about impacts of zebra mussels on native mussels in Michigan inland lakes although zebra mussels occur in at least 260 Michigan lakes (Michigan Sea Grant, 2008 and United States Geological Survey Nonindigenous Aquatic Species Website, 2008). Studies of zebra mussel habitat requirements have found that pH, temperature, salinity, substrate, nutrients, and calcium may limit zebra mussel colonization (Strayer, 1991; Ramcharan et al., 1992; Stanczykowska and Lewandowski, 1993; Mellina and Rasmussen, 1994; and Hincks and Mackie, 1997). The establishment of zebra mussels and their impact on unionids in European lakes has been well documented. In European lakes, calcium concentrations 28.3 mg/L were found to be required for survival of zebra mussel veligers and to support zebra mussel colonization (Ramcharan et al., 1992). Results of a risk assessment for zebra mussel invasion into 3000 North American streams and rivers showed the majority of zebra mussel establishments were in regions where calcium concentrations were > 28.3 mg/L or where surface water drained high calcium areas into regions where concentrations were 28.3 mg/L (Whittier et al 2008). In laboratory studies, calcium requirements for zebra mussel reproductive and colonization success has been reported as low as 20 mg/L (Cohen and Weinstein, 2001).

In contrast, calcium requirements of unionids vary among species and some inhabit soft water lakes (lakes with calcium concentrations less than 28.3 mg/L) (Boycott, 1936; Mackie and

Flippance, 1983). In a study of six low-alkalinity lakes in Ontario, *Pyganodon* (= *Anodonta*) *grandis* and *Elliptio complanata* were found in Blue Chalk Lake and Harp Lake with calcium concentrations of 2.99 mg/L and 3.15 mg/L respectively (Rooke and Mackie, 1984). A large population of *Pyganodon* (= *Anadonta*) *grandis* is found in Shell Lake, a small arctic lake, with a calcium concentration of 10 mg/L (Green, 1980). *Elliptio coniplanata* is known to occur in calcium-poor waters (Hinch et al., 1988) and is found in Mirror Lake, New Hampshire with calcium concentrations of 2 -3 mg/L (Strayer et al., 1981). In this study, nine Michigan soft water inland lakes were surveyed for native unionids to determine which species occur naturally in these systems and to determine if colonization of zebra mussels has occurred. There are several Michigan inland lakes that meet the criteria of 28.3 mg/L calcium concentration and hypothetically will not support zebra mussel colonization (Michigan Department of Environmental Quality's Surface Water Information Management System). Nine soft water lakes investigated in this study are: Lake Independence (Marquette Co.); Larks Lake (Emmet Co.); Douglas Lake (Cheboygan Co.); Long Lake (Grand Traverse Co.); Otsego Lake (Otsego Co.); Lake Mitchell (Wexford Co.); Houghton Lake and Lake St. Helen (Roscommon Co.); and Round Lake (Iosco Co.) (MDEQ's Mi SWIMS). These lakes have public boat access, and with the exceptions of Lake Independence and Larks Lake are judged to experience heavy use. All lakes but Lake Independence are in close proximity to lakes and streams that are colonized by zebra mussels that could serve as sources of zebra mussels colonists.

Methods

Unionid Survey

Native unionids were collected from inland lakes chosen for study for the purpose of establishing a species inventory list for each lake. Searches were performed along 3 transects perpendicular to the shore to a depth of 1 to 2 m where snorkeling and/or visibility were allowable. Unionids were photographed and their length, height, and breadth were measured using calipers. Unionids were

returned into the habitat where they had been collected from and placed into the substrate in the same position in which they were found. Where unionids were biofouled, zebra mussels were collected from the unionids and placed in labeled zip lock bags for transfer to the laboratory. Unionids were identified by following Cummings and Mayer (1992), Goodrich (1902), Heard and Burch (1966), Thorp and Covich (2001), and by comparisons with taxonomic reference collections (Detroit Edison Company, Detroit Michigan).

Zebra Mussel Survey

A sampling of substrate suitable for zebra mussel attachment, specifically, cobble and rocks, logs and sticks, living snails and mussels, shells of dead snails and mussels, boat hoists, dock filings, and vegetation in each lake were searched for zebra mussels. The survey was limited to substrate found in water depths to a maximum of 1 m. In lakes where zebra mussels were present, zebra mussels were collected through searches within 5-0.25 m² quadrats placed in zebra mussel habitat. All zebra mussels were removed from each quadrat and placed in labeled zip lock bags for storage and transfer back to the laboratory.

Calcium and pH Determination

Water samples were collected from each lake, and calcium concentrations were determined. Samples were collected in locations where unionids and zebra mussel surveys were performed. Two 250 mL samples were collected directly into clean acid washed polyethylene bottles that had been rinsed in lake water and then water samples were treated with concentrated HNO₃ to a pH of less than 2. Samples were stored at 4°C and transported to the laboratory. Calcium determination was performed using atomic absorption flame spectrometry following methodology in Standard Methods for the Examination of Water and Wastewater (1985). pH was determined using a Fisher Scientific accumet portable pH/mV meter model AP10.

Data Analysis

Student t-test was used to determine if there was a difference in the mean of calcium concentrations of lakes where zebra mussels were absent and the mean of calcium concentrations of lakes where zebra mussels were present using Minilab 14.

Results

Unionid Survey

A total of 143 unionid individuals and 5 species were found in 7 of the 9 lakes surveyed (Table 1). *Lampsilis siliquoidea* was found in 5 of the 7 lakes and *P. grandis* occurred in 6 of the 7 lakes surveyed. Zebra mussels and unionids were found coexisting only in Houghton Lake, and 3 of the 8 unionids collected were biofouled with zebra mussels. Of the 143 unionid individuals collected, 55.5% were from Lake Independence in Michigan's Upper Peninsula. Zebra Mussel Survey Zebra mussels were found in 3 of the 9 lakes surveyed: Houghton, St. Helen, and Douglas Lakes. Zebra mussels occurred in very low densities between the shoreline and to a depth of 1 m in all three lakes. Zebra mussels were found only on living or dead snails and/or unionids in Houghton Lake and Douglas Lake and were found on sticks, branches, and small rocks in Lake St. Helen, however this survey was limited to the shallow littoral zone.

Calcium and pH Determination

Total calcium concentrations in the 9 lakes ranged from 17 — 34 mg/L (Table 2). Lake Independence (Marquette Co.) had the lowest total calcium concentration and Houghton Lake (Roscommon Co.) had the highest total calcium concentration (Fig.1). The mean of calcium concentration of lakes with zebra mussels present differed significantly from the mean of calcium concentration of lakes where zebra mussels were absent ($p = 0.009$, $df=6$) (Fig. 2), and the mean calcium concentration of lakes with zebra mussels was 32 mg/L and of lakes without zebra mussels was 24 mg/L (Fig. 2). The 9 Michigan lakes studied all had pH values that ranged between 7.9 and 8.8 (Fig. 2).

Discussion

A significant difference in the mean of total calcium concentrations in lakes where zebra mussels were absent and in the mean of lakes where zebra mussels were present was observed. Mean calcium concentration for lakes with zebra mussels present was 32 mg/L and for lakes without zebra mussels was 24 mg/L. Calcium concentrations for lakes here were determined through a single sample, and calcium content is reported to vary minimally with depth and seasonality in soft water lakes (Wetzel, 1975). In laboratory studies, minimum calcium requirements for zebra mussel reproductive and colonization success has been reported as 20 mg/L (Cohen and Weinstein, 2001) however, in a study of European lakes, zebra mussels were not found in lakes with calcium concentrations below 28.3 mg/L (Ramcharan, et al., 1992). In this study, zebra mussels were absent in 6 lakes, and of those lakes 5 have calcium concentrations ≥ 26 mg/L. All lakes have one or more public boat access sites and/or campgrounds/parks and have lakes and/or streams nearby that are colonized by zebra mussels, and with the exception of Lake Independence and Larks Lake are judged to be used heavily for recreation. Lake Mitchell (calcium concentration = 20 mg/L) is frequently fished as is the Manistee River at Tipee Dam, which is heavily infested with zebra mussels, however Lake Mitchell has remained zebra mussel free (Larry Solce, Unit Supervisor, Mitchell State Park, Cadillac, MI, pers. comm.). In Long Lake (calcium concentration = 26 mg/L) Eurasian water-milfoil, another invasive that like zebra mussels is transported between water bodies on boats, has been established since 2006 (Michigan Sea Grant). It is likely that zebra mussels have been introduced into Long Lake too but were unsuccessful. Zebra mussels are absent from Larks Lake (calcium concentration = 01 mg/L), however it is not a heavily-used lake and may not have received potential colonists. European lakes without zebra mussels all have pH values below 7.3 (Ramcharan, et al., 1992), and all 9 Michigan lakes in this study have pH values that ranged between 7.9 and 8.8. pH values fluctuate diurnally owing to photosynthesis and with depth (Wetzel, 1975). Because only single

pH values were measured here, pH may not be a useful predictor of zebra mussel presence here. Zebra mussel densities were low in Houghton Lake, Lake St. Helen, and Douglas Lake and absent altogether in the remaining 6 lakes surveyed. Zebra mussel establishment has been reported for Houghton Lake, Lake St. Helen, and Douglas Lake as 1993, 1994, and 2001 respectively, (USGS Nonindigenous Aquatic Species Website, 2008 and University of Michigan Biological Station Website, 2008). Houghton Lake and Lake St. Helen had experienced population explosions in 2006 and Douglas Lake in 2005, and zebra mussel populations have declined since their explosion in all three lakes especially where water depths are shallower than 1 m (Pam Tynning, Progressive AE, Grand Rapids, MI, pers. comm.; Pete Rieli, Lake St. Helen Lake Association, St. Helen, MI, pers. comm.; and Rex Lowe pers. comm.). Zebra mussel density in a dozen European lakes has fluctuated over a thirty-year period, and population declines after population explosions with large zebra mussel individuals has occurred (Stanczykowska and Lewandowski, 1993). Zebra mussel density in Houghton Lake, Lake St. Helen, and Douglas Lake may experience similar fluctuations and explain present low densities; however, zebra mussels have successfully colonized these lakes.

Live *A. ferussacianus*, *E. complanata*, *L. siliquioidea*, *L. nasuta*, and *P. grandis* were found in 6 of the 9 lakes studied, and 5 of the 6 lakes where unionids were present have calcium concentrations below the theoretical zebra mussel colonization calcium concentration requirement (Ramcharan, et al., 1992). The results of this study suggests that lakes with calcium concentrations below 26 mg/L may serve as refugia from zebra mussel induced mortality and/or extirpation for *A. ferussacianus*, *E. complanata*, *L. siliquioidea*, *L. nasuta*, and *P. grandis*.

However, Michigan has many hardwater lakes and few calcium poor lakes that have been identified. Lakes in Michigan's western Upper Peninsula (UP) region are low in calcium because of underlying igneous bedrock (Dorr and Eschman, 1970; Rapp, et al., 1987), but generally

calcium concentrations of lakes in the remainder of the state are high because they are situated in lacustrine deposits or limestone that contain calcium carbonate (Dorr and Eschman, 1970).

In a study of 12 lakes along Lake Superior, 3 lakes found to have lower buffering capacities are situated in sandy lacustrine deposits while 9 lakes having higher buffering capacities are situated in lacustrine deposits with a clay component (Rapp, et al., 1987). Soft Water lakes in the Lower Peninsula (LP) may be calcium poor because they are shallow and/or seepage lakes and situated in glacial sand several feet thick (Table 3) (Akers, 1938; Western Michigan University, 1981).

Lake water calcium concentration in Houghton Lake may be greater than that of other lakes in this study because a lacustrine clay, one derived from limestone, underlies the lake's margins just below a layer of sand a few inches thick (Dennis Albert, pers. comm.).

More research is needed to identify lakes where unionids live and zebra mussels cannot, so these lakes can be protected. Surveys that include a dive component to detect species presence and establish abundance for the purpose of monitoring unionid status should be done. Additional work to identify calcium poor lakes could serve to provide temporary or permanent refuges for threatened mussels from the Great Lakes and other water bodies.

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Figure 1: Calcium concentrations of Michigan inland lakes surveyed.

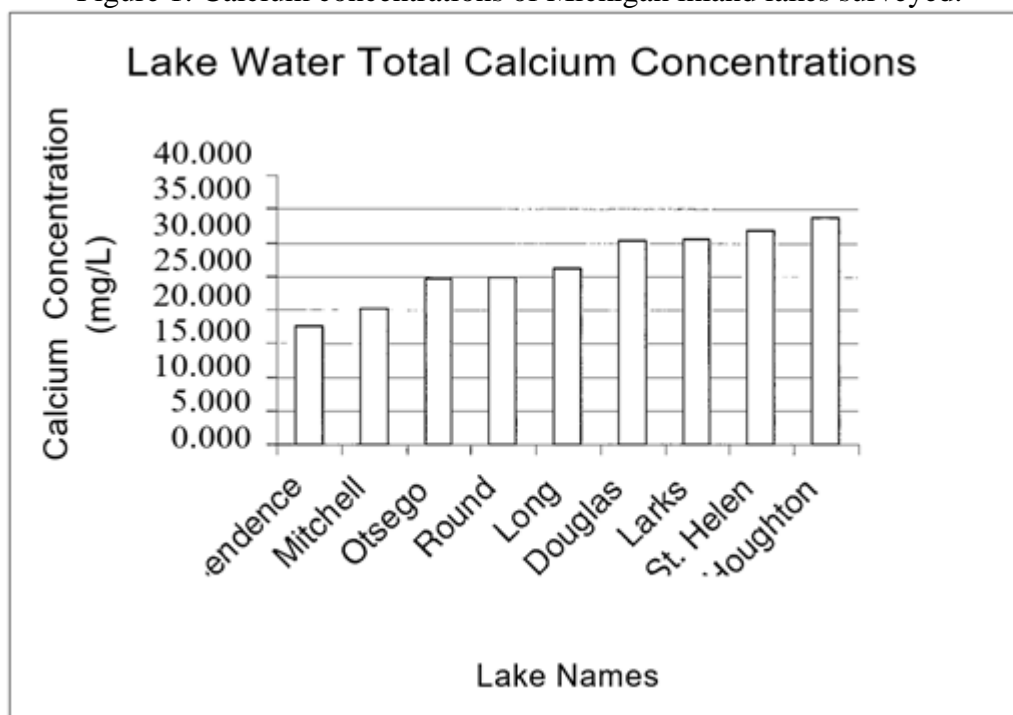
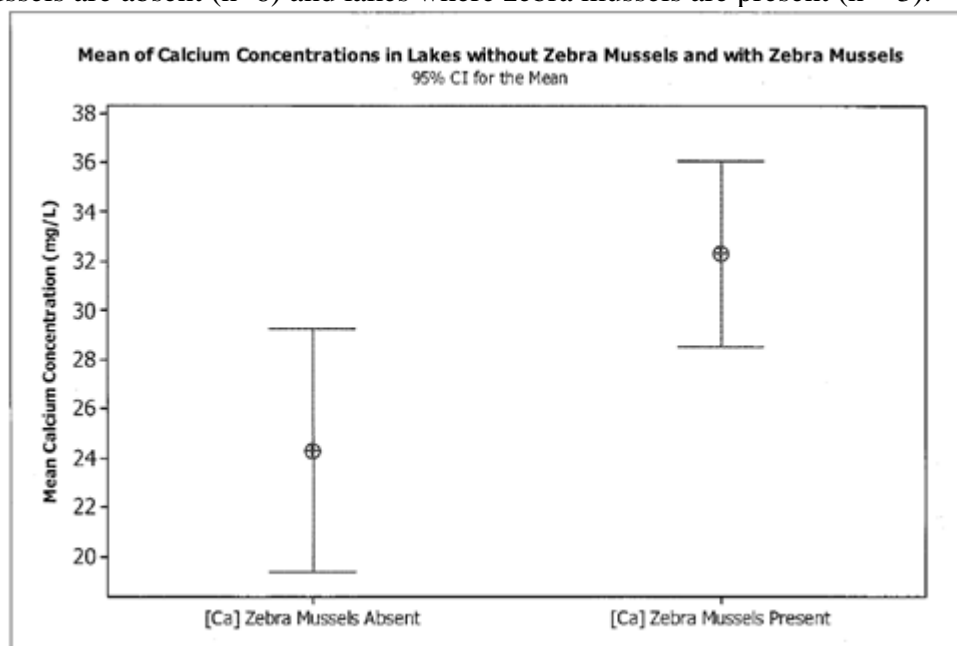


Figure 2: Mean of calcium concentrations and 95% confidence intervals for lakes where zebra mussels are absent (n=6) and lakes where zebra mussels are present (n=3).



| Table 1. Species lists of unionids in Michigan inland lakes surveyed. | | | | | | |
|--|-----------------------------------|----------------------------|------------------------------|-----------------------|--------------------------|--|
| Unionid Species and Lake Names | <i>Anodontoidea ferussacianus</i> | <i>Elliptio complanata</i> | <i>Lampsilis siliquoidea</i> | <i>Ligumia nasuta</i> | <i>Pyganodon grandis</i> | |
| Douglas | | | • | | • | |
| Houghton | | | | • | | |
| Independence | | • | • | | • | |
| Larks | | | • | | • | |
| Long | • | | | | • | |
| Mitchell | | | • | | • | |
| Round | | | • | | • | |

Table 2. Total calcium concentrations and pH values for Michigan inland lakes surveyed.

| Lake Name | Total Calcium (mg/L) | pH |
|------------------------------|-----------------------------|-----------|
| Independence (Marquette Co.) | 18 | 8.1 |
| Mitchell (Wexford Co.) | 20 | 8.0 |
| Otsego (Otsego Co.) | 25 | 7.9 |
| Round (Iosco Co.) | 25 | 8.1 |
| Long (Grand Traverse Co.) | 26 | 8.4 |
| Douglas (Cheboygan Co.) | 31 | 8.8 |
| Larks (Emmet Co.) | 31 | 8.8 |
| St. Helen (Roscommon Co.) | 32 | 8.6 |
| Houghton (Roscommon Co.) | 34 | 8.4 |

Table 3. Glacial drift thickness, maximum depth, inlets, and outlets for Lower Peninsula lakes (Western Michigan University, 1981; Michigan Recreational Boating Information System Website)

| Lake Name | Glacial Drift Thickness (ft) | Maximum Depth (ft) | Inlets | Outlets |
|------------------------------|------------------------------|--------------------|--------|---------|
| Mitchell (Wexford Co.) | 801-1,000 | 20 | • | • |
| Otsego (<u>Otsego Co.</u>) | 801-1,000 | 23 | | |
| Round (Iosco Co.) | 201-400 | 19 | | |
| Long (Grand Traverse Co.) | 401-600 | 80 | | • |
| Douglas (Cheboygan Co.) | 201-400 | 89 | • | • |
| Larks (Emmet Co.) | 201-400 | 9 | • | • |
| St. Helen (Roscommon Co.) | 401-600 | 25 | • | • |
| Houghton (Roscommon Co.) | 401-600 | 21 | • | • |

Figure Legend

Figure 1: Calcium concentrations for Michigan inland lakes surveyed.

Figure 2: Mean of calcium concentrations in lakes where zebra mussels are absent and of lakes where zebra mussels are present.

Table Legend

Table 1: Species lists of unionids mollusks in Michigan inland lakes surveyed.

Table 2: Total calcium concentrations and pH values for Michigan inland lakes surveyed.

Table 3. Glacial drift thickness, maximum depth, inlets, and outlets for Lower Peninsula lakes.