GULL LAKE WATERSHED MONITORING PROGRAM 2013 ANNUAL REPORT

Jeffrey White, Department of Fisheries & Wildlife
Dr. Stephen K. Hamilton, Kellogg Biological Station
Michigan State University

Gull Lake Watershed Monitoring Program 2013 Annual Report

Report Date: December 2013

Cover photo: Autumn reflections on Little Long Lake by Jeffrey White

GULL LAKE WATERSHED MONITORING PROGRAM

The Gull Lake Quality Organization (GLQO) supports monitoring of Gull Lake, Little Long Lake, and the inflowing streams to Gull Lake by researchers at the W.K. Kellogg Biological Station (KBS) and Michigan State University (MSU). The sampling is designed to track the ecological condition of the lakes and how changing land use and cover in the watershed may affect water quality.

Jeffrey White performed the sampling and some of the lab analyses in 2011 -2013, and wrote this year's report with Dr. Hamilton, whose KBS lab also contributed to the chemical analyses. Jeff is a doctoral student in the Department of Fisheries and Wildlife at MSU, studying the ecology of *Microcystis*, an undesirable blue-green alga (cyanobacterium) that often becomes common in Gull Lake in late summer, which MSU research has shown to be a result of invasive zebra mussels. Gull Lake was sampled more frequently and more variables were measured in 2011-2013 than had been planned for the long-term GLQO monitoring program because the sampling coincided with the field work for Jeff's dissertation.

BACKGROUND ON GULL AND LITTLE LONG LAKES

Gull and Little Long Lakes are located in Kalamazoo and Barry counties, Michigan (Figure 1; see Appendix B for bathymetric maps). Gull Lake is one of the largest and deepest inland lakes in southern Michigan. Little Long Lake is much smaller and shallower. Two smaller lakes—Wintergreen and Miller Lakes—also drain into Gull Lake. These lakes lie in a glacial landscape that abounds with wetlands, ponds, and other lakes.

Gull Lake

Gull Lake has a surface area of 2,030 acres and a maximum depth of 110 feet. The lake is unusual in southern Michigan because it supports a diverse fishery, including both warm- and cold-water species, and serves as an important recreational site for the region. Residential development lines the lakeshore; unlike most local lakes, there is no wetland along its shores and aquatic plant growth is sparse. The most important stream inflow to Gull Lake is Prairieville Creek, which enters from the north. The Gull Lake outflow, which flows year round, is regulated by a sluice-gate dam.

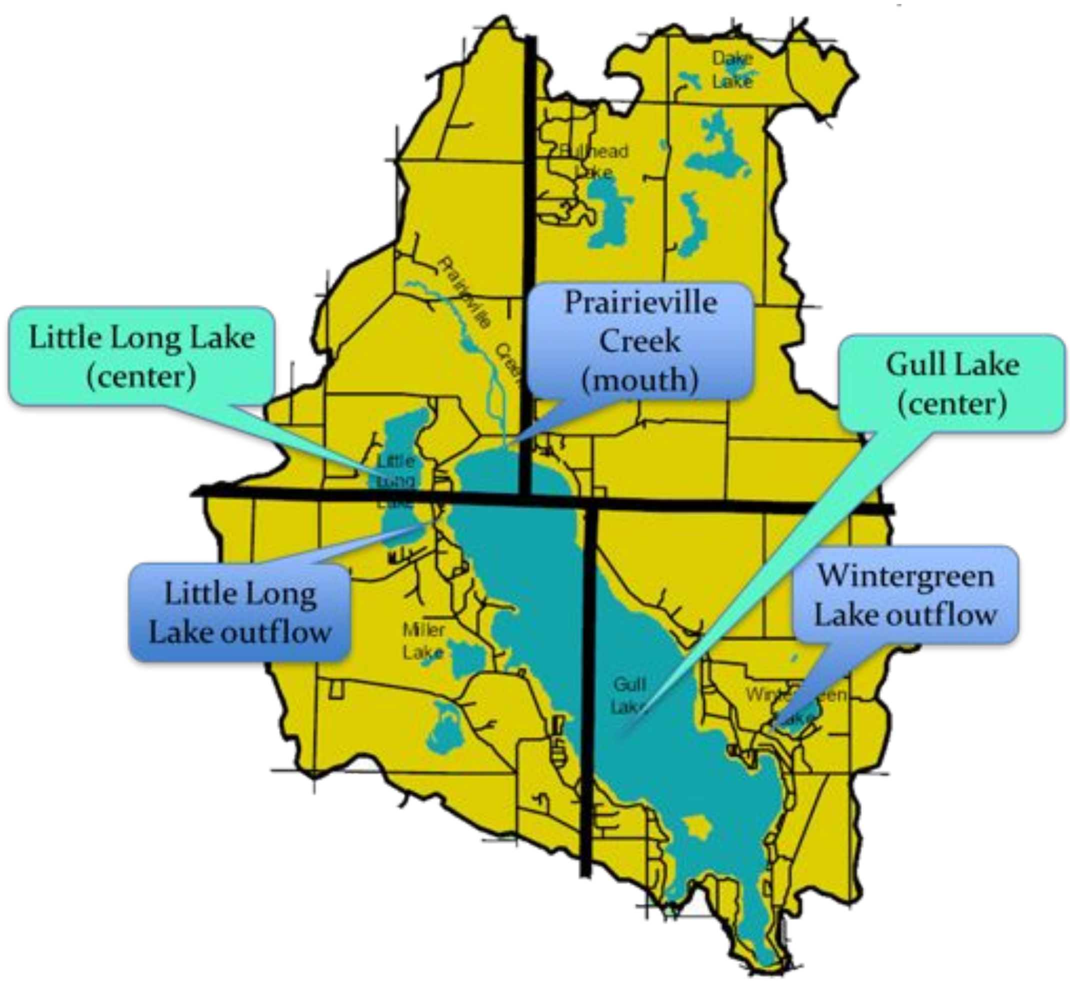

Fig. 1. *The Gull Lake watershed, indicating lake and stream sampling sites.*

Observations in the 1970s suggested that Gull Lake was becoming increasingly eutrophic (i.e., supporting undesirably high algal growth), prompting studies of the linkage between nutrient loading and algal blooms. These studies established that phosphorus was the principal limiting nutrient for algal growth in Gull Lake, and that reducing phosphorus inputs would ameliorate the eutrophication (Tessier and Lauff 1992).

Citizen action, supported by state and Federal grants, resulted in construction of a sanitary sewer around the perimeter of Gull Lake in 1984. This diversion of a significant source of phosphorus from Gull Lake resulted in a rapid reversal in eutrophication trends and marked improvement in water quality (Tessier and Lauff 1992).

Current water quality in Gull Lake is considered very good, although late-summer blooms of the blue-green alga *Microcystis aeruginosa* cause some concern. This species produces microcystin, a toxin that is potentially harmful if water with abundant *Microcystis* cells is ingested directly without filtration or treatment. *Microcystis* blooms have developed since the invasion of zebra mussels, which promote this particular species in lakes like Gull Lake.

Little Long Lake

Little Long Lake is located adjacent to the northwestern end of Gull Lake and is much smaller (169 acres) and shallower (maximum depth, 32 feet). Residential development lines the lake except for parts of its western edge where riparian wetlands occur. The lake receives groundwater inputs, some of which emerge in the wetlands along its western shore to form visible springs or very small streams, and it supports an outflow stream to Gull Lake. The water is alkaline, reflecting the importance of groundwater inputs. Water levels are very stable.

PREVIOUS AND EXISTING SAMPLING PROGRAMS

A number of ecological studies have been conducted on Gull Lake by KBS researchers, producing theses and peer-reviewed publications that are available in the KBS Library. Early work was summarized by Tessier and Lauff (1992) and Sippel and Hamilton (1998). Little Long Lake has not been studied except for occasional water sampling by KBS researchers.

David Tague estimated water and phosphorus budgets for Gull Lake in his 1977 master's thesis. He found that, in 1974, Gull Lake received 40% of its water from groundwater inflow, 25% from direct precipitation onto the lake surface, and 35% from stream inflows (Tague 1977; Figure 2). The water budget was combined with information on the phosphorus concentrations of these inputs to formulate a phosphorus budget for the lake (Tague 1977). The phosphorus budget demonstrated that septic systems and lawn fertilizers comprised 76% of the annual phosphorus inputs at that time (Figure 3), and that most of the phosphorus input was ultimately retained within the lake by sedimentation.

In 1994-95, well after the sewer system was installed, the GLQO supported a re-evaluation of the phosphorus budget of Gull Lake by Dr. Alan Tessier, with the objective of following up on Tague's study. That work included sampling of the stream inflows and precipitation over the year.

Tessier's study found that the total phosphorus (P) loading to Gull Lake had been reduced considerably from ~2,331 kg P/year in 1974 to ~517 kg P/year in 1994-95. The inputs from septic systems that had been diverted to the sewer system were presumed to account for most of this decrease (Figure 3). Phosphorus inputs originating from lawn fertilizers likely became the most important source of phosphorus to the lake following the construction of the sewer, although this input is not well quantified. Tributary inputs were dominated by Prairieville Creek (high discharge, low phosphorus concentrations) and the Wintergreen Lake outlet (low discharge, high phosphorus concentrations). Today's phosphorus budget is not likely to differ greatly from that estimated by Tessier (1995).

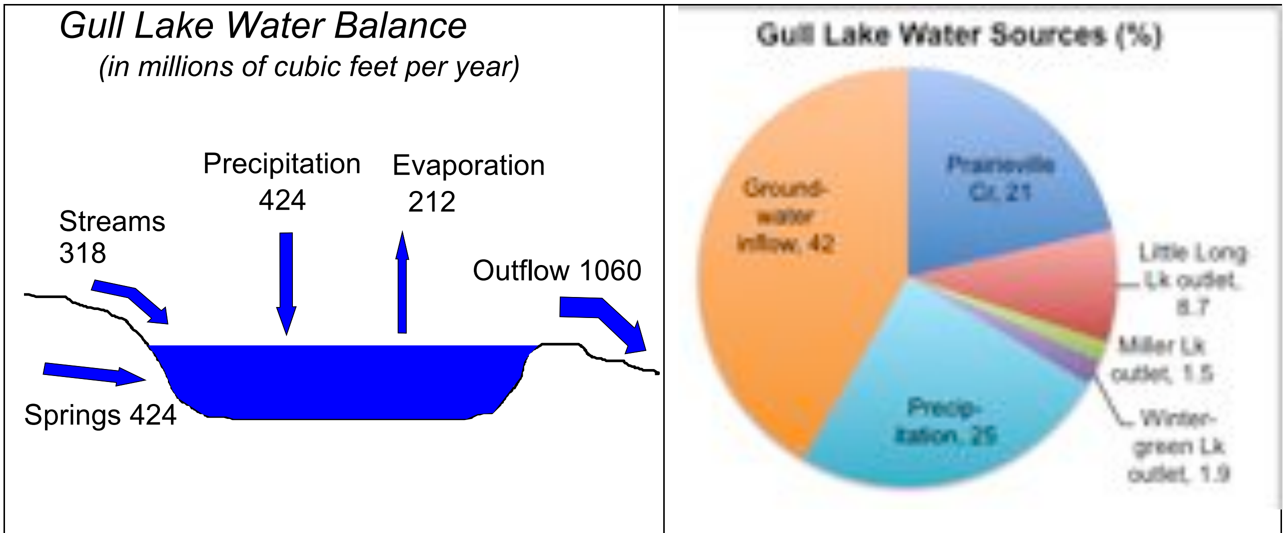

Fig. 2. *Gull Lake water budget (left, from Tague 1977) and proportional contributions from tributary inflows, precipitation, and groundwater inflows (right, from Tessier 1995).*

Although water sampling supported by research grants over the past two decades has contributed to our knowledge base, it has been sporadic and inconsistent in its coverage due to the short-term nature of grant-funded work. Fortunately, during the past decade, KBS/MSU researchers have regularly sampled Gull Lake in conjunction with several specific research programs. The main research activities have included studies of zebra mussel and *Microcystis* ecology by Drs. Orlando Sarnelle and Stephen Hamilton and their graduate students, with most activity between 2001-02 and 2005-present, and limnological research by Dr. Elena Litchman, which began in 2005 and continues to the present.

Since 2005, the GLQO has provided funds for sampling and analysis of Gull Lake's inflow streams during summer, with water quality analyses conducted by Dr. Hamilton's lab. Sampling sites in the past included Prairieville Creek, Little Long Lake outflow, Miller Lake outflow, and Wintergreen Lake outflow, as well as a ditch along the Gull Lake Country Club that carries water draining from its golf course. Prairieville Creek is also sampled several times per year as part of a broader stream monitoring program conducted by Dr. Hamilton in connection with the KBS Long-Term Ecological Research site. Because stream flows can vary so greatly through time, stream sampling effort was re-focused in 2012 toward more frequent measurements of only the three most important streams (in terms of flow and nutrient contribution to Gull Lake): Prairieville Creek, Little Long Lake outflow, and Wintergreen Lake outflow.

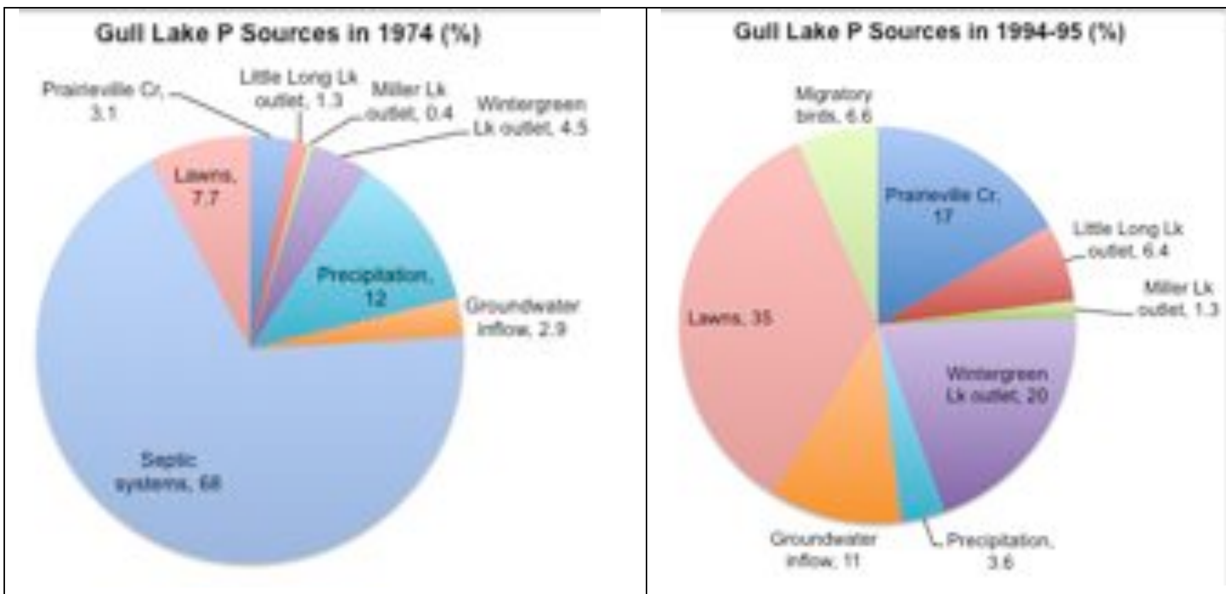

Fig. 3. *Gull Lake phosphorus (P) budgets in 1974 (left, from Tague 1977) and 1994-95 (right, from Tessier 1995). The total loading of P to the lake in 1994-95 was estimated to be only 25% of the 1974 loading, mainly as a result of the sewer system installed in 1984, which essentially eliminated septic inputs.*

Both Gull and Little Long Lakes have been sampled since 2009 by GLQO volunteers as part of the Cooperative Lakes Monitoring Program (CLMP), following standardized protocols and contributing data to a statewide database. This program provides an opportunity to see how Gull Lake compares to other lakes across the state. CLMP data for 2013 were not available at the time of this report. More information can be found at http://www.micorps.net/lakeoverview.html.

MONITORING PROGRAM UPDATE FOR 2013

The 2013 monitoring program consisted of biweekly sampling of Gull and Little Long Lakes, as well as the three main Gull Lake inflows (Prairieville Creek, Little Long Lake outflow, and Wintergreen Lake outflow) from early May to early October. Variables of particular interest for understanding the ecological status of the lakes are presented in the main body of this report for the past three years of GLQO monitoring. Longer-term time series of Gull Lake data are given in Appendix A for historical context. *These data will eventually be used in scientific publications, and therefore the authors of this report request that the data not be used or distributed beyond the local community without permission.*

Temperature, Dissolved Oxygen, and Transparency

Water temperature is an important variable that affects the strength and duration of summer stratification of the water column into a warmer upper layer (epilimnion) and a colder deeper layer (hypolimnion; Figure 4), and is an important driver of biological processes including plant and algal production. Warmer temperatures also tend to be associated with a greater abundance of *Microcystis* (Jeff White, unpublished data), an undesirable blue-green alga (cyanobacterium) found in both Gull and Little Long Lakes since the establishment of zebra mussels.

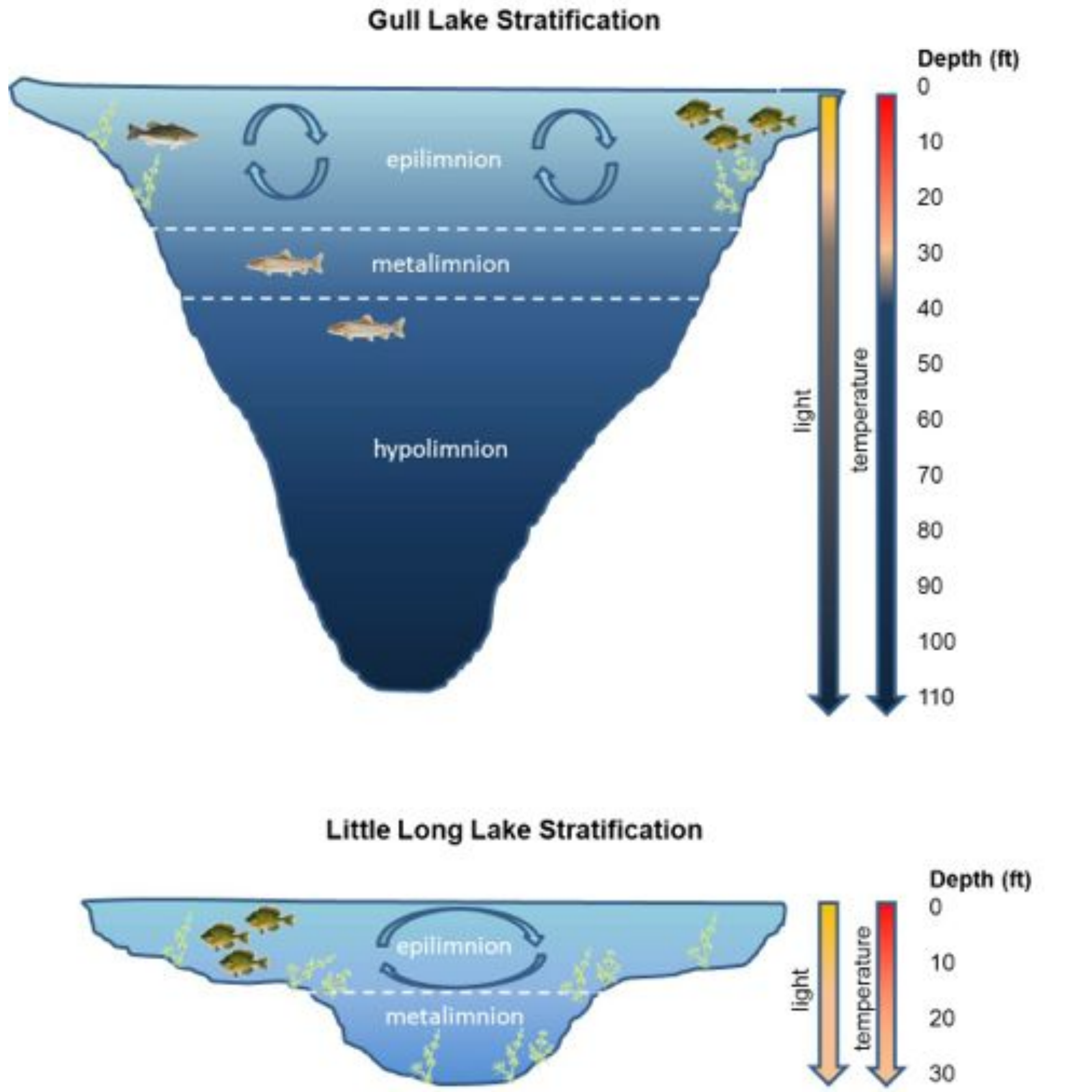

Fig. 4. *Schematic of mid-summer temperature stratification in Gull Lake (top) and Little Long Lake (bottom). Vertical arrows indicate gradients of temperature and light in the water column, with relatively higher values in yellow or red. Curved arrows in the epilimnion indicate wind-driven and convective water circulation (mixing).*

Temperature stratification was observed in Gull Lake for the duration of sampling in 2013. Compared to recent summers, the summer of 2013 was notably cooler and high water temperatures were of shorter duration (Figure 5). Gull Lake surface waters reached extremely high, sustained temperatures in the three summers prior to 2013, including a peak at 88.5°F in 2012 at a depth of 2 feet, as recorded by automatic temperature loggers hung in the water column taking readings every hour. Loggers this summer recorded a very brief temperature maximum of 87.6 °F on July 18th during a heat wave, though water temperatures quickly dropped back into the mid-70's with the return of milder weather. These recent data are put into context with the previous decade in Appendix A1.

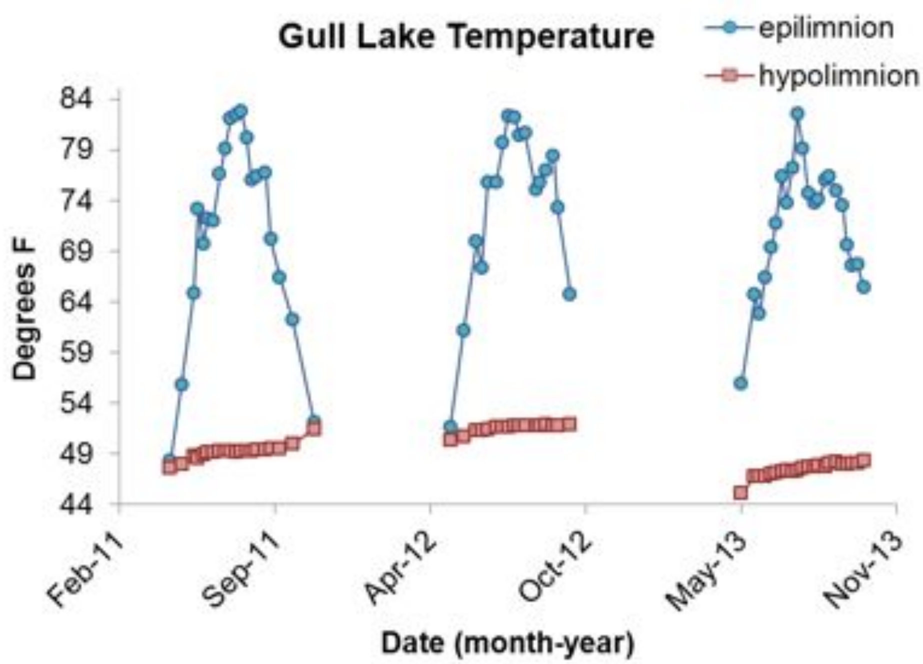

Fig. 5. *Gull Lake water temperature, 2011-2013. Measurements are shown from near-surface (epilimnion) and 66 feet (hypolimnion), well below the summer thermocline (metalimnion). For the complete, long-term dataset, see Appendix A1. Temperatures are similar at both depths when the water column is completely circulating (mixed).*

Little Long Lake was stratified during summer 2013 over the deepest basin until mid- September. Like Gull Lake, Little Long Lake briefly held its peak temperature during the July heat wave and generally remained in the mid to upper 70's during the summer months (Figure 6). For the first time, a continuous temperature logger was also deployed in Little Long Lake in 2013, at a depth of 6 feet. This logger recorded an absolute maximum temperature of 90.3°F in the afternoon of July 17th. It is very likely this temperature was exceeded during the hot summer of 2012, although previous temperature data were not collected frequently enough to capture such ephemeral extremes.

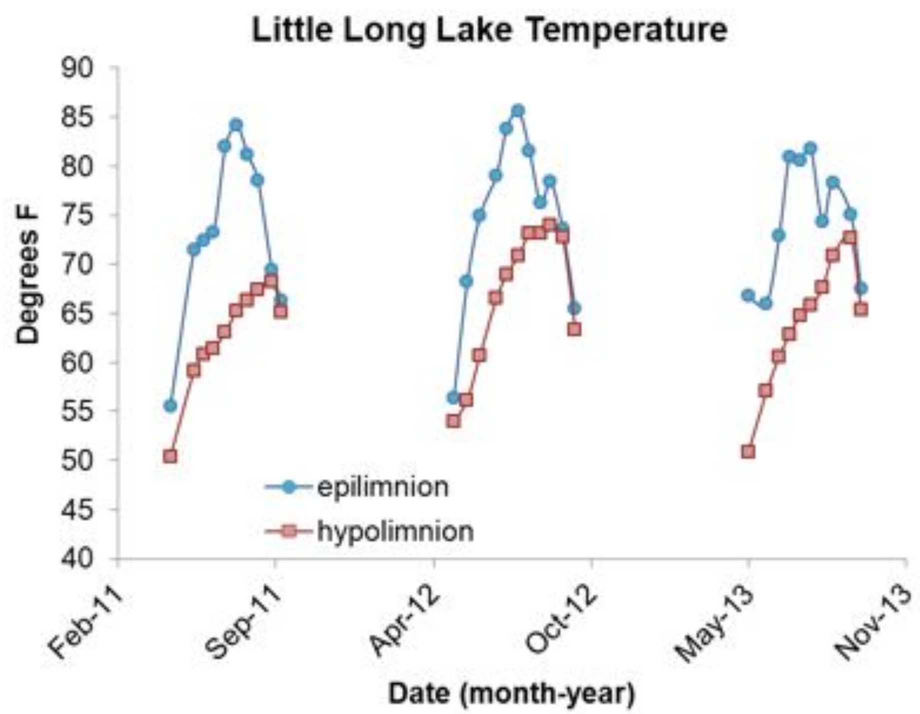

Fig. 6. *Little Long Lake water temperature, 2011- 2013, measured at 3 feet (epilimnion) and 23 feet (hypolimnion). Temperatures are similar at both depths when the water column is completely circulating (mixed).*

Dissolved oxygen in lake water reflects the net effect of biological activity (photosynthesis, which produces oxygen, and respiration, which consumes oxygen), and can become a limiting factor for aquatic life, especially fish, when its concentration falls below about 4 mg/L. Daytime oxygen concentrations in the surface waters are influenced by the rate of photosynthesis by suspended algae (phytoplankton) and aquatic plants.

Gull Lake oxygen levels in the epilimnion were within their typical range (at or near saturation) this year, as compared to last year, which saw more elevated concentrations (Figure 7). Oxygen concentrations in the deeper waters of Gull Lake (hypolimnion) decline progressively over the summer stratification period as bacteria decompose (respire) organic matter at depths that are too dark to support photosynthesis. Due to stratification, these deep waters are isolated from the atmosphere and the oxygenated upper waters, and so oxygen is not replenished here until the lake cools down and completely circulates ("mixes") in the fall. In all recent years where measurements were taken, including 2013, the very bottom waters of Gull Lake have gone anoxic—that is, oxygen was eventually fully depleted to 0 mg/L. Compared to previous summers, and in particular 2012, the onset of anoxia in the hypolimnion was later in 2013 and did not extend as far up into the water column off of the bottom (Figure 7). This is attributable to cooler water temperatures (Figure 5), which slow the rates of both organic matter production and bacterial respiration. Recent data, combined with data collected by KBS researchers in the late 1980s and early-mid 1990s, indicate that late-summer anoxia in the hypolimnion of Gull Lake is typical (see Appendix A2).

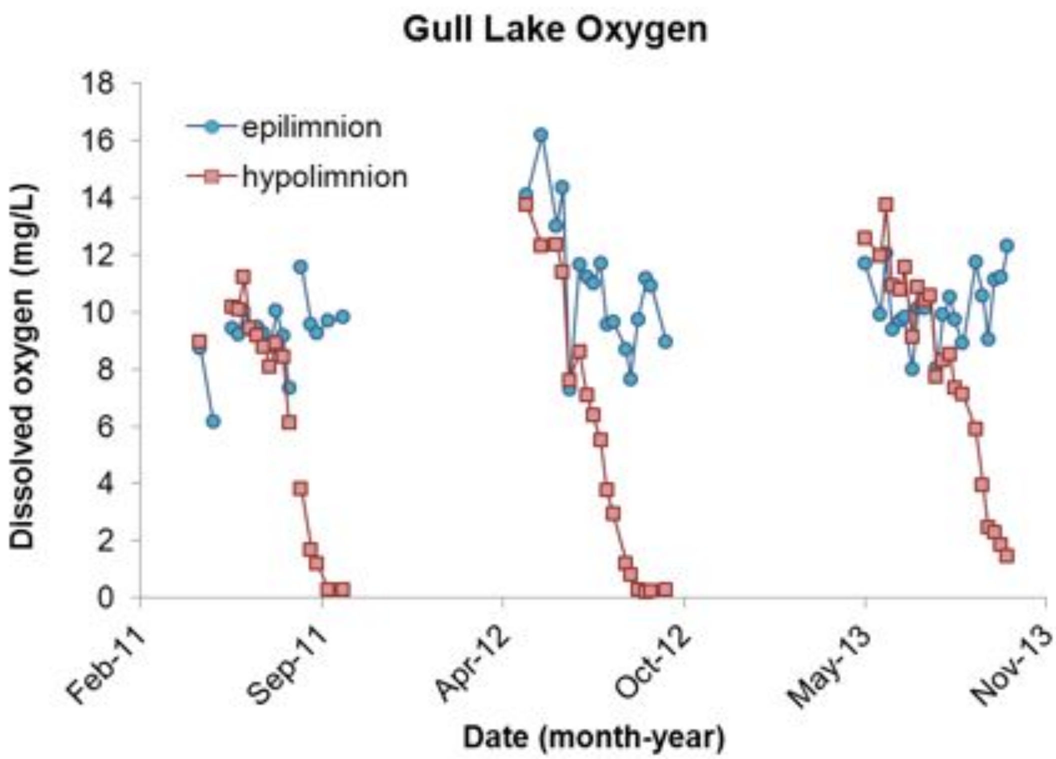

Fig. 7. *Gull Lake dissolved oxygen, 2011-2013. Measurements are shown from just below the water surface (epilimnion) and at a depth of 66 feet (hypolimnion), well below the summer thermocline (metalimnion). For the complete, long-term dataset, see Appendix A2.*

As was the case last year, oxygen levels in the hypolimnion of Little Long Lake (at a depth of 23 feet) tended to exceed levels in the surface waters for much of the summer, though concentrations were not as elevated in 2013 (Figure 8). Given the shallow depth of Little Long Lake, stratification tends to be less stable and sufficient light penetrates to the bottom of the entire lake basin to support the growth of plants. Thus, oxygen levels remain high in the deepest waters of Little Long Lake. Unlike in deeper Gull Lake, hypolimnetic anoxia has not been observed in Little Long Lake.

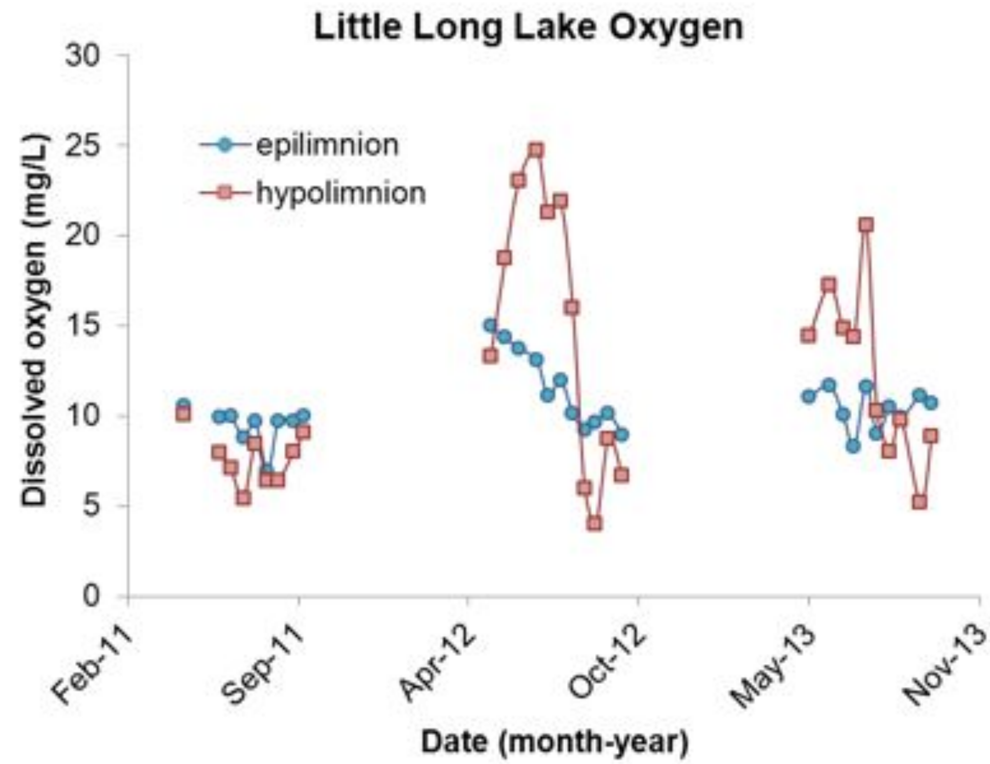

Fig. 8. *Little Long Lake dissolved oxygen, 2011-2013, measured at a depth of 3 feet (epilimnion) and at a depth of 23 feet (hypolimnion).*

Transparency (water clarity) is a function of the amount of living and non-living particulate material in the water column, though dissolved organic matter can be important as well (although not in these lakes). In Gull and Little Long Lakes, the major factors that reduce transparency are algae and a mineral known as calcium carbonate. Chalk is an example of calcium carbonate. Microscopic crystals of calcium carbonate form in the water column as a result of summer warming in combination with algal uptake of carbon dioxide during photosynthesis. When these crystals are very abundant, they impart a milky-turquoise color to the water referred to as a "whiting" event. These factors vary seasonally and tend to reduce transparency the most during mid to late summer. Transparency in lakes is measured by lowering a black-and-white Secchi disk into the water column and determining the depth at which it disappears from view.

Transparency of Gull Lake ranged from a maximum of 23.6 feet in May to a minimum of 7.5 feet in August (Figure 9), similar to previous years (1989-2013 average: 14.7 feet; see Appendix A3). Spring transparency was exceptional in Little Long Lake, with visibility extending to the lake bottom in May. Summer transparency was similar to previous years (Figure 10).

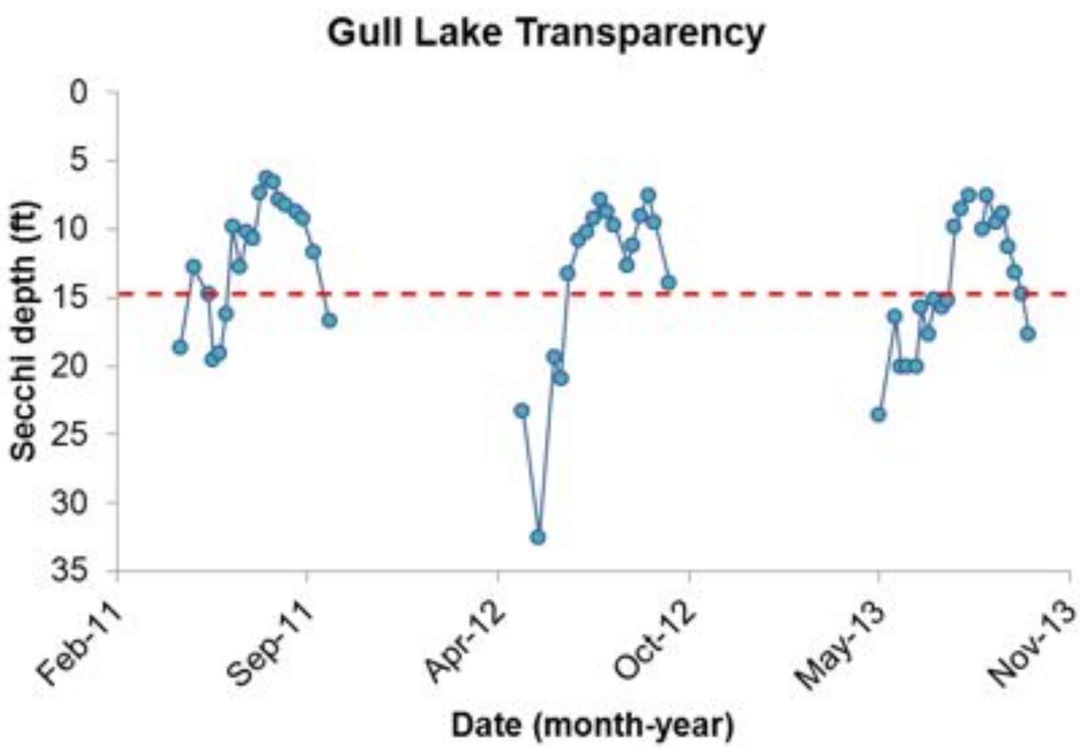

Fig. 9. *Gull Lake transparency, 2011-2013, measured with a Secchi disk. Note that the numbers on the y-axis are in reverse order, such that data points near the bottom of the graph indicate deeper visibility (clearer water). The dashed line indicates the overall, long-term (1989-2013) average. For the complete, long-term dataset, see Appendix A3.*

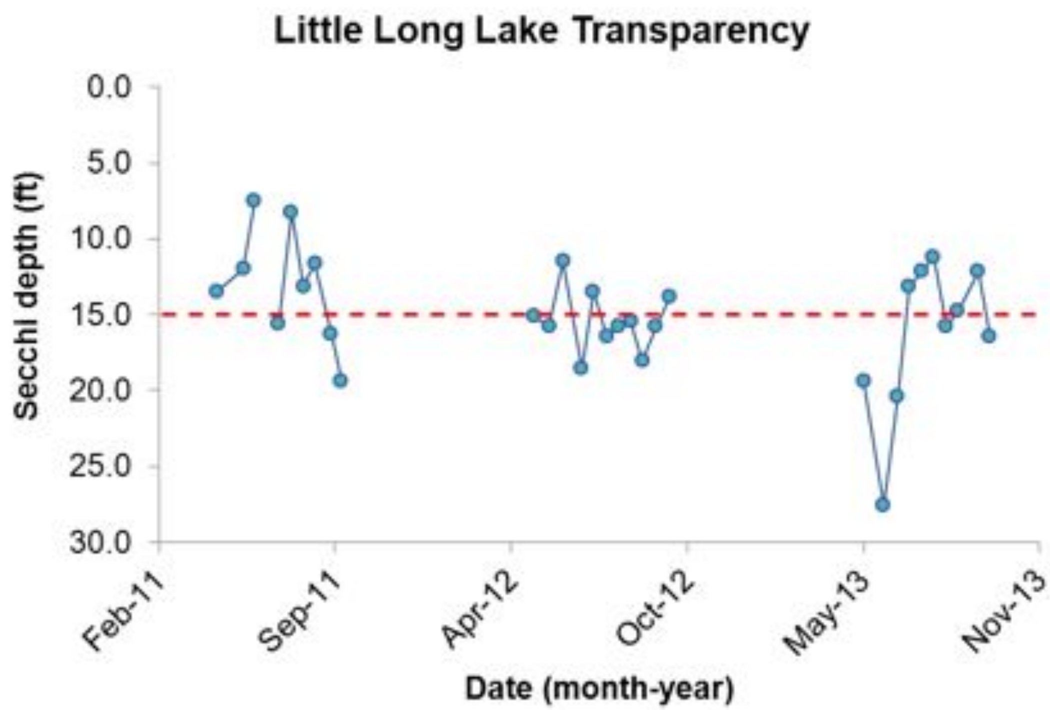

Fig. 10. *Little Long Lake transparency, 2011-2013, measured with a Secchi disk. Note that the numbers on the y-axis are in reverse order, such that data points near the bottom of the graph indicate deeper visibility (clearer water). The dashed line indicates the overall average.*

Nutrients

Total phosphorus is a useful indicator of the potential for undesirably high algal growth in Gull and Little Long lakes because it is the "limiting nutrient" in these waters. This means that algal (phytoplankton) growth in the water column responds rapidly to added phosphorus, because phosphorus occurs in very low concentrations in the lake water relative to both the biological demand and the availability of other nutrients, including nitrogen, which are relatively more abundant.

Total phosphorus concentrations in Gull Lake during summer 2013 were within their typical range (~2.8-10.4 ppb, Figure 11); the long-term (1994-

2013, Appendix A4) average is 7.7 ppb. These phosphorus concentrations indicate that the lake is oligotrophic, bordering on mesotrophic. These terms refer to the algal productivity expected in the open waters as a result of the nutrients available for growth (Figure 12). An oligotrophic to mesotrophic state is highly desirable for recreation and fishing: these lakes tend to support diverse fish communities without nuisance levels of algae, and thus tend to have clearer water. Less desirable from a water quality standpoint is the eutrophic state (highly productive), since eutrophic lakes tend to have high growth of algae. In particular, the undesirable cyanobacteria ("blue-green algae") tend to dominate in eutrophic lakes.

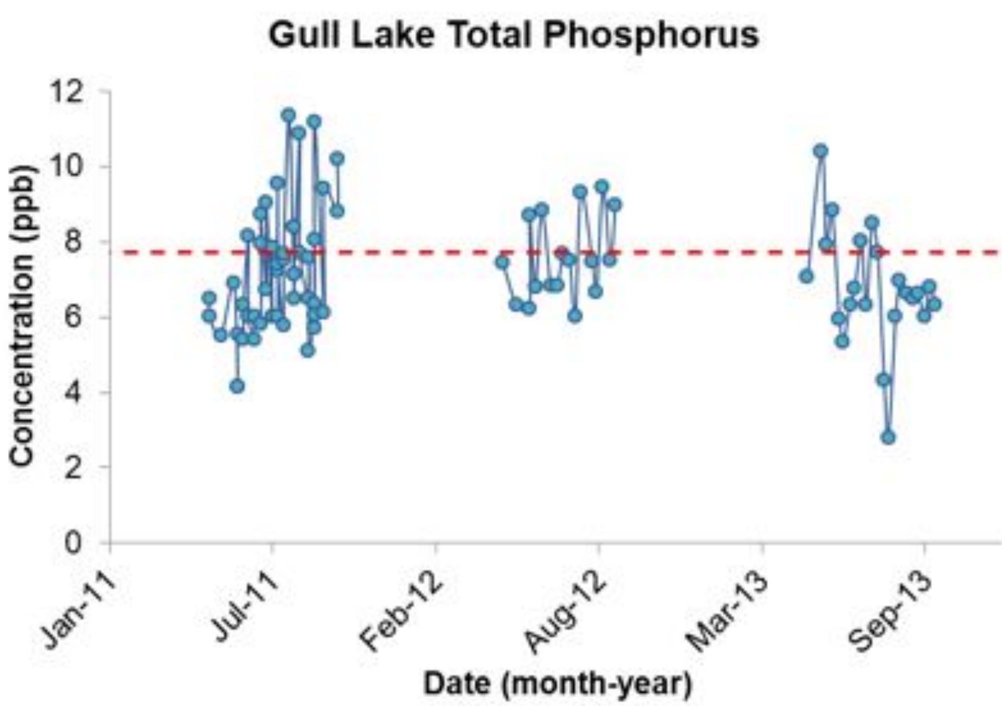

Fig. 11. *Total phosphorus concentrations in Gull Lake, 2011-2013. These measurements include phosphorus in algal biomass (phytoplankton). The dashed line indicates the overall, long-term (1994-2013) average. For the complete, long-term dataset, see Appendix A4.*

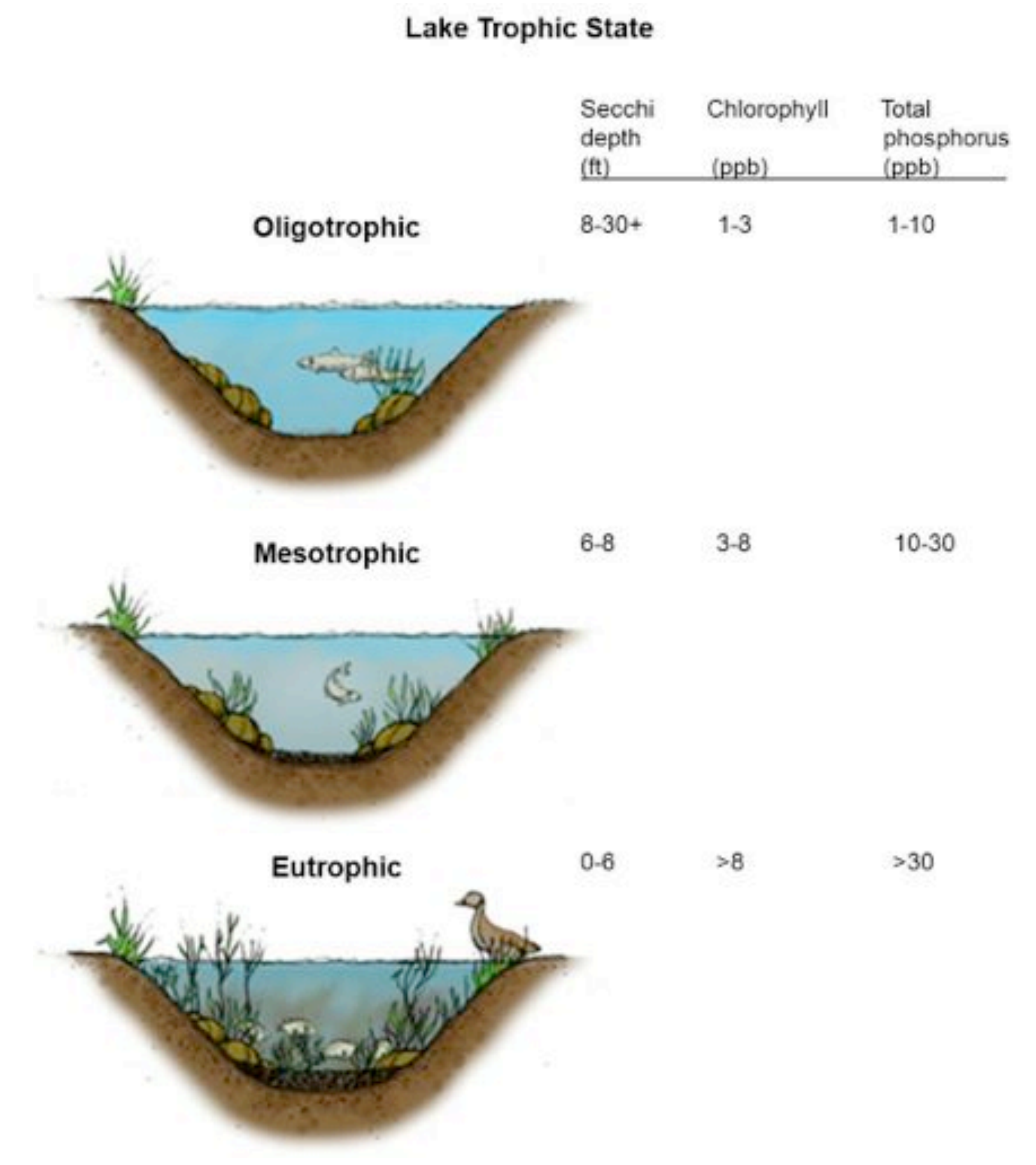

Fig.12. *Generic illustrations of lakes differing in productivity (trophic state), and characteristic ranges of key measured variables.*

No long-term trend in total phosphorus is evident for Gull Lake (Appendix A4), indicating that nutrient levels have been stable over time within the desirable range.

Phosphorus loading rates for the primary inflowing streams to Gull Lake are shown in Figure 13 (top panel). Loading refers to the rate at which nutrients enter the lake and is calculated as concentration (ppb = μg/L) times discharge (L/s). Note that the importance of these various inflows for phosphorus loading to Gull Lake is a function of both phosphorus concentrations in the stream water (middle panel) and stream discharge (i.e., the volume of inflowing water over time; bottom panel).

The outflowing water from eutrophic Wintergreen Lake, not surprisingly, has the highest phosphorus concentrations; however, it also has the smallest and most erratic discharge of the three primary inflows. During the driest period in mid-summer, it is not uncommon for there to be no flow out of Wintergreen Lake (and thus, no contribution of phosphorus to Gull Lake during that time). Prairieville Creek, on the other hand, has much lower phosphorus concentrations but continually delivers far more water to Gull Lake. The net effect is that, on an annual basis, the Wintergreen outflow and Prairieville Creek contribute similar amounts of phosphorus to Gull Lake over time (see the 1995 Gull Lake phosphorus budget depicted in Figure 3). Most of the Wintergreen Lake outflow occurs during the cool season, outside of the monitoring period in Figure 13; the lake is most sensitive to phosphorus inputs during the warm season.

Since the long-term phosphorus concentration of Gull Lake continues to remain stable, these loading rates do not exceed the lake's ability to buffer current additions of phosphorus. Of course, some level of nutrient input is desirable and indeed necessary for the healthy functioning of the lake ecosystem, as it forms the nutritional basis for the lake food web.

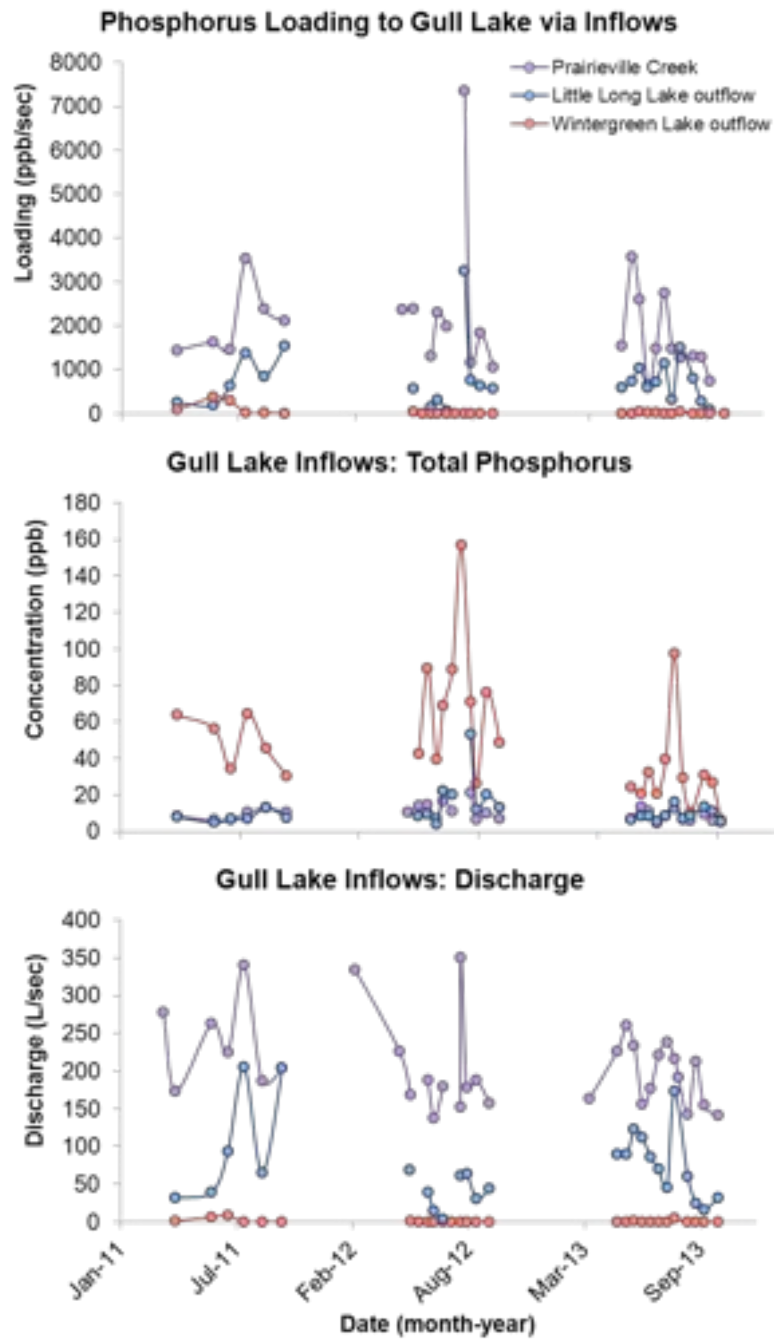

Fig. 13. *Phosphorus and flow dynamics of the three primary Gull Lake inflows, summers 2011-2013. Phosphorus loading (the rate at which phosphorus is carried into Gull Lake, top panel) is a function of both stream water phosphorus concentrations (middle panel) and stream discharge ("flow rate"; bottom panel).*

Total phosphorus data for Little Long Lake (2011-2013) are shown in Figure 14, and range from 4.4-11 ppb with an average of 7.8 ppb. These data indicate that Little Long Lake is oligotrophic. Some earlier total phosphorus data do exist for Little Long Lake; there is no evidence for major changes over time, although the information base is still limited.

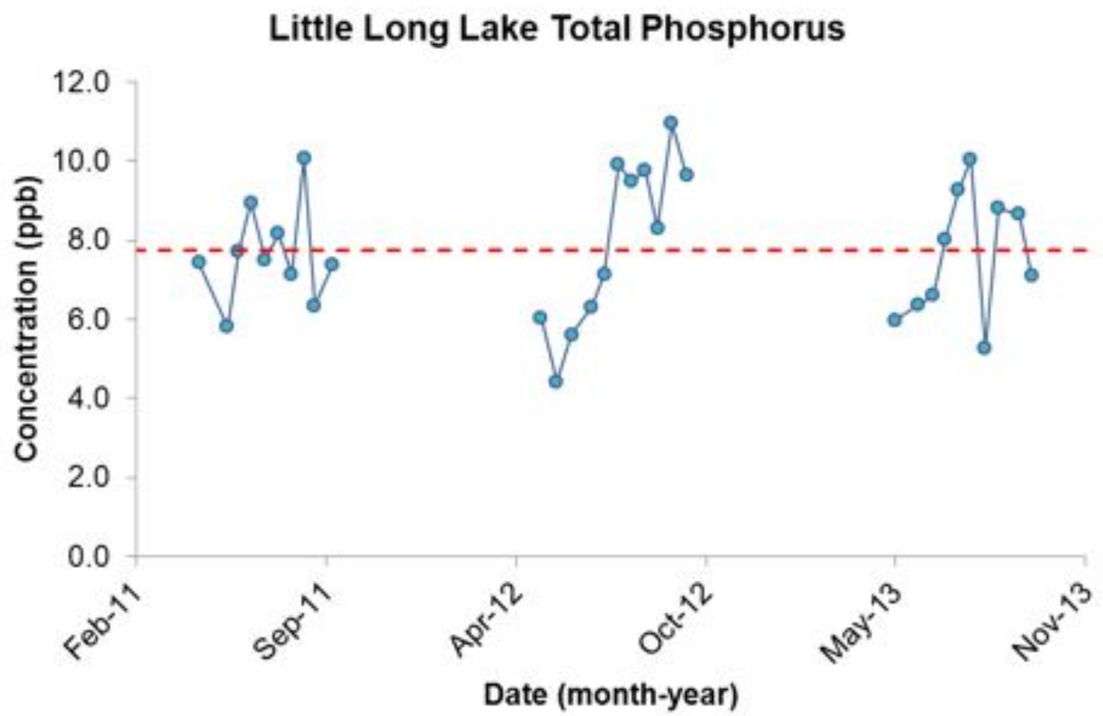

Fig. 14. *Total phosphorus concentrations in Little Long Lake, 2011-2013. These measurements include phosphorus in algal biomass (phytoplankton). The dashed line indicates the overall average.*

Algae

Algae are found in all natural waters and critically form the foundation of the aquatic food web (ultimately supporting fish). The amount of algae a lake supports is referred to as its productivity, and is tightly linked to nutrient concentrations and the lake's trophic state (Figure 12). As nutrient levels increase, a lake becomes more productive and will increasingly support nuisance levels of algae. The amount of algae in lake water can be gauged by measuring the concentration of the pigment chlorophyll-*a*, which functions in photosynthesis and gives algae their greenish color.

Chlorophyll concentrations show considerable year-to-year and within-year variation in Gull Lake (0.6-8.7 ppb, 1998-2013 average = 3.7 ppb; Figure 15 and Appendix A5). These concentrations span the productivity range from oligotrophic to mesotrophic. As is evident for 2013, algal abundance tends to be lower in cooler summers. The mass die-off of invasive zebra mussels (efficient “filterers” that consume algae) that occurred in Gull Lake in 2010, and the reduced numbers of live mussels in the shallow waters in the years since (see update later in this report), have not had a significant impact on either algal biomass (as measured by chlorophyll) or water clarity (see longer-term records in Appendix A). This is consistent with studies that show zebra mussels typically impact chlorophyll and water clarity only in shallow, well-circulated (mixed) lakes.

Little Long Lake chlorophyll concentrations in 2013 were similar to those observed previously (Figure 16). The range for the past three years is 2.1-8.1 ppb, with an average of 3.9 ppb. These values are comparable to earlier data, where they exist, and place Little Long Lake into the oligotrophic to mesotrophic state.

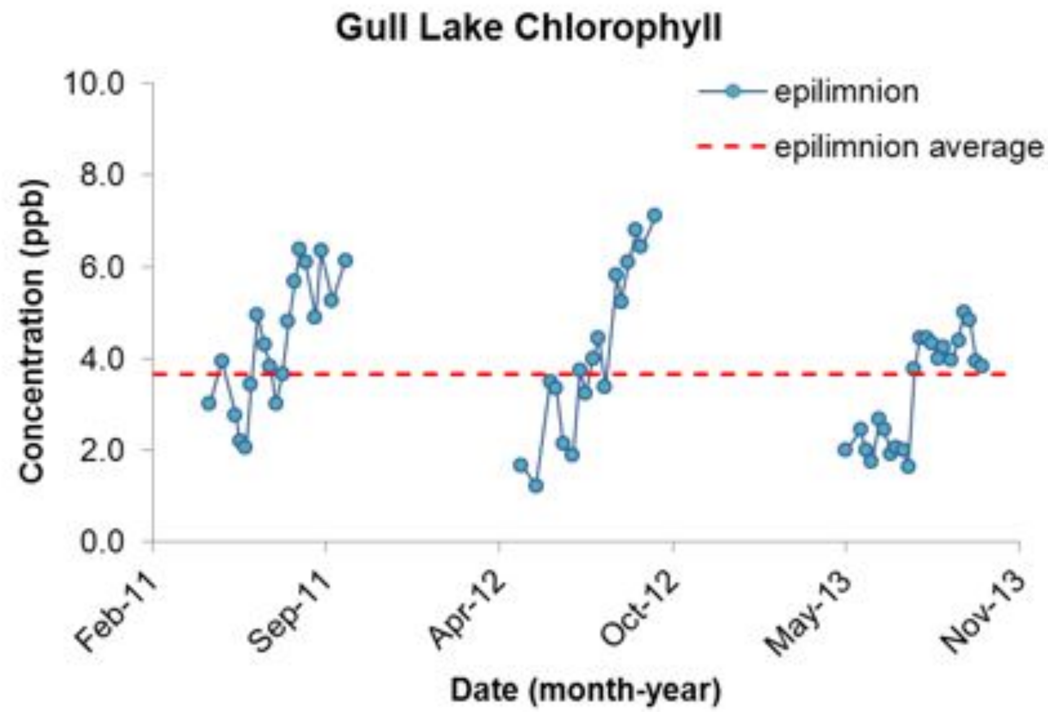

Fig. 15. *Chlorophyll-a concentrations (epilimnetic) in Gull Lake, 2011-2013. These measurements reflect the amount of algal biomass (phytoplankton). The dashed line indicates the overall average (1998-2013). For the complete, long-term dataset, see Appendix A5.*

Blue-green algae (cyanobacteria), some of which produce toxins, can be a public health concern when they are abundant. In Gull and Little Long Lakes, *Microcystis aeruginosa* is the only common toxic species; it produces the toxin microcystin. The dynamics of *Microcystis* and microcystin in Gull Lake are a focus of Jeff White's doctoral research.

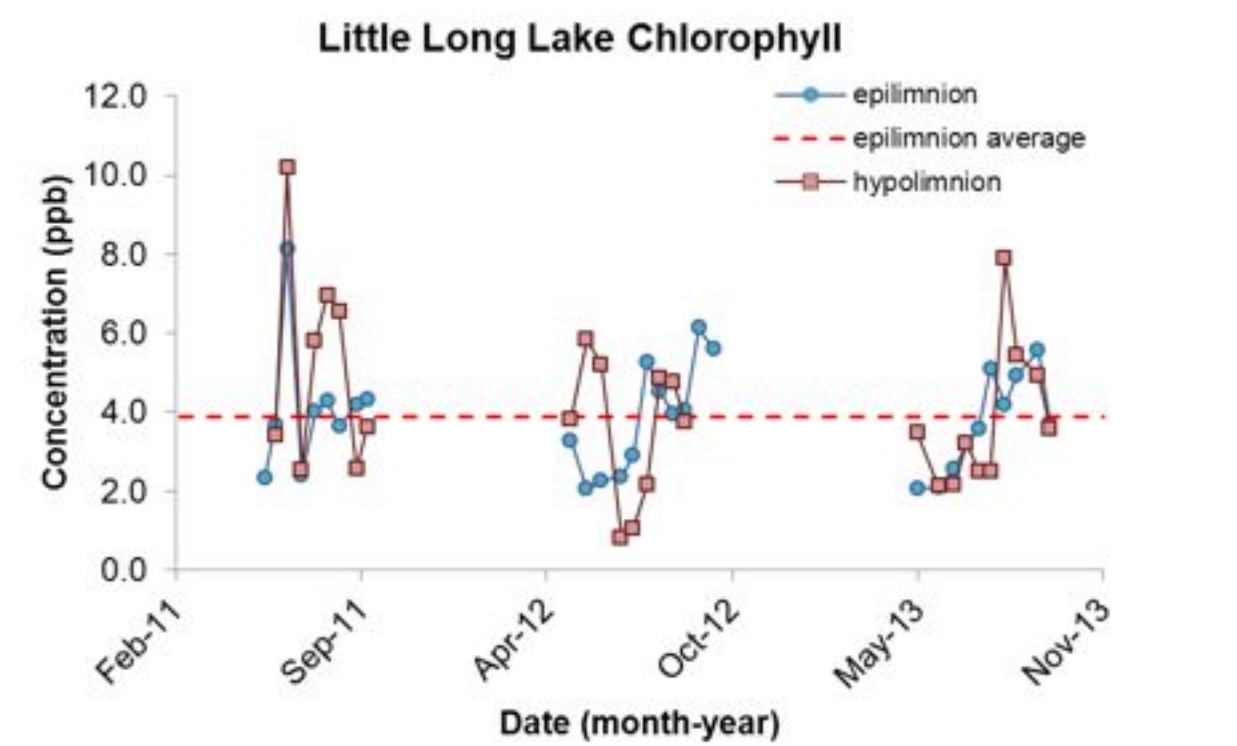

Fig. 16. *Chlorophyll-a concentrations in Little Long Lake, 2011-2013. These measurements reflect the amount of algal biomass (phytoplankton). The dashed line indicates the overall average.*

Microcystin is generally found in measurable concentrations (0.01-0.5 ppb) in the surface waters of Gull Lake during summer (Figure 17), and is proportional to the biomass of *Microcystis aeruginosa* (J. White, unpublished data). The World Health Organization (WHO) has developed exposure guidelines for microcystin of 1.0 ppb for drinking water and 20.0 ppb for recreational use (WHO 2003). Gull Lake surface-water concentrations are typically well below these guideline levels (Figure 17).

Microcystin concentrations in Gull Lake have been notably low (less than 0.1 ppb) since the summer of 2010, when the zebra mussel population died back substantially. Zebra mussels promote *Microcystis aeruginosa* (and associated microcystin) in high quality lakes like Gull Lake, where it wouldn't otherwise be common: *Microcystis* would typically be abundant only in eutrophic lakes with excessive phosphorus levels. Although *Microcystis aeruginosa* prefers high temperatures like those experienced in 2011-2012, its abundance was nonetheless low in Gull Lake while zebra mussels were essentially absent from the shallow waters. Zebra mussels successfully recolonized the shallow waters in the fall of 2012, however their densities have not returned to historical levels (pre 2010) as of the fall of 2013. This, in combination with cooler summer temperatures during the 2013 growing season, likely explains the low concentrations of microcystin observed in Gull Lake again during this past summer.

Little Long Lake, which also has zebra mussels and good water quality, would also be expected to have higher levels of microcystin and *Microcystis aeruginosa* compared to similar lakes without zebra mussels. However, the density of zebra mussels in Little Long Lake appears to be much lower than the former density of mussels in Gull Lake, perhaps due in part to the lack of suitable substrate for attachment (no recent die-offs have been observed there). Microcystin has only been measured in Little Long Lake from 2011-2013, though the range of concentrations observed has been similar to Gull Lake. Concentrations have generally been below 0.1 ppb, though a September peak of 0.2-0.3 ppb occurred in 2012 (Figure 18).

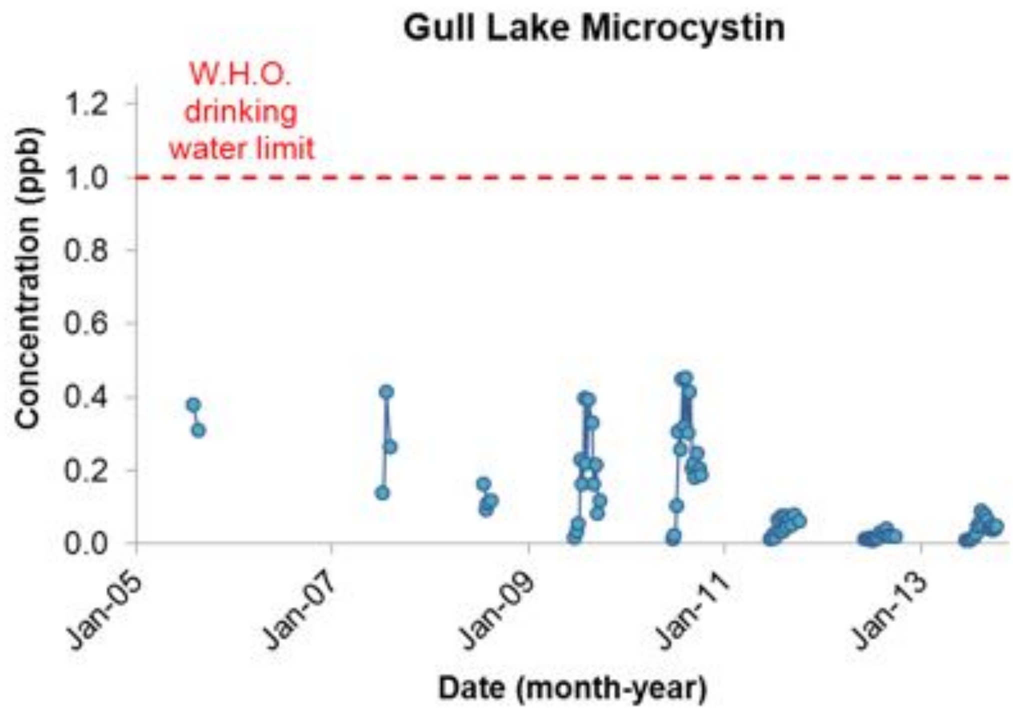

Fig. 17. *Microcystin, an algal toxin, in Gull Lake surface waters (2005-2013). These measurements are toxin collected on filters (i.e., contained in algal cells), whereas the World Health Organization limit for drinking water (1 ppb, red dashed line) is for the total microcystin concentration (i.e., includes dissolved toxin "leaked" from cells into the water). The dissolved fraction is probably small and perhaps only of consequence when blooms of* Microcystis *die back.*

Lake users should bear in mind that *Microcystis aeruginosa* tends to float up to and concentrate at the surface, in which case the toxin can accumulate to much higher levels than what is shown here (for the overall epilimnion). Therefore, people and pets should avoid ingesting water with visible algal blooms, which in the case of *Microcystis aeruginosa* often appear like pollen, yellow-green or blue-green in color.

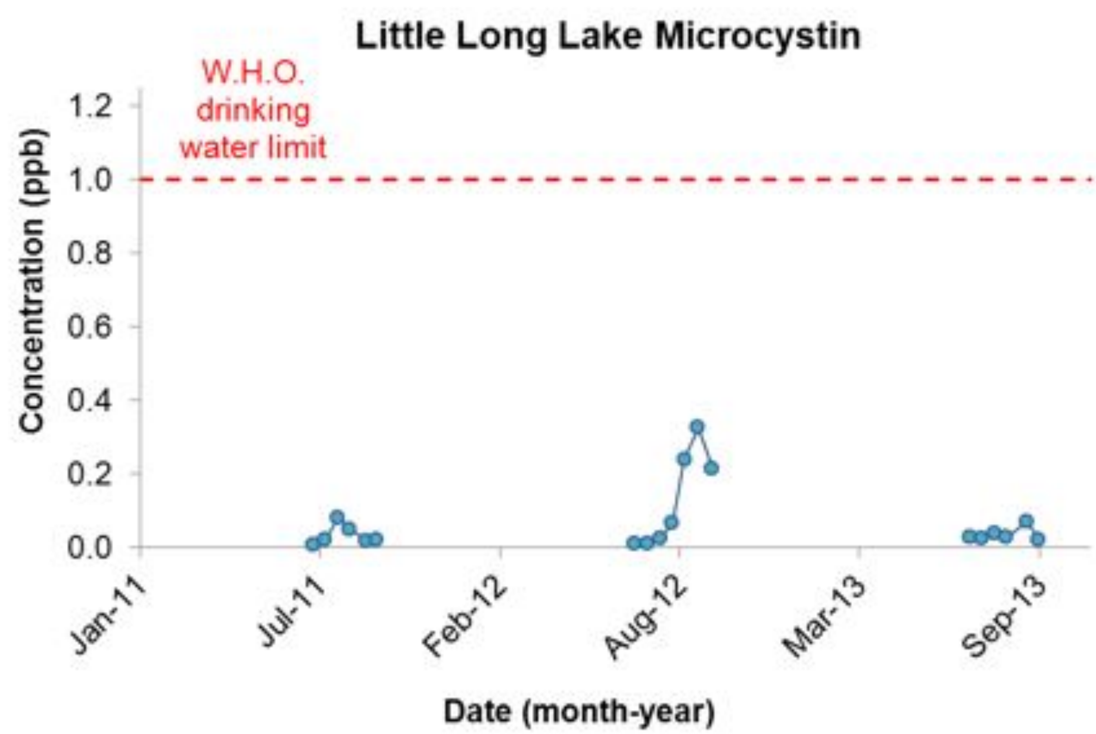

Fig. 18. *Microcystin, an algal toxin, in Little Long Lake surface waters (2011-2013). These measurements are toxin collected on filters (i.e., contained in algal cells), whereas the World Health Organization limit for drinking water (1 ppb, red dashed line) is for the total microcystin concentration (i.e., includes dissolved toxin "leaked" from cells into the water). The dissolved fraction is probably small and perhaps only of consequence when blooms of* Microcystis *die back.*

OTHER OBSERVATIONS

Invasive Plants in Gull and Little Long Lakes

Invasive aquatic and riparian plants pose a continuing challenge for management of lakes. Previous years' reports described the recent appearance and expansion of stands of the native sedge known as the jointed spikesedge (*Eleocharis equisetoides*) in Little Long Lake, particularly along its western edge, where the stands continued to expand from 2012 to

2013. In summer 2013 we surveyed the outer boundaries of the various stands of this plant using a GPS, which will facilitate future tracking of its expansion. Dr. Hamilton has confirmed the existence of this plant at two other local lakes (Deep and Otis Lakes in Barry County), which together with Little Long Lake have the only documented populations in southwest Michigan.

Invasive plants of particular concern in other area lakes include submersed vascular plants, particularly Eurasian Water Milfoil (*Myriophyllum spicatum*) and Carolina Fanwort (*Cabomba caroliniana*), with the latter having become troublesome in our area more recently. Both have been the target of aggressive control efforts in other local lakes, most often using herbicides. Gull and Little Long Lakes do not seem likely to be suitable habitat for dense growths of these two invaders, or else they would have become evident by now.

In summer 2012 the GLQO was alerted by a local environmental consulting firm (Kieser & Associates) to the possible presence in Gull Lake of another notorious invasive plant known as starry stonewort (*Nitellopsis obtusa*). This plant is actually a macroalga related to two common native genera in local waters, *Chara* (also called stonewort, or muskgrass) and *Nitella*. Starry stonewort has caused serious problems in Michigan lakes because of the dense mats it forms in shallow waters and its tendency to outgrow and displace native plants.

GLQO member Mike Gallagher and Dr. Hamilton searched for this plant in Gull Lake in the locations where it was reportedly seen, as well as other locations, and samples were sent to an expert on classification of these plants (Dr. Kenneth Karol of the New York Botanical Garden). Our samples turned out to be native species of *Chara* and *Nitella*; we did not confirm the presence of starry stonewort in Gull Lake, although without a more thorough survey we cannot rule out its existence in Gull Lake.

Fig. 19. *Starry stonewort, an invasive plant that has possibly colonized local lakes. A. Closeup of the plant with its diagnostic star-shaped structures ("bulbils"); B. Starry stonewort (right hand) compared with native* Chara*; C. Beds of starry stonewort (identity to be confirmed) in canals at Gun Lake; D. A similar species (*Nitella*) from 30 feet deep in Gull Lake. Photos A-C courtesy of Pam Tyning and Paul Hausler of Progressive AE.*

Two local lakes similar to Gull Lake that evidently have starry stonewort populations are Gun and Upper Crooked Lakes. Dr. Karol has confirmed the identification of starry stonewort in Upper Crooked Lake. There are thought to be populations in Goguac Lake and Payne Lake, as well as a number of lakes south of Kalamazoo.

Starry stonewort can be difficult to identify, so samples from any local lakes should be sent to Dr. Hamilton, who will consult Dr. Karol if needed. The photos in Figure 19 show what to look for. Samples are best kept refrigerated in water; freezing or drying damages them. The spread of this plant is most likely to occur via fragments carried on or in boats, and in recreational equipment. Lake users must be vigilant about cleaning all traces of vegetation before moving between lakes, and not to transfer water and organisms from lake to lake via boats, bait buckets, aquaria, etc.

Surveying Aquatic Plants in Gull and Little Long Lakes

In summer 2013 GLQO member Mike Gallagher surveyed aquatic plant communities along transects distributed throughout the shallow waters of Gull Lake, assisted by Jodie McManus, a Parchment High School science teacher funded by a Research Experience for Teachers grant from the National Science Foundation to KBS, and advised by Dr. Hamilton. Surveys were conducted following CLMP protocols, and the transects were located from aerial photos. Plants were identified with assistance from Dr. Hamilton, Dr. Jo Latimore of MSU, and Dr. Ryan Thum of Grand Valley State University (the latter an expert on water milfoils). Some invasive species were detected, but none appear to pose serious threats at the present time. This is a valuable dataset that will enable future detection of significant changes in aquatic plant cover and species composition in repeat surveys.

Vegetation in Little Long Lake was surveyed on August 17, 2013 by GLQO members Susan Houseman and Gary Mittelbach, along with MSU graduate student Angela DePalma-Dow. Angela is an expert on invasive aquatic species in Michigan and helps coordinate the CLMP exotic aquatic plant watch program (EAPW). The goals of this program are to train and use volunteers in the early detection of troublesome exotic aquatic plants. The survey of Little Long Lake found none of the truly worrisome invasive species common to some Michigan lakes, which is very good news. However, one plant species detected in Little Long Lake, spiny naiad (*Najas marina*, a small, low-growing species), bears watching, as it seems to be spreading and it is difficult to distinguish the native and non-native varieties of the genus *Najas*. We are also monitoring the spread of jointed spikesedge in Little Long Lake (as noted above).

Status of Zebra Mussels in Gull Lake

The zebra mussels is a prolific aquatic invasive species that arrived to the Great Lakes in the 1980s from Eurasia. Like many other large, publicly accessible lakes in Michigan, Gull Lake was soon infested (1994). The Gull Lake population remained rather stable for 16 years. However, Gull Lake experienced an unprecedented, near-complete die-off of its population of zebra mussels down to about 20 feet deep (within the epilimnion) in early August of 2010 (Figure 20). Mussels in deeper water survived and appeared healthy. Mussels failed to re-establish in the shallow waters during 2011, and healthy juvenile mussels were not observed at this depth again until September of 2012. Those juvenile mussels largely persisted through the winter and, for the first time since the die-off, Gull Lake had live zebra mussels in the epilimnion during the entire stratified season in 2013. Juvenile mussels are currently most abundant at 10-20 feet deep, where they can be found attached to submerged plants. Densities are still low in shallower water, compared to pre-2010, with most rocks only having 1-2 individual mussels attached (Figure 21).

After the die-off occurred in 2010, MSU/KBS researchers began to explore the possible cause(s). Temperature was suspected because record-high shallow-water temperatures (>85 °F) occurred during this period, while mussels survived in deeper, cooler water below the thermocline. During the springs of 2011-2013, mussels were harvested from the deeper, surviving population and stocked into cages at three different depths (6, 16, and 30 feet) selected because they differ greatly in temperature regime, and span the range of depths where mussels are found. The goal was to monitor how the death rate and condition of zebra mussels varied as a function of these different temperature regimes throughout the summer. Temperatures at each depth were logged hourly by sensors.

Fig. 20. *Empty shells of recently expired zebra mussels litter the bottom of Gull Lake (left), and dead mussels recovered from about 8 feet deep (right), following the 2010 die-off. (Photos by Jeffrey White [left] and Stephen Hamilton [right])*

Mussel mortality (death) rates were very high within the shallow cages in 2011-2012. During the relatively cool summer of 2013 (as compared to 2011-2012), mortality of mussels was far lower. In all years, mortality was always minimal in the deepest cages where temperatures are much cooler and more constant. Thus, results obtained to date from the study of caged mussels in Gull Lake are consistent with the temperature-driven mortality hypothesis. In particular, the duration of time spent above a certain threshold temperature seems to play a more important role than the absolute maximum temperature the water reached in any given year.

Fig. 21. *Recently colonized, healthy zebra mussels were observed in the shallows of Gull Lake again throughout the entire 2013 ice-free season, though their densities remain low. (Photo by Jeffrey White)*

Recently, information regarding the status of zebra mussels in lakes statewide was solicited by Dr. Hamilton via electronic survey of MiCorps and MLSA members. To date, reports from 39 different lakes across the entire Lower Peninsula have been received. In 32 (82%) of the cases, the population density of zebra mussels was reported to have visibly declined over the last 2-3 years—the same general time frame as in Gull Lake. Often zebra mussel densities stabilize at lower levels following initially explosive growth upon first establishment. It remains to be seen whether the recent changes in mussel density observed across Michigan inland lakes, including Gull Lake, will be temporary or are indicative of a new "balance."

Gull Lake Ice Cover

Over the past century, the duration of ice cover has been decreasing for many inland lakes throughout the Northern Hemisphere, and this reflects a warming climate. The Gull Lake ice record (Figure 22), maintained since 1924, also exhibits this long-term decrease. The declining trend for the entire time series is statistically significant, following the winter of 2011-2012 in which the lake froze for a mere 5 days.

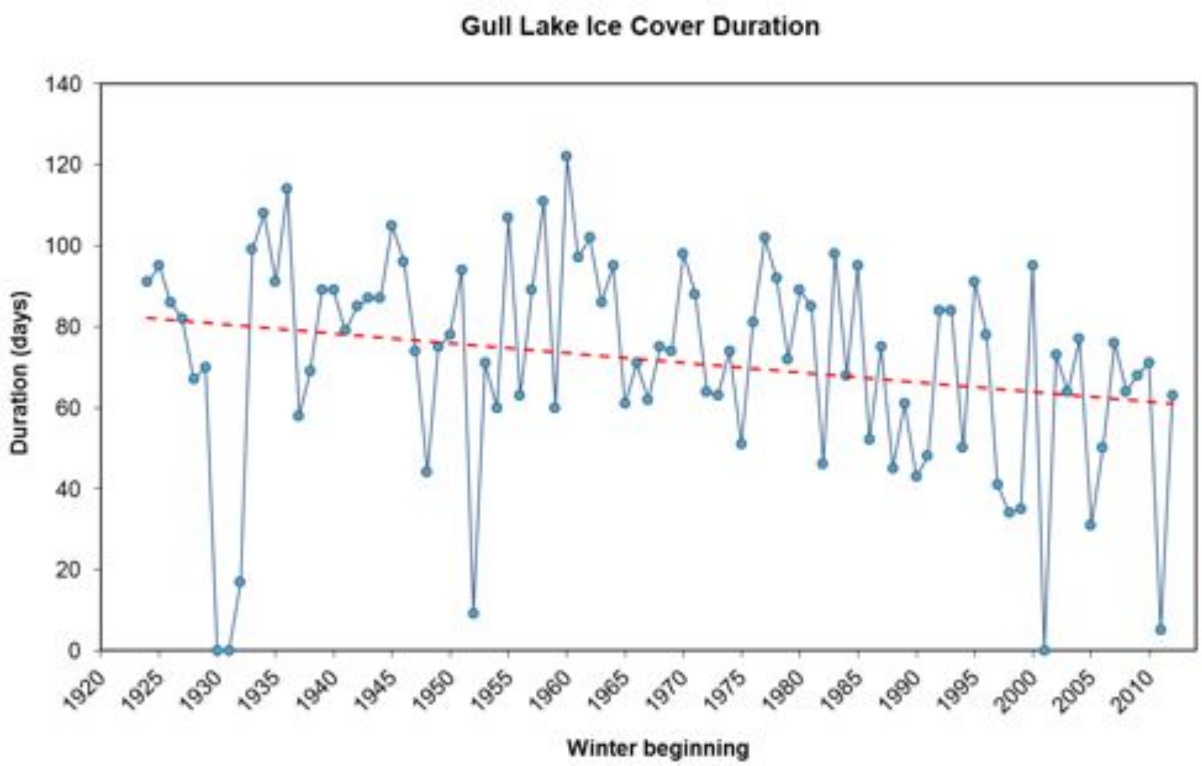

Fig. 22. *Duration of ice cover on Gull Lake since the winter of 1924-25. Data were collected by the GLQO and its predecessor organizations, and by Dr. Hamilton since 1995. The red trend line was estimated by linear regression, and represents a statistically significant decline in ice cover duration over the period of observation. The x-axis labels represent the year beginning each winter (e.g., 1975 = winter of 1975-76).*

The trend in diminishing ice cover duration on Gull Lake is actually a result of both later freeze dates *and* earlier thaw dates (Figure 23). The ecological implications of diminished ice cover duration are a current topic of discussion in the scientific literature.

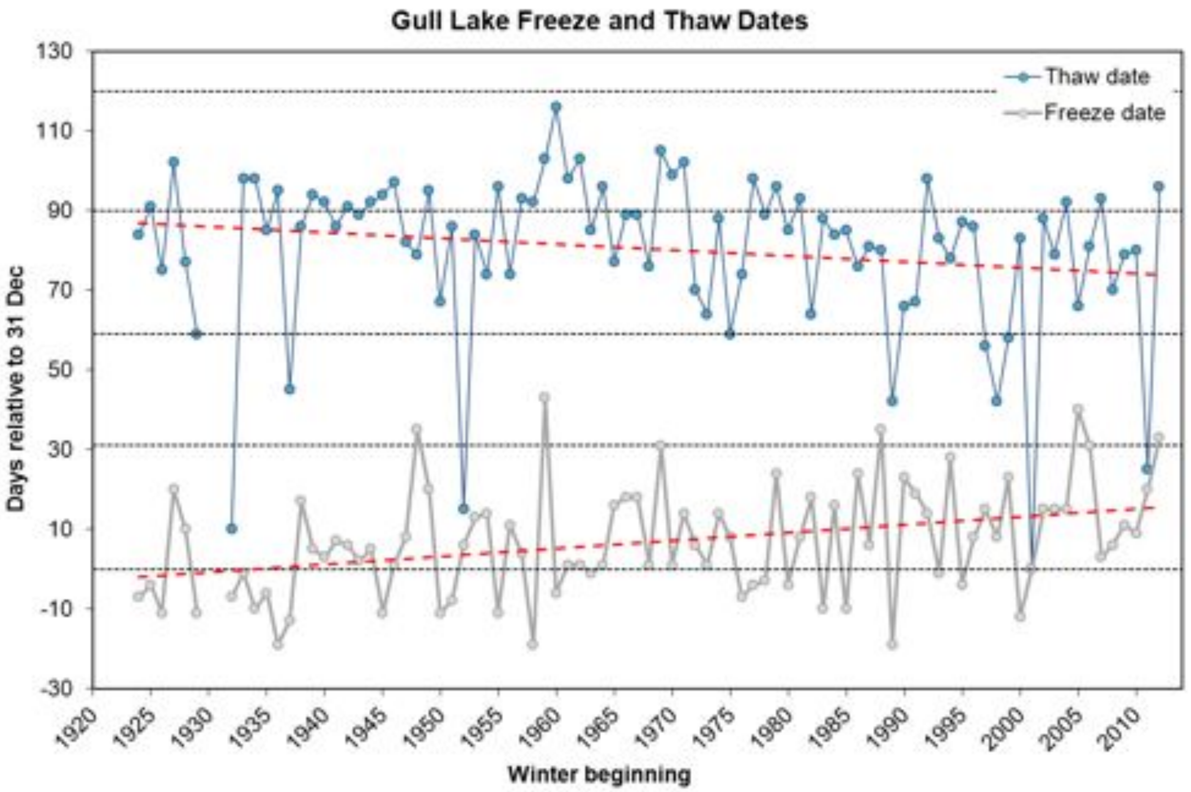

Fig. 23. *Trends in the freeze and thaw dates of ice on Gull Lake since the winter of 1924-25. Data were collected by the GLQO and its predecessor organizations, and by Dr. Hamilton since 1995. The overall trend is toward both later freeze dates and earlier thaw dates. The x-axis labels represent the year beginning each winter (e.g., 1975 = winter 1975-76).*

SUMMARY

Overall, water quality is excellent in Gull and Little Long Lakes, with the observed ranges of critical variables (total phosphorus, transparency, and chlorophyll) placing the lakes within the highly desirable oligotrophic - mesotrophic range. There is no evidence for systematic changes in those critical variables over the past 1-2 decades in Gull Lake.

Temperatures were cooler, on average, during the 2013 season as compared to other recent summers. Thus, conditions in the lakes this year contrasted somewhat with last year, particularly with respect to the lower rate of primary production (as assessed from dissolved oxygen concentrations) and lower rate of bacterial decomposition of organic matter (as assessed from the extent and rate of oxygen depletion in the hypolimnion of Gull Lake) in summer 2013.

Zebra mussels have recolonized the shallow waters of Gull Lake since a mass die-off occurred in 2010, though their densities remain low. The population rebound, and limited mortality observed in cages deployed in the lake in 2013, may reflect more favorable temperature conditions during 2013. Zebra mussel densities in Little Long Lake appeared to have increased from last year as well. Gull Lake is one of many lakes across the state to have experienced recent declines in zebra mussels.

The algal toxin microcystin, produced by the cyanobacterium ("blue-green alga") *Microcystis,* was detected at low concentrations again in Gull Lake as compared to past years. Concentrations may have been low in recent years due to the decline in zebra mussels (which promote *Microcystis* in Gull Lake). The combination of cooler temperatures and low mussel density in 2013 likely both account for the low microcystin concentrations measured this season.

An analysis of discharge ("flow rate") and phosphorus concentrations in the three primary inflowing streams to Gull Lake indicates that the Wintergreen Lake outflow, though phosphorus -rich, makes a relatively small contribution to the total amount of phosphorus entering Gull Lake during the summer (due to its low flow rate). It is important to note that these dynamics are seasonally variable, so these are rough estimates given that monitoring data are largely restricted to the summer months. A 1995 study of the phosphorus budget of Gull Lake found that, on an annual basis, the amount of phosphorus entering Gull Lake from Prairieville Creek and Wintergreen Lake were similar. There has been no change in the long-term average total phosphorus concentration observed in Gull Lake.

ACKNOWLEDGEMENTS

We are grateful to the Gull Lake Quality Organization for supporting the stream sampling since 2005 and the lake sampling since 2011. Many people contributed to the collection of data depicted in this report from before 2011, including faculty, graduate students, and technicians at KBS and MSU, with funding provided by the Michigan Sea Grant, the U.S. Environmental Protection Agency, the National Science Foundation (Long-term Ecological Research program), and the Kalamazoo Community Foundation. David Weed in the Hamilton Lab performed the chemical analyses on water samples. Assistance to Jeff with sampling was provided by Carrie Kozel in 2011, Theresa Geelhoed in 2012, and Theresa Geelhoed and Shelby Flemming in 2013, providing MSU Fisheries and Wildlife undergraduate students with hands-on training and experience. Dr. Gary Mittelbach of KBS and Dr. Orlando Sarnelle of MSU provided feedback.

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APPENDIX A: LONGER-TERM DATA FOR GULL LAKE

Selected variables are depicted here for the past two decades of observations on Gull Lake (where available) to provide historical context for more recent observations, and a sense for the typical extent of year-to-year and within-year variation.

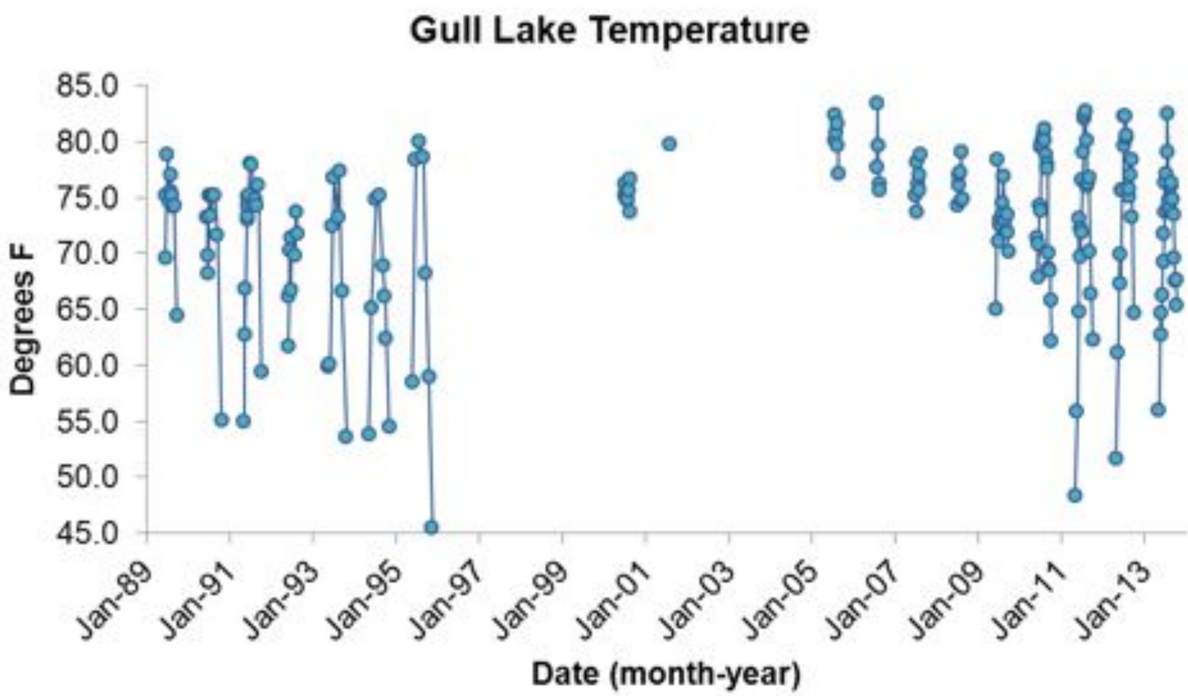


Fig. A1. *Gull Lake water temperature, 1989-2013, measured just below the water surface (epilimnion). Note that the period of sampling differs among years: though colder temperatures were not measured in all years, the warmest period was probably observed in most years. Data from 1989-1995 are from research by Dr. Alan Tessier and his graduate students at KBS. Data from 2000-2010 are from research by Drs. Orlando Sarnelle and Stephen Hamilton and their graduate students at MSU/KBS.*

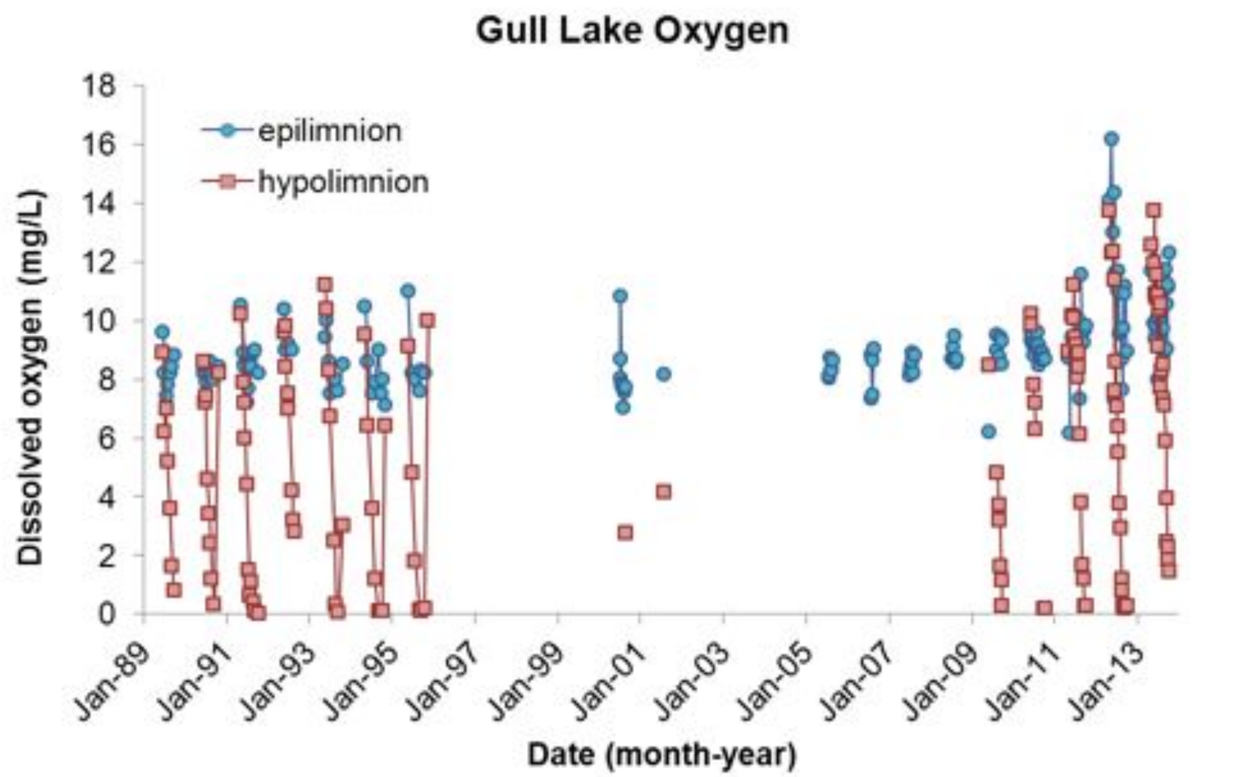


Fig. A2. *Gull Lake dissolved oxygen, 1989-2013. Measurements are shown from just below the water surface (epilimnion) and at a depth of 66 feet (hypolimnion), well below the summer thermocline (metalimnion). Data from 1989-1995 are from research by Dr. Alan Tessier and his graduate students at KBS. Data from 2000-2010 are from research by Drs. Orlando Sarnelle and Stephen Hamilton and their graduate students at MSU/KBS.*

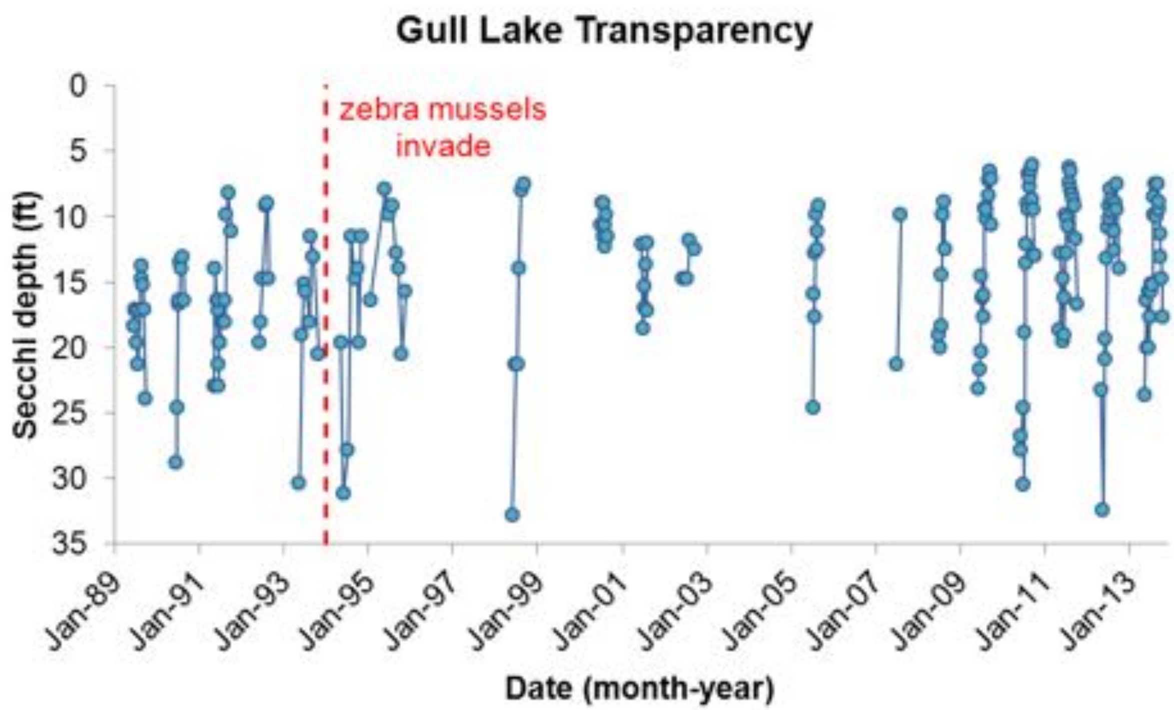


Fig. A3. *Gull Lake transparency, 1989-2013, measured with a Secchi disk. The vertical dashed line indicates when zebra mussels were first discovered in Gull Lake. Note that the numbers on the y-axis are in reverse order, such that data points near the bottom of the graph indicate deeper visibility (clearer water). Data from 1989-1995 are from research by Dr. Alan Tessier and his graduate students at KBS. Data from 1998-2010 are from research by Drs. Orlando Sarnelle and Stephen Hamilton and their graduate students at MSU/KBS.*

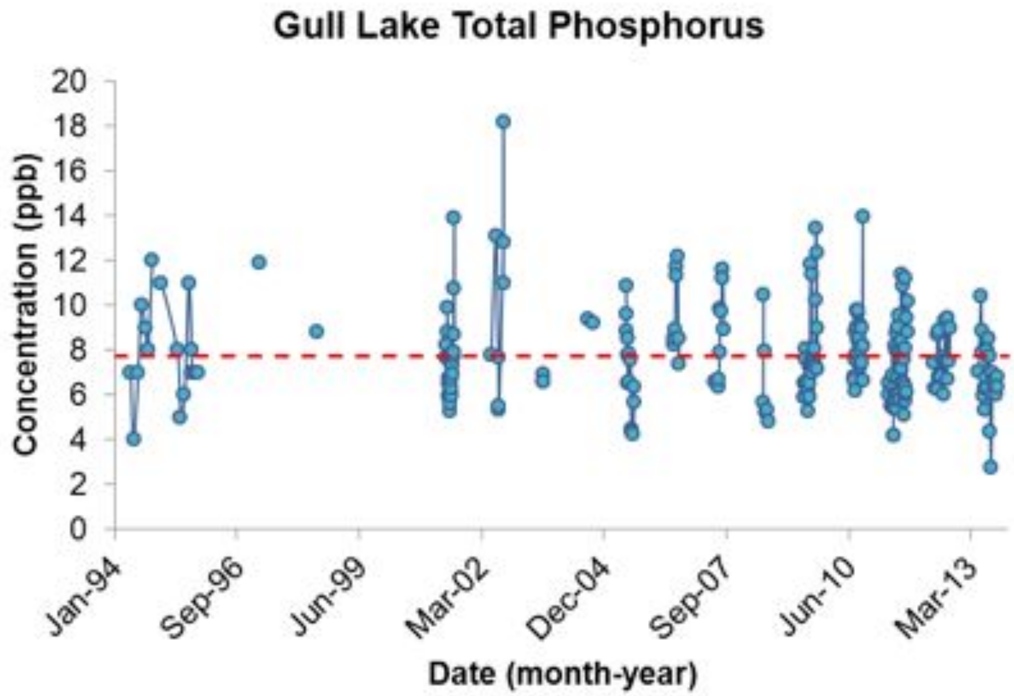


Fig. A4. *Total phosphorus concentrations in Gull Lake, 1994-2013. These measurements include phosphorus in algal biomass (phytoplankton). The dashed line indicates the overall, long-term (1994-2013) average. Data from 1994-1995 are from research by Dr. Alan Tessier and his graduate students at KBS. Data from 1997-2010 are from research by Drs. Orlando Sarnelle and Stephen Hamilton and their graduate students at MSU/KBS.*

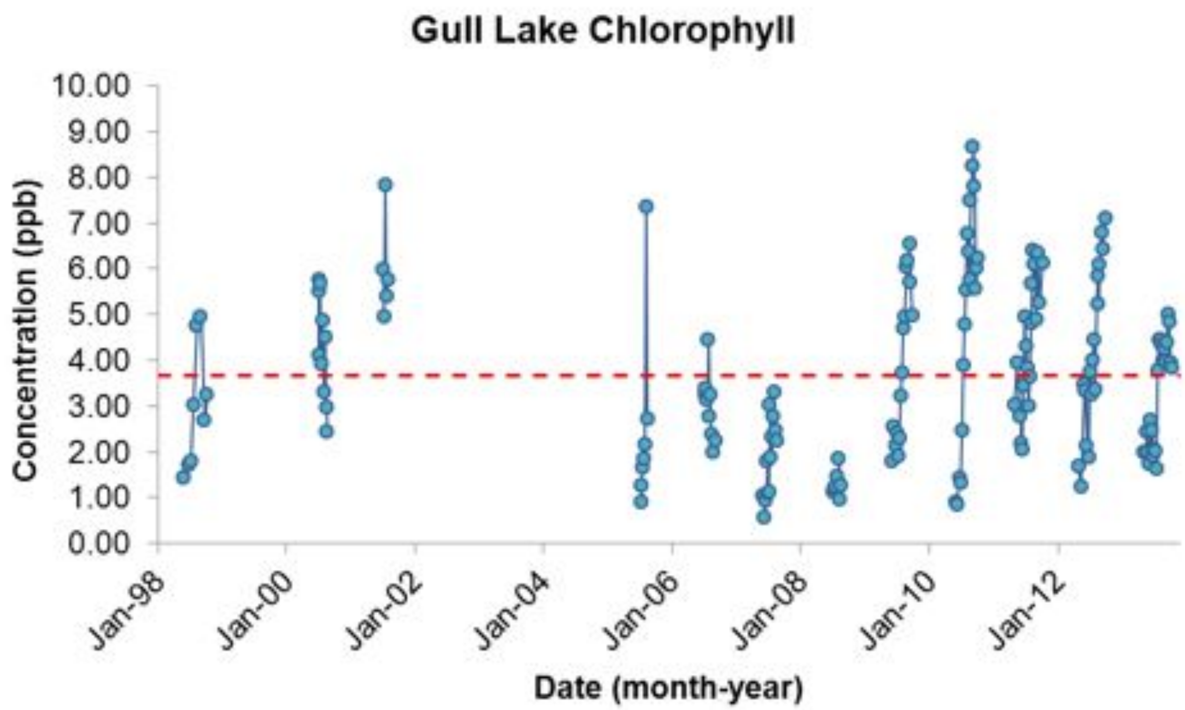
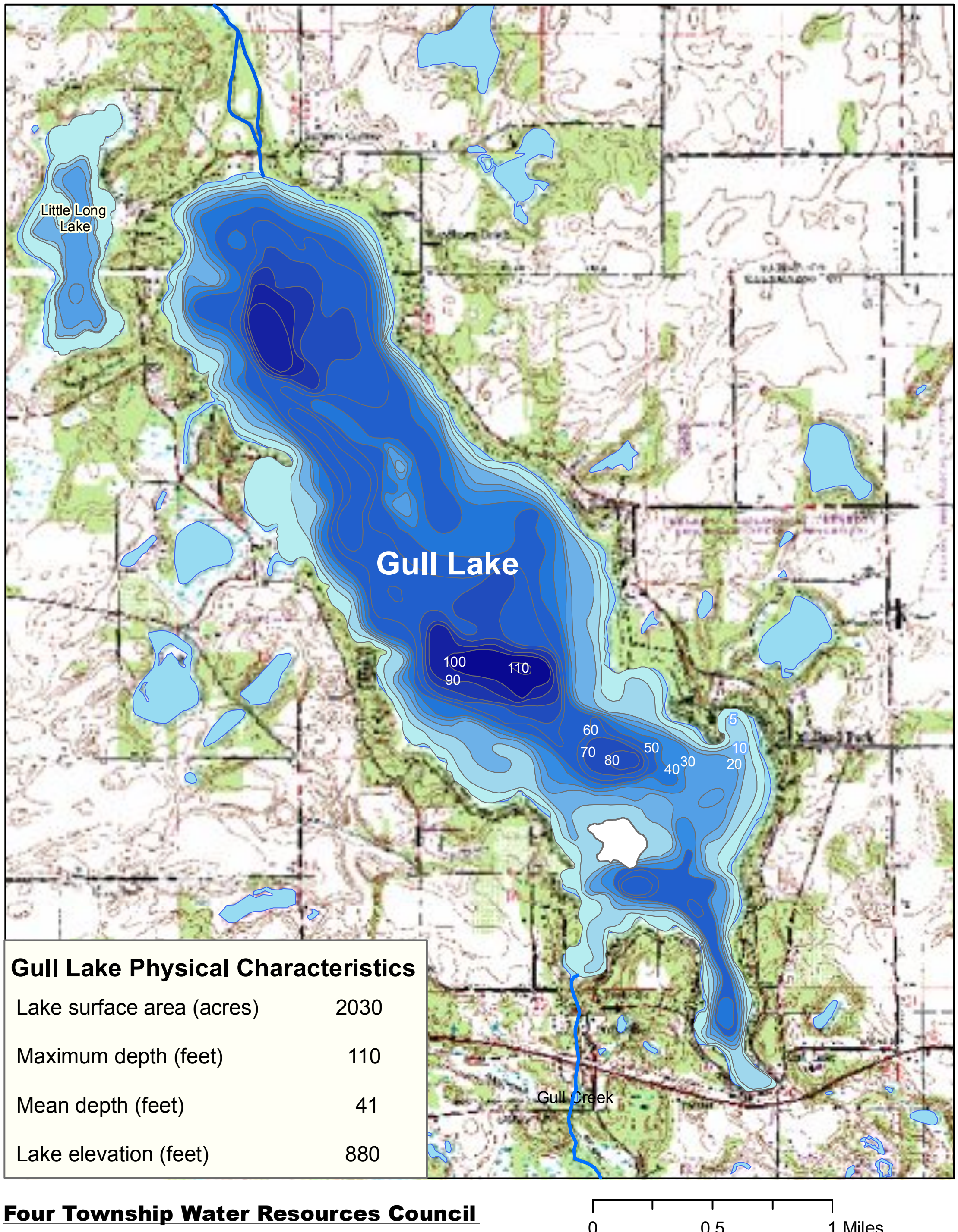


Fig. A5. *Chlorophyll-a concentrations (epilimnetic) in Gull Lake, 1998-2013. These measurements reflect the amount of algal biomass (phytoplankton). The dashed line indicates the overall, long-term (1998-2013) average. Data from 1998-2010 are from research by Drs. Orlando Sarnelle and Stephen Hamilton and their graduate students at MSU/KBS.*

APPENDIX B: BATHYMETRIC MAPS

Maps of lake bathymetry (depth contours in intervals of 10 feet).

Gull Lake



Gull Lake Physical Characteristics

Lake surface area (acres)	2030
Maximum depth (feet)	110
Mean depth (feet)	41
Lake elevation (feet)	880

Four Township Water Resources Council
Prairievile and Barry Townships, Barry County
Richland and Ross Townships, Kalamazoo County

Map prepared by Kellogg Biological Station, Michigan State University, GIS Lab, June 2007

Little Long Lake