2018 Water Quality Report
And
Historical Analysis
Long Lake
Mickey Lake
Ruth Lake

Monitoring Years 1993-2018

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

Prepared with assistance of:

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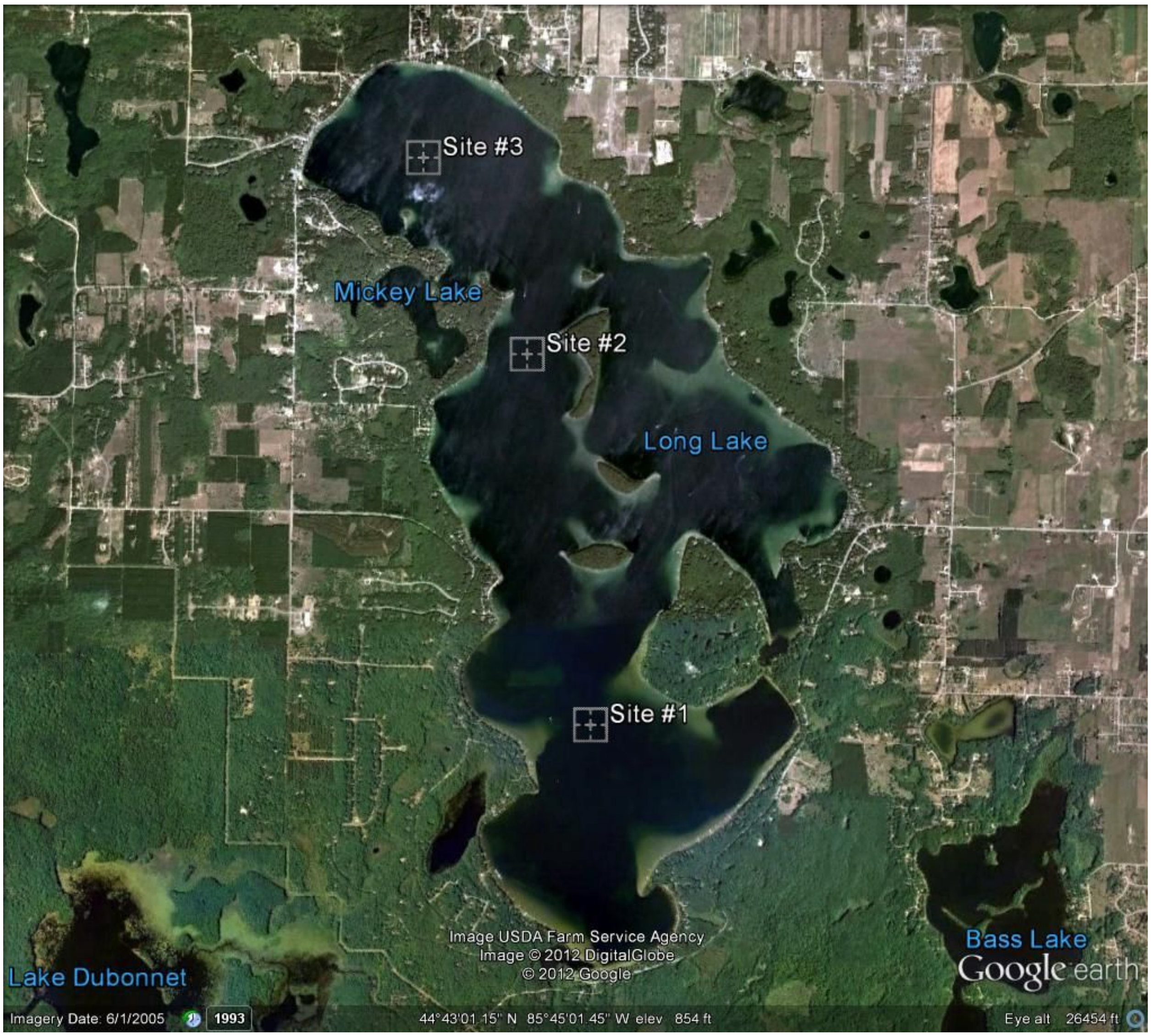
Table of Contents

Figure 1. Water quality sampling sites on Long Lake, 1997-2018



Executive Summary of Results

Analysis of data collected in Long Lake during 2018 showed some changes in chemical parameters measured over the last few years.

In Long Lake total phosphates remained at low levels and near oligotrophic levels. Nitrate-nitrite nitrogen levels show some increase over values measured in the early 2000's. Lack of nitrate- nitrite data from 2005 to 2017 suggest further testing of this parameter in the future.

Only a slight increase in Chlorophyll a in Long Lake was observed ,but it still remains well into the oligotrophic range. Mickey and Ruth Lakes data showed an increase in total phosphates and had generally mesotrophic levels for chlorophyll a.

Plankton analysis of Long Lake indicated a relatively oligotrophic condition with a unique dominance of the blue green alga *Gleotrichia.* The presence of the freshwater jellyfish *Craspedcrusta soweri* in Mickey Lake was noted.

Reference Tables

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 (ft)	>13	6.6-13	>6.6

Table 2. Nitrogen Trophic Classification (University of Massachusetts, Water Watch Partnership)

Trophic Status of Lakes vs Nitrate-Nitrogen levels	
NO3-N (mg/l)	**Trophic Level**
< 0.3	Oligotrophic
0.3 - 0.5	Mesotrophic
0.5 - 1.5	Eutrophic
> 1.5	Hypereutrophic

Table 3. Phosphorus Data for Area Lakes and Sediments - *referenced from 2017Long Lake Report*

Lake	Water Total Phosphorus (µg/L)	Sediment Phosphorus (mg TP/kg DW)
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
Mickey Site 1	11.5 (top)/19.1 (bottom)	1625
Mickey Site 2	7.6 (top)/7.3 (bottom)	87

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

Section I:

2018 Lake Water Quality Assessment on Long Lake, Mickey Lake, and Ruth Lake

The 2018 Lake Monitoring for Long Lake, Mickey Lake, and Ruth Lake was initiated by the Long Lake Association, Long Lake Foundation, Olsen 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 The continuation of the lake monitoring program is essential in assessing lake water quality and comparison to older data collected allows for emerging trends to become established. Examining past data, concerns can be addressed with the appropriate action plans created.

The 2018 season's water quality monitoring of Long Lake, Mickey Lake, and Ruth Lake was collected using by using a YSI multiparameter water quality probe, supplied by CLMP and an Hydrolab supplied by GLEC, both of which measure qualities such as temperature, DO, pH and conductivity. This sampling year, an introduction to phytoplankton capture was collected by using a phytoplankton net. The collection of water samples for the analysis of total phosphorus at the surface and near bottom of the lakes, and single calcium sample collected at each sampling site, along with levels of Chlorophyll a at each sampling site, measurement for secchi disk depth at each sampling points at the sampling sites, and sample collected at each site for nitrate/nitrite.

Long Lake:

Water Chemistry

Total Phosphorus: As noted in the 2017 report, Long Lake's total phosphorus levels are slightly higher than other area lakes, but remains currently favorable in the area. Site #2 on the lake had the highest concentration of TP, especially lake bottom samples taken. The TP levels are down significantly for Long Lake in all three sampling sights in this year's sampling .

Chlorophyll A: Chlorophyll a levels are down since the 2017 monitoring season, but should be noted that the numbers can vary widely from each year as it is easily influenced by the time of year it was sampled, or specific environmental conditions that are present on the lake during the monitoring year. Chlorophyll a provides a reasonable estimate of algal biomass within the lake.

Secchi Depth: The secchi depths, which are the measurement of water clarity were measured during the 2018 spring/summer sampling season and have continued to fall within the range of previous years' historical data. It should be noted that secchi depth measurements can be influenced by the time of year it was sampled, specific weather and lake conditions, so the numbers may vary from each year.

This sampling year total coliform and E. Coli were tested at two different locations on Long Lake, Taylor Park and Gilbert Park.

Hydrolab (Physical Data)

Hydrolab profiles for spring and summer exhibited much of the same healthy characteristics as seen in previous years, as stated in the 2017 report, the trends emerged in 2018 showed the same desirable levels. Dissolved oxygen levels declined with depth as expected, due to temperature stratification that occurs in the lake during the summer in deeper areas of the lake. It should be noted that in the 2017 report, there was indication that in the 2014 data analysis it showed concern for anoxic conditions. The prolonged DO deficits near the bottom sediments on the lake lead to a release of phosphorus bound in the sediments, thus contributing to the lake's higher phosphorus levels. The previous year, and this year indicate typical levels of DO for the lake. The solubility of oxygen decreases as the temperature of the water increases, so a decrease in the D.O levels as the testing progressed through the season is typical. Historical low oxygen trends seen in the hypolimnion means there could be a potential source of internal loading of phosphorus in the lake. It is noted in the 2017 report that additional samples should be taken from the sampling points and analyzed for phosphorus, it is also recommended this year that it be done within the next collection year to ensure accuracy. Typical calcium concentrations for fresh lake waters are less than 15 mg/L but this year's sampling from one testing center indicated higher than normal levels, it should be noted that the data from the two testing centers may be a result from a lab or sample error. It is recommended that calcium sampling be done the following sampling year to ensure accuracy. Nitrate/ Nitrite was sampled in the year's data collection, but there has not been testing for the nutrient since 2003, therefor not enough data has been collected to establish a trend. All other data fell within the healthy parameters for the lake and oligotrophic conditions are highly observable.

Conclusions

The 2018 sampling season indicate the continuation that Long Lake is considered an oligotrophic lake, based on the secchi depth readings, total phosphorus, and chlorophyll a in the lake. All three sampling sites on Long Lake indicate that the total phosphorus numbers are well under the max load according to the state's classification table as seen in table 1. It should be noted that this oligotrophic classification has been maintained for the past 25 years, since formal documentation of the lake first began in 1993. It is recommended that Long Lake continue to have a comprehensive outreach and education component regarding nutrient use near the lakeshore, including the continuation efforts for surface water runoff control. Both of these will help in limiting the introduction of additional phosphorus loading to the lake's ecosystem and help in the preservation of it's long held oligotrophic status.

Mickey and Ruth Lake:

Water Chemistry

Total Phosphorus: Total phosphorus levels in both Mickey Lake and Ruth Lake fell within the oligotrophic range. It should be noted that the levels in Ruth Lake are significantly down from the 2017 sampling year.

Chlorophyll a: Collection of data for both Mickey Lake and Ruth Lake indicate much lower levels than previous years sampled, but should be noted that chlorophyll a numbers can widely vary each year because of the influence by the time of year samples were taken, or specific environmental conditions present on the lake during the sampling. Field errors are possible and should not be ruled out for the reason of such low levels.

Secchi Depth: As noted in the 2017 report, the clarity of Ruth Lake has been historically low due to it's tannic qualities. The secchi readings for Mickey Lake continued to stay in the same range this sampling year as they were in last year's sampling. It should be noted that secchi readings can widely vary each year because of the influence by the time of year readings were taken, or specific environmental conditions present on the lake during the reading.

Hydrolab (Physical) Data

As noted in the 2017 report, the hydrolab data is comparative to previous years for both Mickey Lake and Ruth Lake. The water quality in Ruth lake is generally good, with a dense aquatic and shore plant growth, low clarity, and slightly elevated phosphorus levels, which is historically expected. Mickey Lake's water quality is generally also good, with slightly higher levels of phosphorus than Long Lake, but lower than Ruth Lake, semi high clarity. Both lakes exhibit shallow hydrological connections, resulting in low exchange rates between Long Lakes and themselves.

Conclusions

It is recommended that lakeshore management be continued for both Mickey Lake and Ruth Lake to limit additional phosphorus loading, which will help in the reduction of subsequent accumulations of the nutrient in both lakes.

Long Lake Water Chemistry Data

Chlorophyll a (µg/L)

May 07, 2018			*August 31, 2018*		
Site 1	**Site 2**	**Site 3**	**Site 1**	**Site 2**	**Site 3**
0.85	3.4	2.16	1.7	1.7	1.88
0.78	---	---	1.76	---	---

Total Phosphorus (µg/L)

	May 07, 2018			*August 31, 2018*		
Location	**Site 1**	**Site 2**	**Site 3**	**Site 1**	**Site 2**	**Site 3**
Surface	6	7.2	6	6.5	11.2	4.9
Depth	7.5	9.9	7.1	4.2	3.7	7.3

Calcium (mg/L)

May 07, 2018			*August 31, 2018*		
Site 1	**Site 2**	**Site 3**	**Site 1**	**Site 2**	**Site 3**
28	31	34	22.9	22.9	25.1

Nitrogen (mg/L)

	August 31, 2018		
Location	**Site 1**	**Site 2**	**Site 3**
Nitrate	< 1.0	< 1.0	< 1.0
Nitrite	< 0.05	< 0.05	< 0.05

Coliform Bacteria (per 100mL)

	May 07, 2018	
Location	**Total Coliform**	**E. Coli**
Taylor Park	307.6	3.1
Gilbert Park	770.1	8.6

Mickey Lake Water Chemistry Data

Chlorophyll a (µg/L)

May 07, 2018	*August 31, 2018*
Site 1	**Site 1**
4.19	3.27

Total Phosphorus (µg/L)

	May 07, 2018		*August 31, 2018*	
Location	**Site 1**	**Site 2**	**Site 1**	**Site 2**
Surface	9.5	9.1	18.9	---
Depth	15.4	---	10.4	---

Calcium (mg/L)

May 07, 2018	*August 31, 2018*
Site 1	**Site 1**
27	22.9

Ruth Lake Water Chemistry Data

Chlorophyll a (µg/L)

May 07, 2018	*August 31, 2018*
Site 1	**Site 1**
5.82	12.69
---	13.00

Total Phosphorus (µg/L)

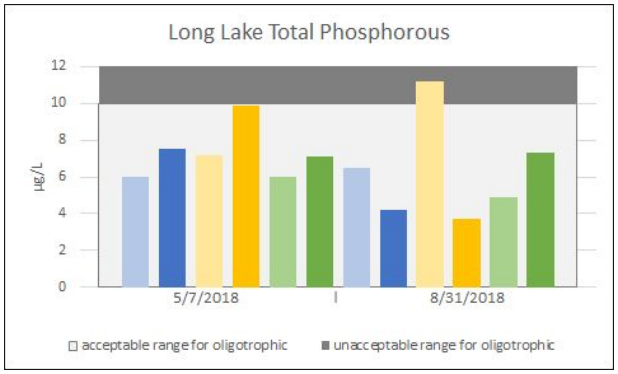
	May 07, 2018	*August 31, 2018*
Location	**Site 1**	**Site 1**
Surface	26.6	15.4

Calcium (mg/L)

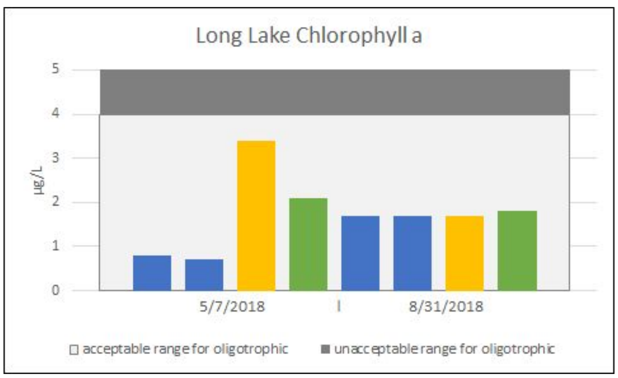
May 07, 2018	*August 31, 2018*
Site 1	**Site 1**
5	9.6

Water Chemistry Data Graphs 2018

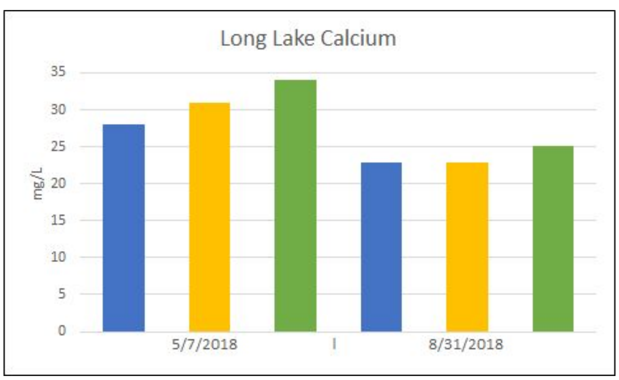
Long Lake | *Legends*



Site 1 Surface
Site 1 Depth
Site 2 Surface
Site 2 Depth
Site 3 Surface
Site 3 Depth

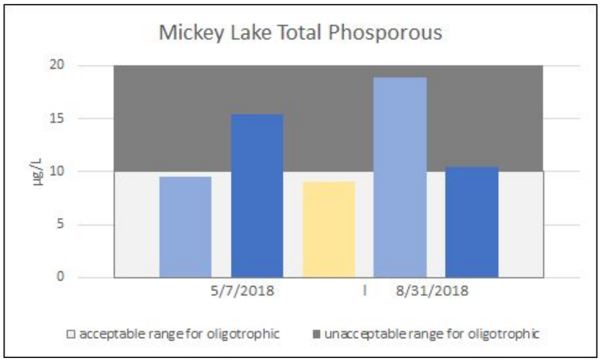


Site 1
Site 2
Site 3

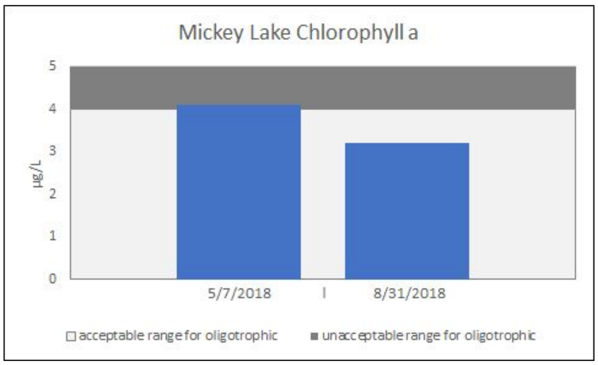


Site 1
Site 2
Site 3

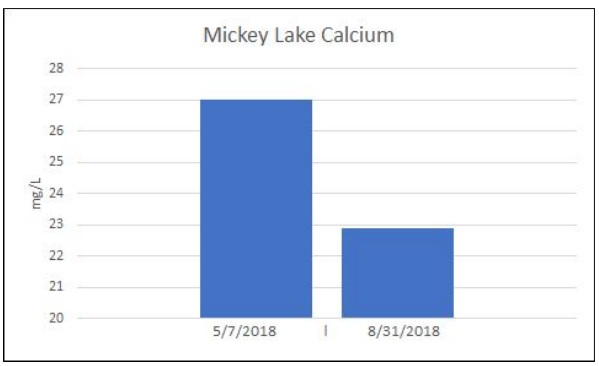
Mickey Lake | *Legends*



Site 1 Surface
Site 1 Depth
Site 2 Surface
Site 2 Depth
Site 3 Surface
Site 3 Depth



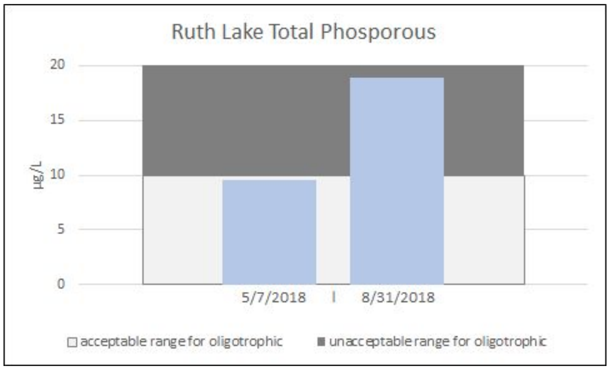
Site 1
Site 2
Site 3

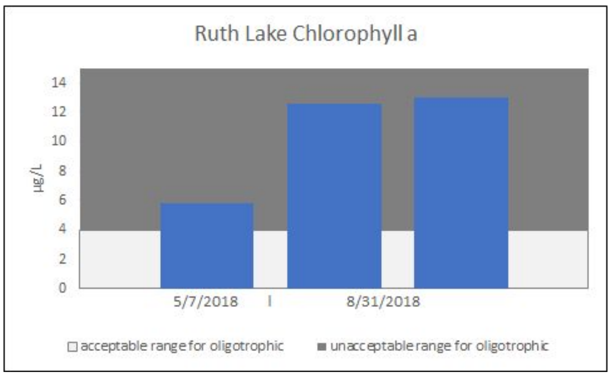


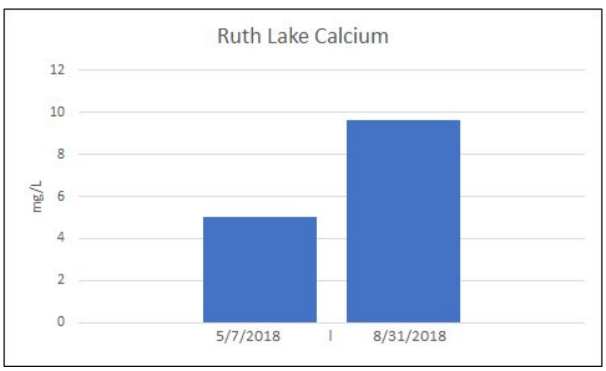
Site 1
Site 2
Site 3

Ruth Lake

Legends







Physical Data 2018

May 07, 2018

Long Lake Site #1

Air Temperature: 58℉	Weather: Overcast	Average Secchi Depth: 7 m

Depth (m.)	Temperature (℃)	Dissolved Oxygen (mg/L)	pH	Conductivity (µS/cm)
Surface	15.6	10.62	8.45	163.7
3	9.9	11.62	8.81	324.6
6	9.2	11.84	8.07	325.5
9	8.1	11.94	7.99	325.7
12	7.4	11.78	7.95	327.3
13	7.1	11.6	7.92	327.6

Long Lake Site #2

Air Temperature: 64℉	Weather: Overcast	Average Secchi Depth: 7.5 m

Depth (m)	Temperature (℃)	Dissolved Oxygen (mg/L)	pH	Conductivity (µS/cm)
Surface	12.2	11.1	8.07	279.1
3	9.6	11.55	8.24	323.9
6	8.5	11.8	8.20	326.2
9	7.1	11.94	8.14	326.3
12	6.3	11.61	8.03	327.1
13	6.2	11.52	7.98	327.1
15	6.1	11.38	7.84	327.2
18	6.0	11.34	7.78	327.5
21	6.0	11.23	7.75	327.7
24	6.0	11.13	7.72	328.1

Long Lake Site #3

Temperature: 61 ℉	Weather: Overcast	Average Secchi Depth: 7.5 m

Depth (m.)	Temperature (℃)	Dissolved Oxygen (mg/L)	pH	Conductivity (µS/cm)

Surface	13.2	11.12	8.53	169.7
3	9.2	11.5	8.99	324.3
9	8.1	11.97	8.62	324.0
12	7.1	12.13	8.41	324.0
15	6.3	11.88	8.21	325.1
18	6.1	8.35	8.07	345.4

Mickey Lake Site #1

Air Temp: 64℉	Weather: Overcast	Average Secchi depth: 2.7 m

Depth (m)	Temperature (℃)	Dissolved Oxygen (mg/L)	pH	Conductivity (µS/cm)
Surface	16.1	10.46	8.31	162.4
2	13.1	10.89	8.64	290.7
4	8.6	11.04	8.71	294.4
6	6.4	10.2	8.53	314.7
8	5.3	6.92	8.14	330.6
9	5.2	4.3	7.93	338.8

Mickey Lake Site #2

Air Temperature: 64℉	Weather: Overcast	Secchi depth: 3 m (at bottom)

Depth (m.)	Temperature (℃)	Dissolved Oxygen (mg/L)	pH	Conductivity (µS/cm)
Surface	16.8	10.33	8.9	312.2
1	13.2	10.98	9.1	290.9
2	12	11.31	8.9	291.8

Ruth Lake Site #1

Air Temperature: 64℉	Weather: Overcast	Secchi depth: 0.9 m

Depth (m.)	Temperature (℃)	Dissolved Oxygen (mg/L)	pH	Conductivity (µS/cm)
Surface	21.8	9.88	8.31	42.9
1	16.2	9.65	8.75	125.8
2	14.4	8.2	7.89	127.6

July 02, 2018

Long Lake Site #1

Air Temperature: 71 ℉	Weather: part cloudy, post thunderstorm, >2 in. rainfall	Secchi depth: 8.5 m

Depth (m.)	Temperature℃	Dissolved Oxygen (mg/L)	pH	Conductivity (µS/cm)
Surface	21.9	8.5	7.13	192

Long Lake Site #2

Air Temperature: 75℉	Sunny, breezy	Secchi depth: 9.15 m

Depth (m.)	Temperature (℃)	Dissolved Oxygen (mg/L)	pH	Conductivity (µS/cm)
Surface	30.7	7.3	7.0	168
1.5	29.3	8.4	---	---
3.0	28.5	5.7	---	---
4.6	27.1	6.1	---	---
5.3	26.9	6.0	---	---
6.1	26.3	5.7	---	---
6.9	25.8	6.5	---	---
7.6	25.5	6.6	---	---
8.4	25.2	6.5	---	---
9.1	24.9	6.7	---	---
9.9	24.3	6.7	---	---
10.7	23.2	7.1	---	---
11.4	22.2	7.1	---	---
12.2	20.9	7.1	---	---
13	19.7	7.3	---	---
13.7	18.2	7.8	---	---
15.2	17.5	8.0	---	---
16.8	16.5	8.2	---	---
18.3	15.3	8.1	---	---
19.8	14.6	8.2	---	---

21.3	14.0	8.5	---	---
22.9	13.5	8.5	---	---
24.4	12.7	8.7	---	---
25.9	12.0	8.9	---	---
27.4	11.8	8.5	---	---

Long Lake Site #3

---	---	Average Secchi depth: 10.5 m

Depth	Temperature℃	Dissolved Oxygen	pH	Conductivity (µS/cm)
Surface	---	---	7.37	159

Mickey Lake Site #1

		Secchi depth: 4.45 m

Depth (m.)	Temperature (℃)	Dissolved Oxygen	pH	Conductivity (µS/cm)
Surface	---	---	8.17	150

Ruth Lake Site #1

---	---	Secchi Depth: 1.1 m

Depth (m)	Temperature (℃)	Dissolved Oxygen (mg/L)	pH	Conductivity (µS/cm)
Surface	28.2	6.7	7.2	74
0.9	27.7	6.4	---	---
1.5	26.1	4.5	---	---
2.3	21.9	0.1	---	---

August 13, 2018

Long Lake Site #2

Air Temperature: 86 ℉	Weather: sunny, humid	Secchi depth: 7.5 m

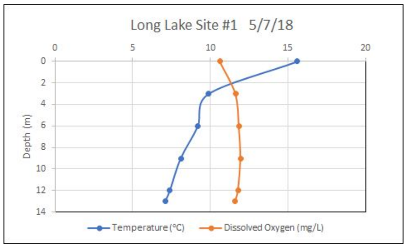
Depth (m)	Temperature (℃)	Dissolved Oxygen (mg/L)	pH	Conductivity (μS/cm)
Surface	26.1	8.1	7.8	---
1.5	25.8	8.0	---	---
3.0	25.4	7.9	---	---
4.6	25.3	8.2	---	---
5.3	25.2	8.1	---	---
6.1	25.1	8.1	---	---
6.9	25.1	8.0	---	---
7.6	24.6	8.2	---	---
8.4	24.5	8.1	---	---
9.1	23.3	7.8	---	---
9.9	22.0	8.0	---	---
10.7	16.5	9.1	---	---
11.4	14.5	9.1	---	---
12.2	12.5	6.8	---	---
13.0	12.0	5.8	---	---
13.7	11.6	4.4	---	---
15.2	11.3	3.7	---	---
16.8	11.1	3.4	---	---
18.3	11.0	2.9	---	---
19.8	10.9	2.8	---	---
21.3	10.9	2.6	---	---
22.9	10.8	2.6	---	---
24.4	10.8	2.6	---	---
25.9	10.7	1.8	---	---
26.7	10.7	0.1		---

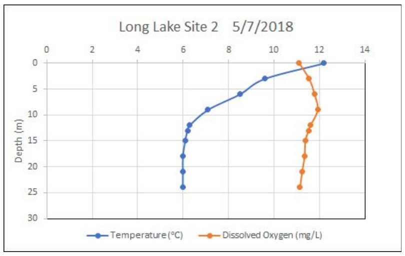
Mickey Lake Site #1

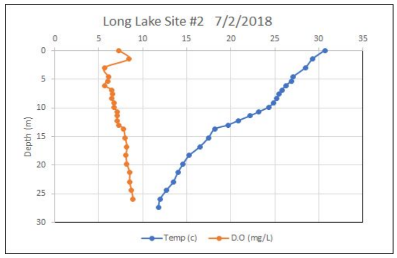
Air Temp:	Weather: sunny, calm	Secchi depth: 4.8m

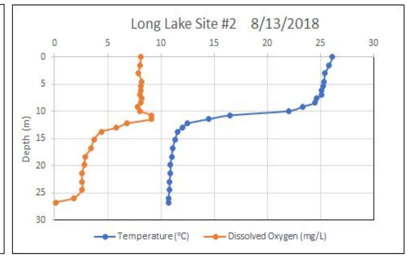
Depth (m)	Temp (℃)	Dissolved Oxygen (mg/L)	pH	Conductivity (µS/cm)
Surface	27.6	8.6	7.9	---
1.5	26.8	8.5	---	---
3.0	26.0	7.9	---	---
4.6	24.4	9.6	---	---
5.3	21.8	12.3	---	---
6.1	18.4	12.3	---	---
6.9	15.4	11.1	---	---
7.6	13.5	7.1	---	---
8.4	12.2	2.9	---	---
9.1	11.6	0.5	---	---

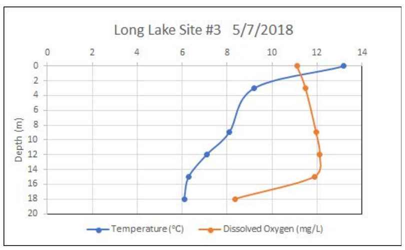
Dissolved Oxygen and Temperature Profiles 2018

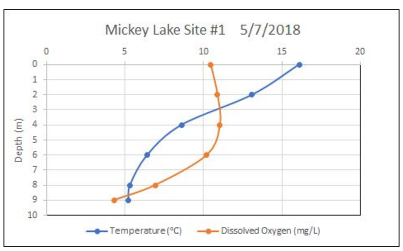


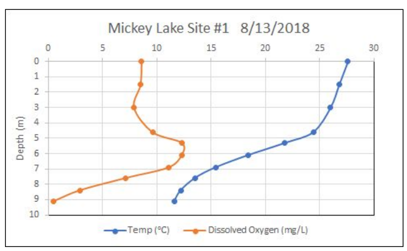


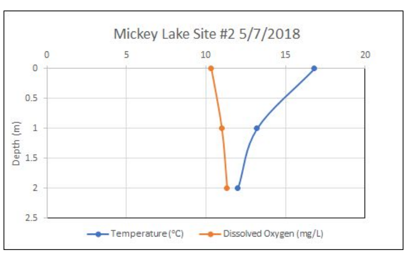


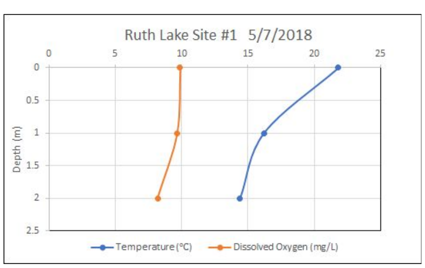


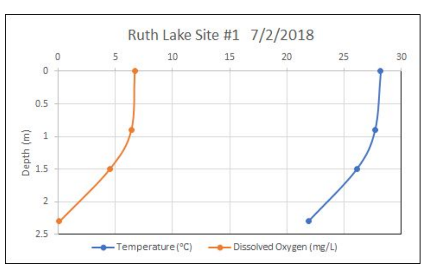












Plankton of Long Lake

December 2018
Dr. Richard A Roeper Professor Emeritus of Biology , Alma College

Introduction and Methods

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 drop 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 + to three +++.

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

Results:

8/2017

Mickey Lake

Phytoplankton

Ceratum ++	Dinoflagellate Algae
Phormidium +	Colonial Filamentous Blue Green Algae – Pollution water indicator
Phacus ++	Chrysophyta Alga – Pollution water indicator

Zooplankton
Notholea +
Anuea Rotifer
Copepods and Cladocera +

Long Lake

Phytoplankton

Coelosphaera +	Colonial Blue Green Alg
Aphanocapsa +	Colonial Blue Green Alga
Flagilaria+	Colonial Diatom
Gleotrichia +++	Colonial Blue Green

Zooplankton
Copepods and Cladocera ++

8/31/2018

Mickey Lake

Phytoplankton

Oscillatoria ++	Filamentous Blue Green – Pollution indicator
Ceratum ++	Dinoflagellate Algae
Phormidium +	Filamentous Blue Green Alga –Pollution indicator
Phacus ++	Chrysophyta Algae- Pollution indicator

Zooplankton

Copepods ++	
Cladoceras++	
Rotifers ++	
Craspedcrusta soweri +++	Freshwater Jellyfish

Long Lake

Phytoplankton

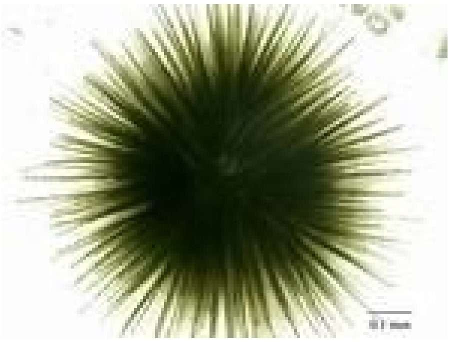
Gloeotrichia ++	Colonial Blue Green
Ceratum ++	Dinoflagellate
Cosmarium +	
Staurastrum+	Desmids

Richteniella +
Closterium+
Oscillatoria ++ Filamentous Blue Green – Pollution indicator
Aphanocapsa + Colonial Blue Green Alga
Nostoc + Colonial Chain of Blue Green Alga

Zooplankton
Rotifers+
Roundworms+
Cililates +

Representative Algae

Oscillatoria



Gleotrichia

Phacus

Discussion:

Gloeotrichia is a concern. It is considered to a meroplankton. Filaments of Gloeotrichia develop as a ball of cell 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 microystin which can cause liver damage if ingested. A swimmers-itch like symptom have been reported during these late summer blooms.

The presence of Oscillatoria, Phormidium, and Phacus indication enrichment in Mickey Lake. Desmids present can also bloom at times.

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

Bibliography

Bold, H.C. and M. L. Wynne. 1985 Introduction to the Algae. 2nd Edition . Prentic 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

The historical data trends for Long Lake, Mickey Lake, and Ruth Lake were established by processing yearly data reports from 1993-2005 from Dr Wallace Fusilier and 2005,'08,'11 & '14 from GLEC with the help of Robert Roeper, and raw data collection done by Northwestern intern Autumn Cottrell, and Western Michigan University student, Sierra Porter of 2018. The intention of the program is to create a record of the lake's variables, in which allows any damaging trends in the water quality to be identified and corrected using the appropriate measure. Maintaining the already established healthy parameters of the lake is essential in the overall biodiversity that each lake possess.

Parameters for seasonal testing of the lakes' water include; total phosphorus, sediment phosphorus, chlorophyll a, secchi depth readings, total nitrate and nitrite, nitrogen, calcium, dissolved oxygen, and temperature profiles. This year invasive species profiles, e coli, chloroform, and phytoplankton were tested, but not all were included in the report. Testing for magnesium, iron, sodium, fluoride, and potassium were done, but not included in the report, as it was not tested in every test sight, or regularly. Along with historical, pH, alkalinity, conductivity, and an overall lake water quality index data were tested, and is recommended to be done fully and added to future reports.

In the collection of data and creating consistency across the various years, it should be noted, as in the 2017 report, that several issues needed to be addressed. Data found within the reports is assumed to be accurate, unless discrepancies were noted otherwise. Some measurements in the 2017 report were converted to create a complete metric record, and with this, possible contamination in 2017 samples are noted in the data when noted in the reports.

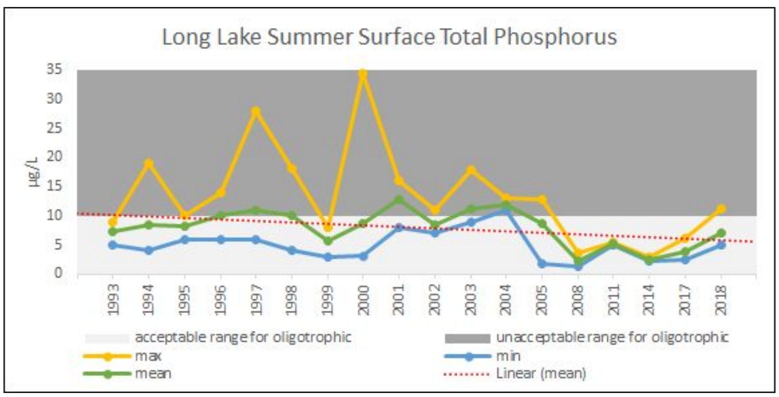
In the cases of only one sampled that has been collected, no graphs were created, and has been noted since no trend is able to be established.

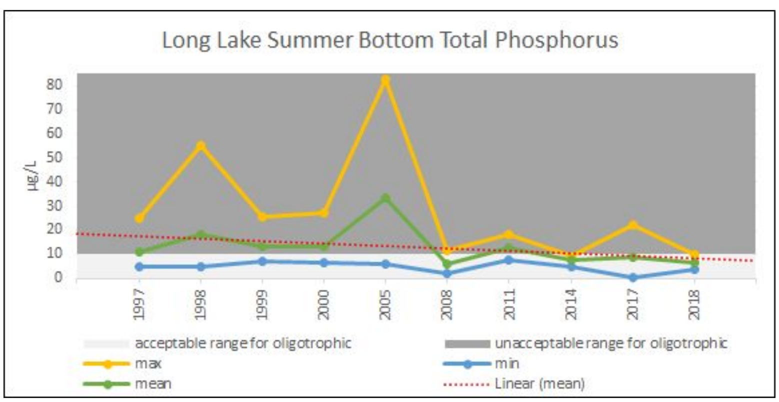
Historical Charts

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-Hypol imnion	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	---	---

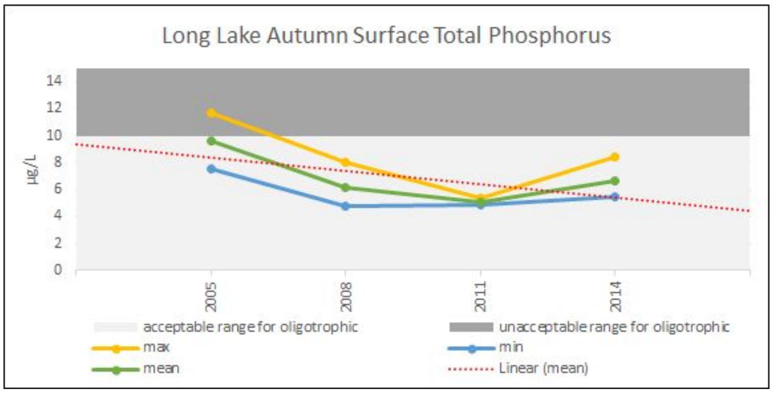
*Possible contamination from bottom sediment

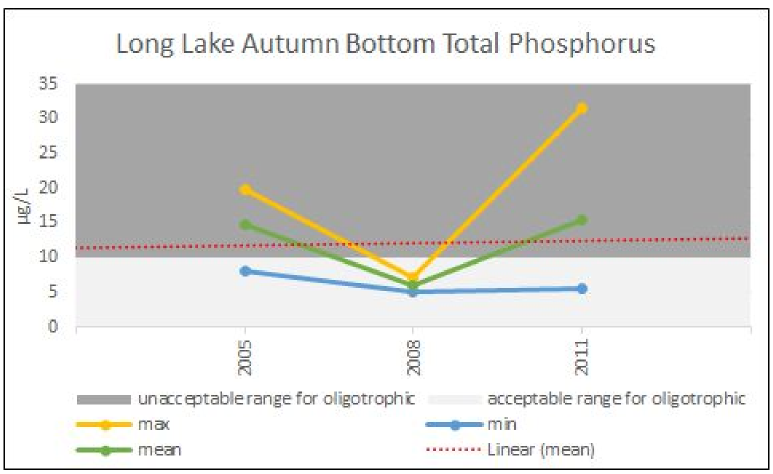




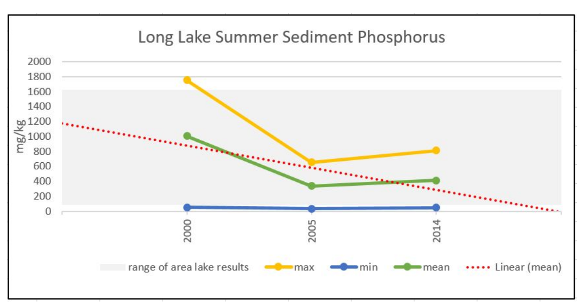
Summary: (see table 1 and 3) * In 2005 there was possible sediment contamination in a sample. This sample was included in the graph, but the overall trend downward is still consistent with what we see in the spring/summer samples. This trend could be slightly more significant if not considering this sample.

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	---	---	---	----	---	---	---	---



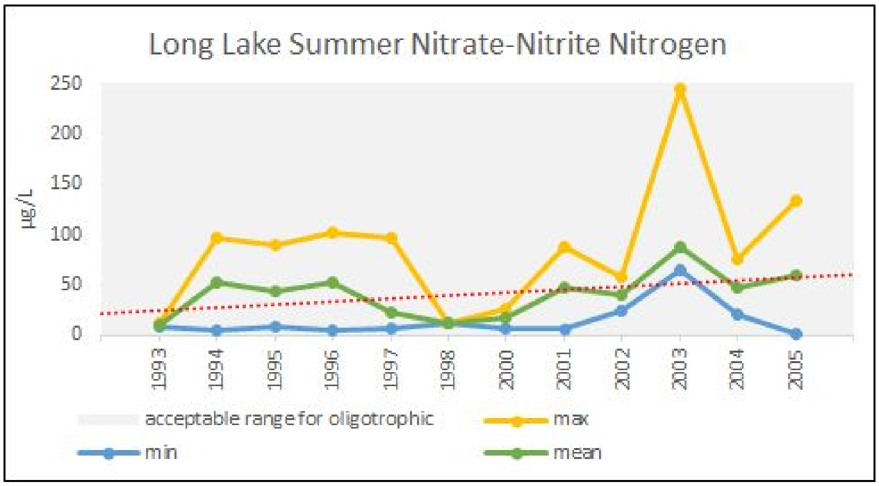


Sediment Phosphorus (mg/kg) SPRING/SUMMER				
Year	# samples	min	max	mean
2000	3	50.6	1754	1005.30
2005	3	33	654	336.33
2008	---	---	---	---
2011	---	---	---	---
2014	3	48	811	412.67
2017	---	---	---	---
2018	---	---	---	---



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
2008	---	---	---	---	---	---	---	---
2011	---	---	---	---	---	---	---	---
2014	---	---	---	---	---	---	---	---
2017	---	---	---	---	---	---	---	---
2018	6	---	<50	---	<1000	---	<525	---

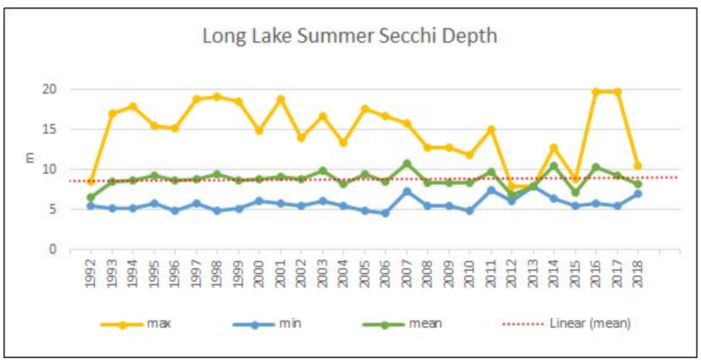
Nitrate-Nitrite Nitrogen (µg/L) AUTUMN								
Year	# samples		min		max		mean	
	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom
1993	---	---	---	---	---	---	---	---
1994	---	---	---	---	---	---	---	---
1995	---	---	---	---	---	---	---	---
1996	---	---	---	---	---	---	---	---
1997	---	---	---	---	---	---	---	---
1998	---	---	---	---	---	---	---	---
1999	---	---	---	---	---	---	---	---
2000	---	---	---	---	---	---	---	---
2001	---	---	---	---	---	---	---	---
2002	---	---	---	---	---	---	---	---
2003	---	---	---	---	---	---	---	---
2004	---	---	---	---	---	---	---	---
2005	3	3	1.5	5.1	6.1	8	4.1	6.6
2014	---	---	---	---	---	---	---	---
2011	---	---	---	---	---	---	---	---
2014	---	---	---	---	---	---	---	---
2017	---	---	---	---	---	---	---	---
2018	---	---	---	---	---	---	---	---

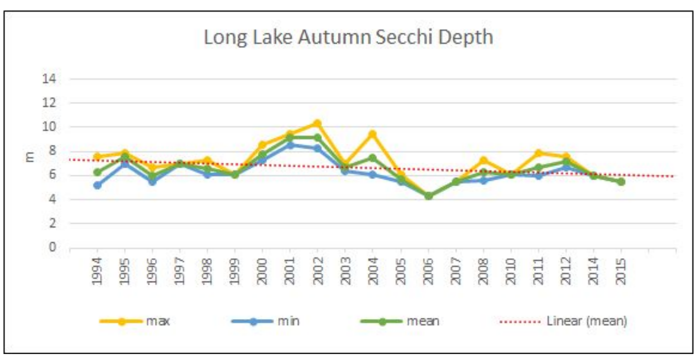


Summary: (see table 2) * There was only 1 bottom sample taken in 2005, so it is not included in the graph. It would have decreased the slope of the trend slightly, but not significantly. The one autumn sample year, 2005, is also not included since no trend could be established.

Secchi Disk (m.)	SPRING/SUMMER			
Year	# samples	min	max	mean
1992	14	5.49	8.53	6.58
1993	25	5.18	17.07	8.56
1994	27	5.18	17.98	8.69
1995	28	5.79	15.54	9.30
1996	25	4.88	15.24	8.66
1997	33	5.79	18.9	8.87
1998	61	4.88	19.2	9.45
1999	24	5.18	18.59	8.65
2000	38	6.1	14.94	8.90
2001	30	5.79	18.9	9.08
2002	30	5.49	14.02	8.86
2003	32	6.1	16.76	9.88
2004	30	5.49	13.41	8.30
2005	27	4.88	17.68	9.42
2006	24	4.57	16.76	8.55
2007	6	7.32	15.85	10.87
2008	10	5.49	12.74	8.37
2009	7	5.49	12.8	8.40
2010	7	4.88	11.89	8.45
2011	4	7.5	15	9.79
2012	3	6.1	7.92	6.81
2013	1	7.92	7.92	7.92
2014	5	6.4	12.74	10.51
2015	2	5.49	8.84	7.17
2016	10	5.79	19.81	10.30
2017	8	5.5	19.81	9.29
2018	7	7	10.5	8.24

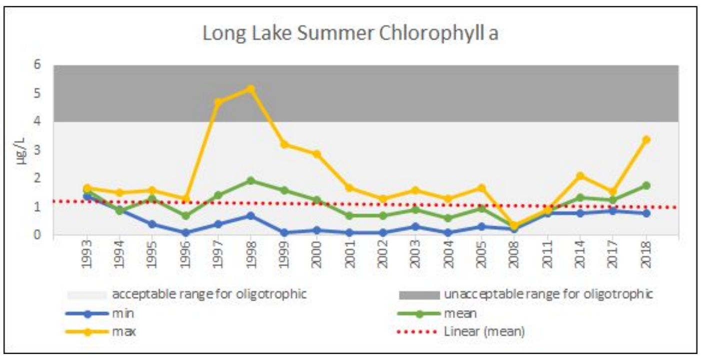
Secchi Disk (m.)	AUTUMN			
Year	# samples	min	max	mean
1992	---	---	---	---
1993	---	---	---	---
1994	4	5.18	7.62	6.33
1995	4	7.01	7.92	7.62
1996	4	5.49	6.71	6.02
1997	1	7.01	7.01	7.01
1998	4	6.1	7.32	6.63
1999	3	6.1	6.1	6.10
2000	3	7.32	8.53	7.82
2001	3	8.53	9.45	9.14
2002	4	8.23	10.36	9.14
2003	2	6.4	7.01	6.71
2004	5	6.1	9.45	7.44
2005	5	5.49	6.1	5.70
2006	1	4.27	4.27	4.27
2007	1	5.49	5.49	5.49
2008	4	5.64	7.32	6.31
2009	---	---	---	---
2010	1	6.1	6.1	6.10
2011	4	6	7.92	6.73
2012	2	6.71	7.62	7.17
2013	---	---	---	---
2014	3	6	6	6.00
2015	1	5.49	5.49	5.49
2016	---	---	---	---
2017	---	---	---	---
2018	---	---	---	---

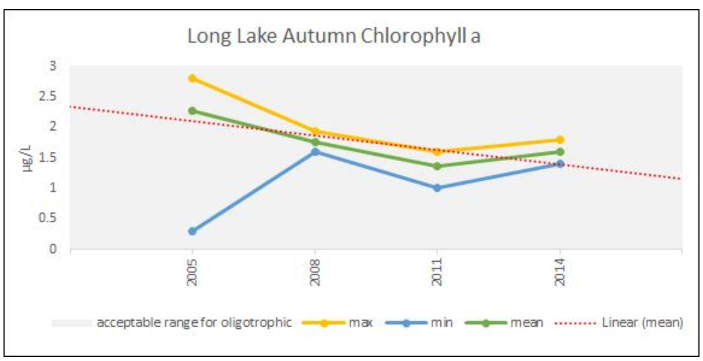




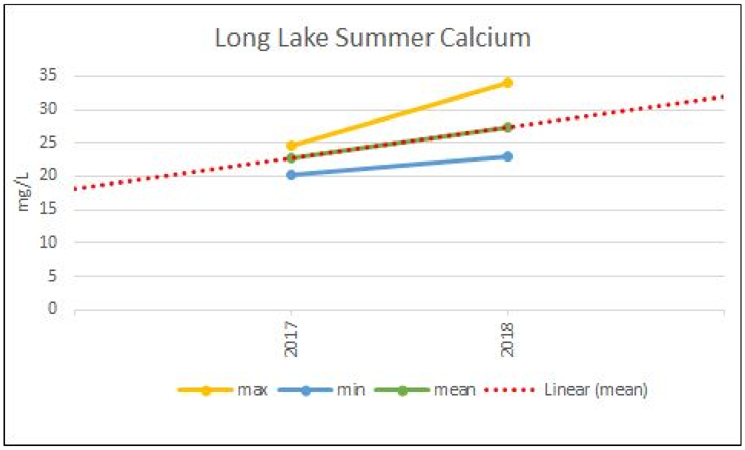
Chlorophyll a (µg/L) SPRING/SUMMER				
Year	# samples	min	max	mean
1993	4	1.4	1.7	1.58
1994	6	0.9	1.5	0.88
1995	4	0.4	1.6	1.28
1996	4	0.1	1.3	0.70
1997	6	0.4	4.7	1.43
1998	5	0.7	5.2	1.92
1999	6	0.1	3.2	1.60
2000	12	0.2	2.9	1.26
2001	6	0.1	1.7	0.72
2002	6	0.1	1.3	0.68
2003	6	0.3	1.6	0.92
2004	6	0.1	1.3	0.60
2005	6	0.3	1.7	0.97
2008	3	0.25	0.35	0.30
2011	2	0.8	0.9	0.85
2014	3	0.8	2.1	1.33
2017	7	0.86	1.57	1.25
2018	8	0.78	3.4	1.76

Chlorophyll a (µg/L) AUTUMN				
Year	# samples	min	max	mean
1993	---	---	---	---
1994	---	---	---	---
1995	---	---	---	---
1996	---	---	---	---
1997	---	---	---	---
1998	---	---	---	---
1999	---	---	---	---
2000	---	---	---	---
2001	---	---	---	---
2002	---	---	---	---
2003	---	---	---	---
2004	---	---	---	---
2005	3	0.3	2.8	2.27
2008	3	1.61	1.93	1.75
2011	3	1	1.6	1.37
2014	3	1.4	1.8	1.60
2017	---	---	---	---
2018	---	---	---	---





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



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+

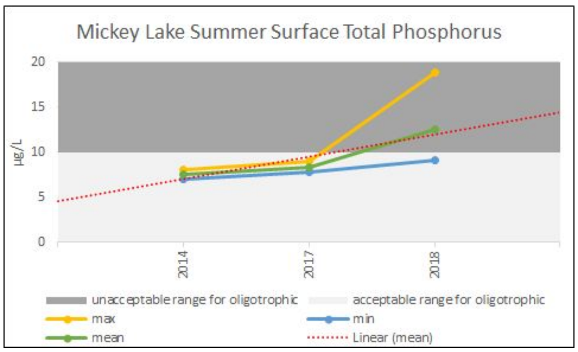
*Michigan DEQ standards

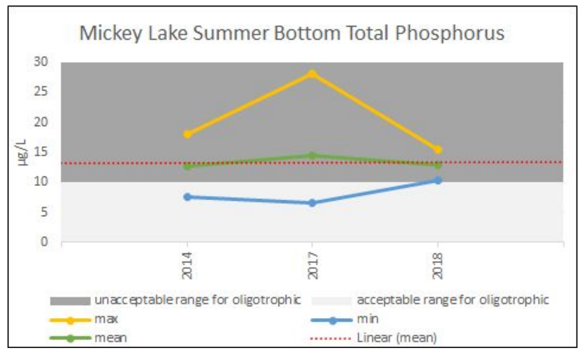
Mickey Lake

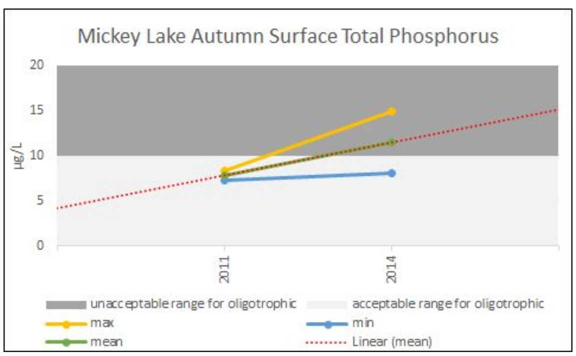
Total Phosphorus (µg/L) SPRING/SUMMER									
Year	# samples		min		max		mean	
	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom
2011	---	---	---	---	---	---	---	---
2014	2	2	7	7.6	8.1	18	7.55	12.80
2017	5	4	7.71	6.5	8.9	28.1*	8.30	14.43
2018	3	2	9.1	10.4	18.9	15.4	12.50	12.90

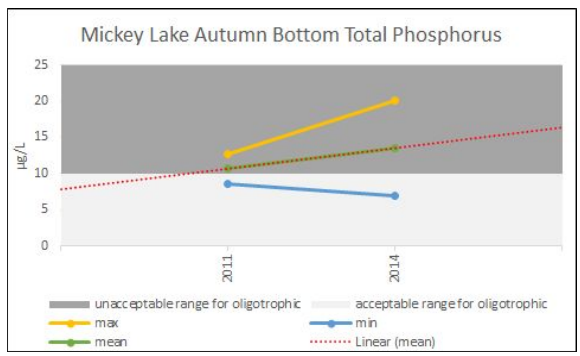
*Possible contamination from bottom sediment

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
2017	---	---	---	---	---	---	---	---
2018	---	---	---	---	---	---	---	---









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

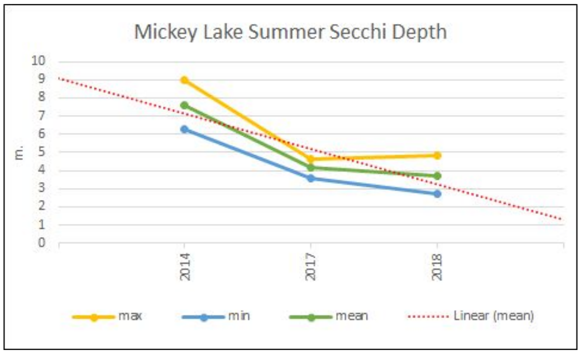
Summary: There is only one sample year, so no trend could be established.

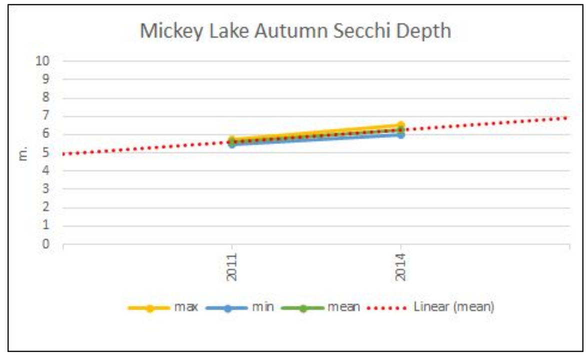
Nitrate-Nitrite Nitrogen (µg/L) SPRING/SUMMER								
Year	# samples		min		max		mean	
	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom
2011	---	---	---	---	---	---	---	---
2014	---	---	---	---	---	---	---	---
2017	---	---	---	---	---	---	---	---
2018	1	---	<50	---	<1000	---	<525	---

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

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

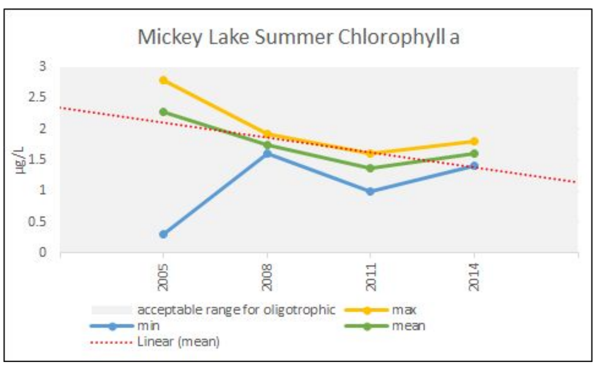
Secchi Disk (m.) AUTUMN				
Year	# samples	min	max	mean
2011	2	5.49	5.7	5.60
2014	2	6	6.49	6.25
2017	---	---	---	---
2018	---	---	---	---

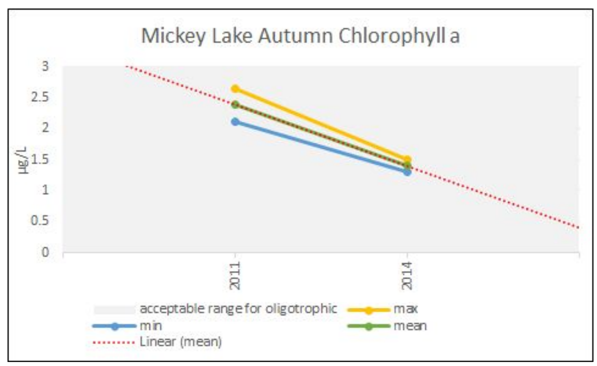




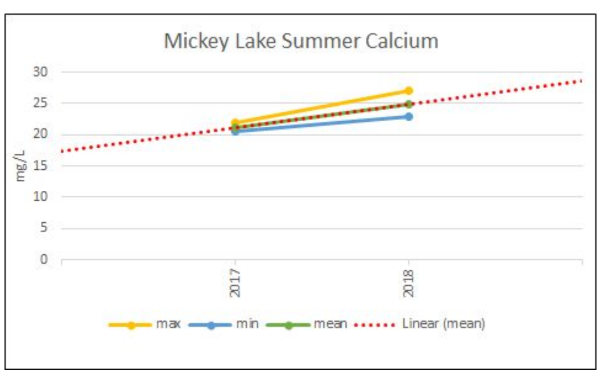
Chlorophyll a (µg/L) SPRING/SUMMER				
Year	# samples	min	max	mean
2011	---	---	---	---
2014	2	2	5.2	3.6
2017	2	2.2	3.1	2.69
2018	2	3.27	4.19	3.73

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
2017	---	---	---	---
2018	---	---	---	---





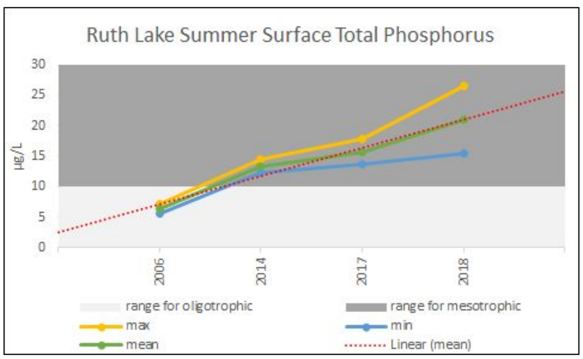
Calcium (mg/L) SPRING/SUMMER				
Year	# samples	min	max	mean
2017	3	20.6	21.9	21.17
2018	3	22.9	27	24.95

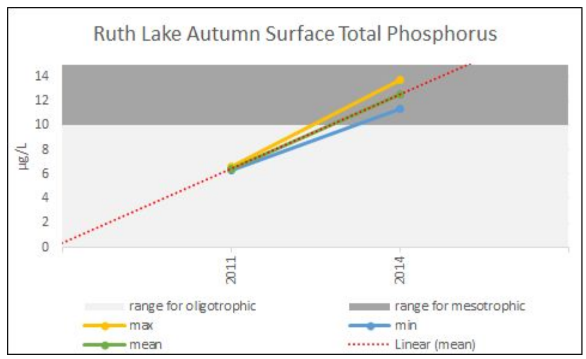


Ruth Lake

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	---

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	---
2017	---	---	---	---	---	---	---	---
2018	---	---	---	---	---	---	---	---





Sediment Phosphorus (mg/kg) SPRING/SUMMER				
Year	# samples	min	max	mean
2014	2	445	461	451
2017	---	---	---	---
2018	---	---	---	---

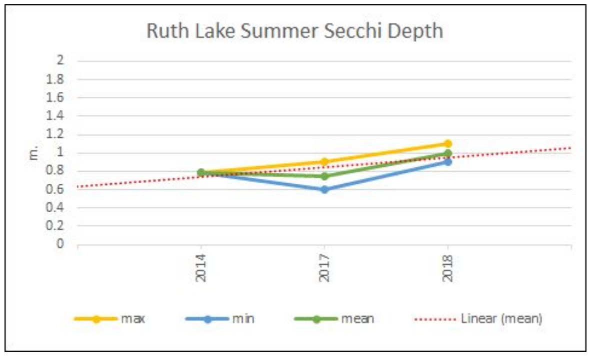
Summary: There is only one sample year, so no trend could be established.

Nitrate-Nitrite Nitrogen (ug/L) SPRING/SUMMER								
Year	# samples		min		max		mean	
	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom
2006	---	---	---	---	---	---	---	---
2011	---	---	---	---	---	---	---	---
2014	---	---	---	---	---	---	---	---
2017	---	---	---	---	---	---	---	---
2018	1	---	<50	---	<1000	---	<525	---

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

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

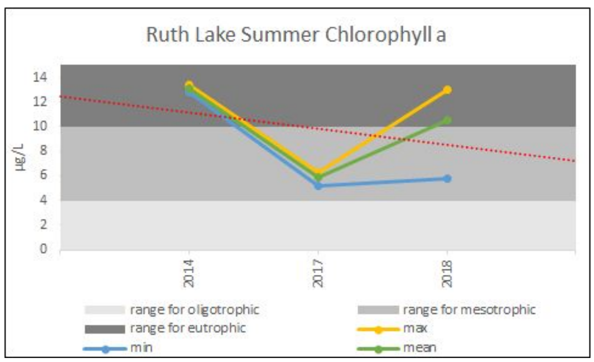
Secchi Disk (m.) AUTUMN				
Year	# samples	min	max	mean
2014	2	1.01	1.01	1.01
2017	---	---	---	---
2018	---	---	---	---



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

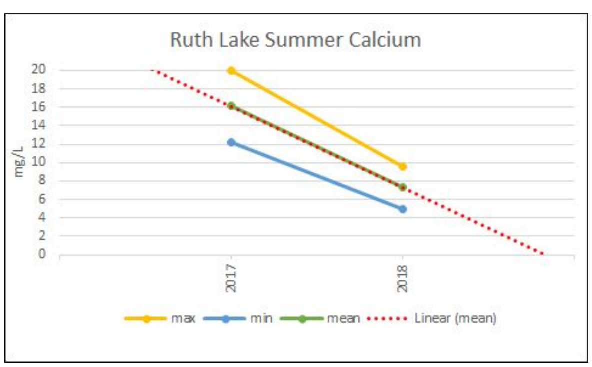
Chlorophyll a (μg/L) SPRING/SUMMER				
Year	# samples	min	max	mean
2014	2	12.8	13.4	13.1
2017	3	5.17	6.27	5.86
2018	3	5.82	13	10.50

Chlorophyll a (μg/L) AUTUMN				
Year	# samples	min	max	mean
2014	2	3.7	10.7	7.2
2017	---	---	---	---
2018	---	---	---	---



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



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.

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 softwater 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 softwater 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 artic 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 softwater 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 softwater 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 (19o2), 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 m^2 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 HNO 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 10c 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 softwater 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 5 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 = o1 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 1n 2005, and zebra mussel populations have declined since their explosion in all three lakes especially where water depths are shallower than 1 m (Pam Tyning, 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. siliquoidea, 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. siliquoidea, 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). Softwater 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.

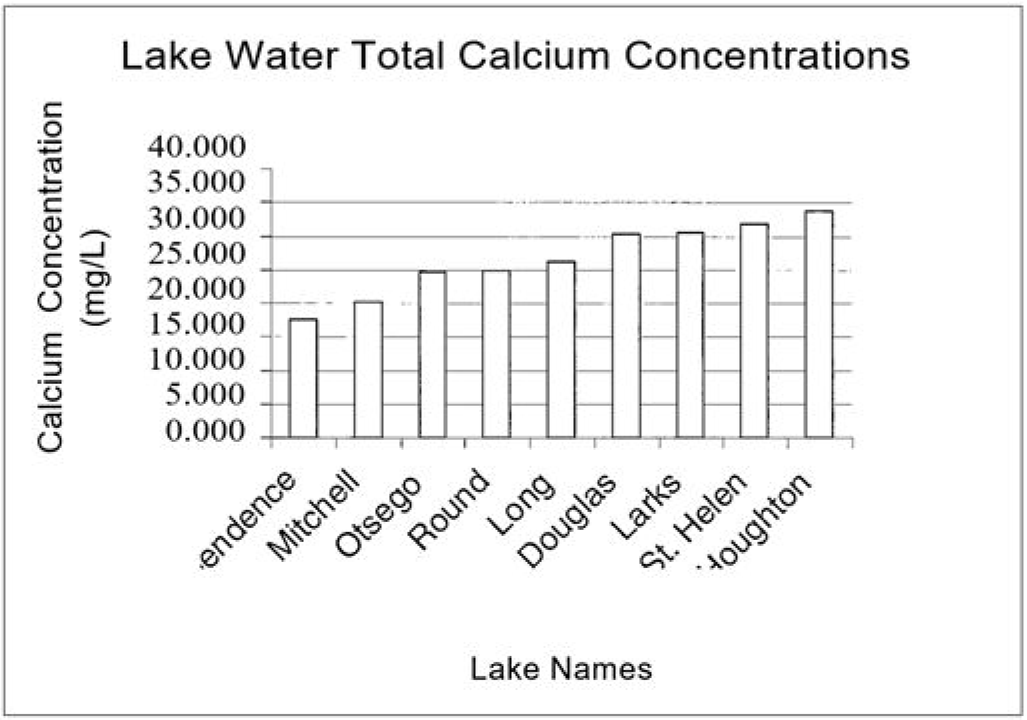

Figure 2: Mean of calcium concentrations and 95% confidence intervals for lakes where zebra mussels are absent (n=6) and lakes where zebra mussels are present (n—3).

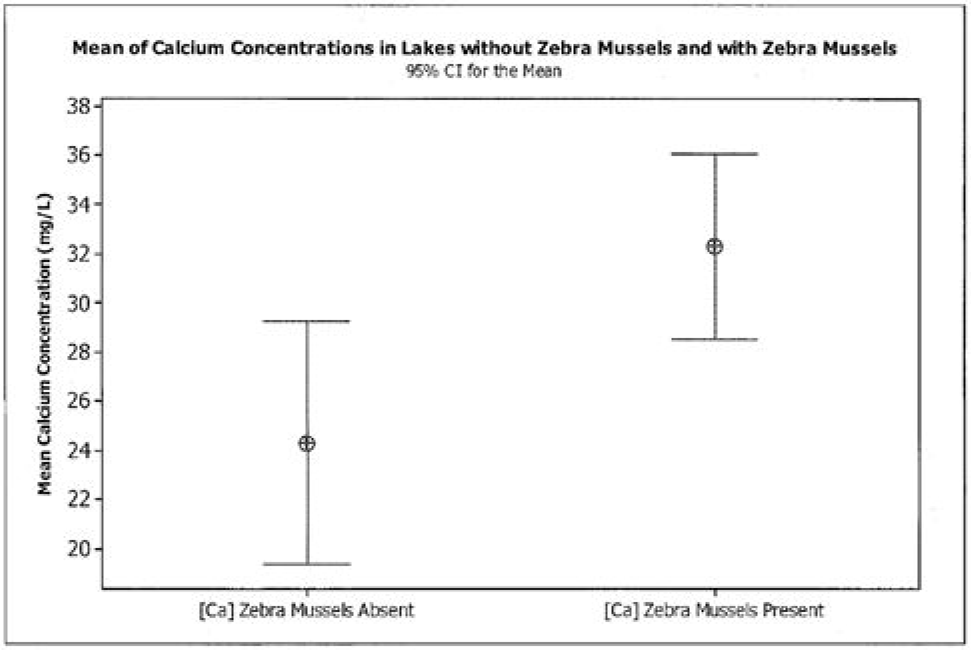

Table 1. Species lists of unionids in Michigan inland lakes surveyed.

Unionid Species and Lake Names	*Anodontoides ferussacianus*	*Elliptio complanata*	*Lampsilis siliquoidea*	*Ligumia nasuta*	*Pyganodon grandis*	
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 (Otsego Co.)	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 and 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.

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