Longterm water quality assessment of eight water bodies in the Township of Georgian Bay (2001-2023): Galla Lake, Gibson Lake, Gloucester Pool, Go Home Lake, Myers Lake, Six Mile Lake, Severn River and Stewart Lake

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GLOSSARY

BAV	Beach Action Value
CFU	Colony Forming Units
CHL	Chlorophyll-a
DO	Dissolved oxygen
EC	*Escherichia coli*
FC	Fecal Coliforms
GBWQO	Georgian Bay Water Quality Objective
PWQO	Provincial (Ontario) Water Quality Objective
MPN	Most Probable Number
TC	Total Coliform
TP	Total Phosphorus
TN	Total Nitrogen
TNN	Total Nitrate-Nitrogen
TSI	Trophic State Index

INTRODUCTION

The Township of Georgian Bay (TGB) is part of the District Municipality of Muskoka and is unique for its large seasonal population (>85%; Williams 2019), which includes cottagers residing in the coastal zone as well as those along the shoreline of many inland lakes, making it the quintessential "cottage country" in Ontario. In 2011, the TGB adopted as one of the three pilllars of sustainability, "to be a community that protects, supports and enhances our natural heritage and environmental assets", and this is very fitting for an economy that is seasonal, almost exclusively associated with serving the needs of cottagers and vacationers (Matthew Fisher & Associates, Inc and Mellor Murray Consulting 2014). A very important, arguably the most important factor that draws people to cottage country is clear, clean water, free of fecal bacteria that at high levels can close beaches and inhibit primary contact water sports. The water should also have low concentrations of primary nutrients (such as phosphorus nitrogen) to prevent symptoms of eutrophication that can decrease property value and degrade habitat for fish and wildlife. Since water from Georgian Bay and inland lakes is also a source of drinking water for cottagers and residents, any impairment in water quality will have a detrimental impact on the lifestyle of residents, the local economy and natural ecosystems.

FECAL INDICATORS

Indicators of fecal contamination in freshwater environments include *Escherichia. coli* (*E. coli;* EC), a member of total coliform bacteria, which are rod-shaped, gram-negative, facultatively anaerobic bacteria commonly found in feces of warm blooded animals, but are also found in soils and in water. All bacteria in this group are referred to as Total Coliform (TC), while the subset associated with feces is referred to as Fecal Coliform (FC) (see **Figure 1**). EC is a common bacterium of the FC group and is commonly found in sewage-contaminated water; however, only a small percentage of EC is itself pathogenic, and therefore it is an ideal indicator of infectious enteric viruses, bacteria and parasitic protozoan that could cause intestinal illnesses in recreational waters. Although there are other fecal bacteria indicators (such as Fecal Enterococcus (FE)), most recreational water quality guidelines in Canada for natural fresh waters use EC for making public health decisions (Health Canada, 2023). In brief, EC is a subset of FC, FC is a subset of TC, <u>and only EC is used as an indicator of fecal contamination</u>.

All widely used and approved methods for enumerating coliforms are based on taking a sample containing coliform colonies and culturing them on selective media under conditions that simulate the gut. The success of all these tests depends on ability of the coliforms in the raw water to survive the sampling and storage conditions and incubation conditions that promote proper growth of the coliform. The oldest and most well-established method is the Membrance Filtration method, which involves filtering aliquots of water through 0.45-μm mesh membrane and allowing colonies to grow on Differential Coliform (DC) media—media that select for different groups of coliforms while inhibiting the growth of others. The membrane filters are incubated at least 24 h at temperatures above 35°C.

Many different environmental conditions can affect the survival of EC in recreational waters (Korajkic et al. 2015) and these need to be considered because the current detection methods rely on bacteria in water samples being successfully isolated under laboratory conditions. To ensure EC in raw water survives but does not multiply prior to the start of analysis, water samples for EC must be stored on ice immediately after collection and analyzed by a qualified laboratory within 6-8 hours. Chlorine or suspended particles in the sample may interfere with the culturing of EC in samples and these must be either neutralized or minimized. In addition, previous studies have shown that even in a frequently closed beach, six replicate samples were required to achieve 70% precision (Whitman and Nevers, 2004). Therefore, conclusions should not be based on fewer than 5 samples during the summer, and for routine display, data should be log-transformed in light of high sample variability.

TROPHIC INDICATORS

In many freshwater environments, phosphorus (P) is the most limiting primary nutrient and exists as inorganic and organic forms. Inorganic P or phosphate is the most bioavailable form assimilated by phytoplankton (planktonic algae) which form the base of the pelagic food web. Algae also require inorganic forms of nitrogen (N) such as nitrates and nitrites. Only one type of algae, cyanobacteria or bluegreen algae, can fix nitrogen gas from the atmosphere. They are never limited by N availability because of the abundance of nitrogen gas in the atmosphere, and this confers a huge competitive advantage on them when there is plentiful phosphorus in the environment. This explains why nitrogen-fixing blue-green algae dominate when there is excess P in lake water. Under natural conditions (i.e. without human influence), lakewater will tend to have low levels of bioavailable phosphates and nitrates because these are readily taken up by algae for photosynthesis as soon as they enter the lake.

The productivity of the lake has been referred to as its *trophic state*, or trophic status reflects the amount of phytoplankton biomass in the lake, which is directly related to the amount of primary nutrients in lake water (Dillon and Rigler 1974; Carlson 1977; Carlson and Havens 2005). The concept of trophic states is a continuum ranging from ultra-oligotrophic lakes (extremely nutrient poor) such as those in the Arctic, to hypereutrophic lakes (extremely nutrient rich) such as agriculturally enriched pot-hole lakes in the prairies. In practice, however, lakes in Ontario have generally been classified as oligotrophic (nutrient-poor), mesotrophic (moderately enriched with nutrient) or eutrophic (nutrient-rich). Parameters that have been used to assess a lake's trophic status include total phosphorus (TP) and chlorophyll-a (CHL; photosynthetic pigment in algae) and Secchi disk transparency, a measure of water clarity. Secchi depth is inversely related to a lake's productivity since the amount of algae in the water column attenuates sunlight and prevents it from penetrating to greater depths. Therefore, reduced water clarity measured by decreased Secchi depths (Secchi) and/or increased turbidity levels are common trophic indicators.

P entering the lake's surface stratum (or *epilimnion*) can come from external diffuse sources such as surface runoff (lawn fertilizers, failing septic systems) or from external point-sources such as effluent from municipal treatment facilities. Large amounts of P can also come from the bottom stratum (or *hypolimnion*) in a process known as "internal loading", which is effectively the release of P from the soil-water interface in lake sediment. The are many drivers of internal P loading but at least one is anoxia or low dissolved oxygen (DO; <1 mg/L) content, which plays a role in the redox state of elements (Orihel et al. 2017). In productive lakes, internal loading may be observed throughout the summer, but in less productive systems, the best time is near the end of the summer, when hypolimnetic oxygen has been used up by bacterial respiration in the sediment, and before the thermal stratification breaks down and replenishes oxygen in the hypolimnion.

Typically, TP levels in lakes within the TGB tend to be low because it is underlain by the Precambrian Shield which produces very little mineral content when weathered. Sources of P from the watershed can increase with amount of modified land cover surrounding the lake. Hence, the amount of P in a lake can be influenced by proportion of modified land near the shoreline. Dillon et al. (1994) found that anthropogenic sources contributed over 58% of the total TP load in some lakes; even so, several studies found that effects of shoreline development and altered shorelines can be masked by several factors including lake morphometry and climatic variables (Quinlan et al 2008, deSellas et al. 2024). Lakes with high cottage developments have also been linked to elevated levels of fecal bacteria (specifically gram-negative *Escherichia coli* (*E. coli* or EC)) in comparison to lakes without cottage developments (Hendry and Leggat 1982).

CARLSON'S TROPHIC STATE INDEX (TSI(TP))

Carlson (1977) created the Trophic State Index (TSI) to help cottagers interpret the quality of their lakes based on measures of TP, CHL and Secchi depth. This is based on the assumption that algal biomass (CHL) is the basis for the trophic state classification, and that the three variables are estimates of algal biomass. Operationally, the TSI scores can range from 0 to 100, although theoretically, the index has no lower or upper bounds. TSI scores can be calculated with all three variables; however, Carlson found TP to be better than CHL for predicting summer trophic status, and that Secchi transparency should only be used when the other two are unavailable. **Table 1** summarizes the range of TSI scores and general characteristics associated with different trophic states in lakes.

WATER-QUALITY MONITORING PROGRAMS

Schiefer and Schiefer (2010) carried out a large-scale, long-term water-quality monitoring program for several inland lakes in the TGB beginning in 2001 that continued until 2008. The lakes included portions of the **Severn River** (above Big Chute), **Gloucester Pool**, **Six Mile Lake**, **Go Home Lake**, **Gibson Lake**, and **Galla Lake**. Volunteers used ColiPlates™ (Bluewater Biosciences, Toronto, ON; see detailed explanations in the Laboratory Methods section) to measure EC and TC. The lakes were sampled bimonthly from late June to early September (at least 5 times each season) except for Gloucester Pool, which was only sampled once in July and once in September (Wiancko 2010). During September, all lakes were surveyed for limnological characteristics at stations that were sufficiently deep to thermally stratify. Variables included Secchi depth transparency, and vertical profiles of temperature and DO. Additionally, measurements of total phosphorus (TP) and conductivity were taken from both epilimnion (above the thermocline) and hypoliminon (below the thermocline). For Gloucester Pool, additional limnological data were also collected during the spring and summer. Unfortunately, no sampling was conducted from 2009 to 2011, but in 2012, Wiancko (2012) coordinated a resumption of the long-term monitoring pogram that continued every year until 2022. Notable changes included addition of **Stewart Lake** in 2012 and **Myers Lake** in 2018, as well as modification in the TP sampling and analytical protocols (see Methods for details).

WATER-QUALITY OBJECTIVES

Human health

In 2012, Health Canada prepared guidelines for Canadian recreational water quality and recommended using EC and FE for freshwaters and marine waters, respectively. The maximum level of EC was a geometric mean (GM) of 200 CFU/100 mL for a minimum of 5 representative samples over a season, and a single sample maximum (SSM) value of 400 CFU/100 mL. Exceedance of the SSM guideline should be followed up with immediate resampling. The GM value was based on a regression analysis of U.S. Environmental Protection Agency (USEPA) that related EC densities to the incidence of swimming-associated gastrointestinal illnesses, whereas the SSM was consistent with the maximum allowable indicator density that corresponded to seasonal gastrointestinal rates of approximately 10-20 highly credible gastrointestinal illnesses (HCGI; defined as vomiting, diarrhea with a fever, or stomach ache/nausea with a fever; Cabelli, 1983). In the updated guidelines, Health Canada currently uses the **Beach Action Value** (BAV) of 235 CFU/100 mL for a single sample (Health Canada, 2023). An exceedance of the BAV should trigger resampling or if this occurs frequently, beach notifications and closures may be warranted. The BAV value represents the 75th percentile value of the water quality distribution corresponding to a potential risk of 36 gastrointestinal illnesses per 1000 people engaged in primary contact activities (equivalent to 8 HCGI).

Given that excellent water quality is foundational to the lifestyle of cottagers and the local economy of TGB, Schiefer (2001) proposed that managers should strive to keep EC levels below 10 CFU/100 mL at all times to match the background levels in undisturbed open waters of Georgian Bay and inland lakes. This has been referred to as the **Georgian Bay Water Quality Objective (GBWQO)** and has been applied consistently in past studies to manage nearshore waters of the Georgian Bay coast, and those in inland lakes.

Aquatic ecosystem health

There is no human health guideline for TP concentration in freshwater. Rather, the **Provincial Water Quality Objectives (PWQO)** of Ontario are intended to provide guidance to prevent surface waters from becoming eutrophic; lakes that are eutrophic experience adverse symptoms such as fish kills due to oxygen depletion and the proliferation of nuisance algae, especially blue-green algae which can produce toxins that at high levels can lead to many ailments including breathing difficulties and eye or throat irritation. During the ice-free season, average TP concentrations **should not exceed 20**

μg/L to avoid eutrophication. To complement the GBWQO for EC, Schiefer (2001) recommended that TP be kept **below 10 μg/L** to maintain the natural oligotrophic character of lakes in this region.

TERMS OF REFERENCE FOR THIS STUDY

Councillors Peter Cooper and Al Hazelton contacted Dr. Chow-Fraser and Mary Muter, Chair of GBGLF, to discuss the feasibility of McMaster carrying out a monitoring program in summer 2023 modelled after the 2020-2022 monitoring program we had just completed in the nearshore areas of the coastal zone of the TGB (see Vinden 2023). Due to other sampling obligations in coastal Georgian Bay, we agreed to analyze the water samples as long as volunteers from the lake associations were willing to collect them. The final proposal presented to the Council included five sampling trips between late June and late August in each of 8 lakes (Galla Lake, Gibson Lake, Gloucester Pool, Go Home Lake, Myers Lake, Severn River, Six Mile Lake, and Stewart Lake). McMaster would supply all sample bottles to volunteers. Volunteers were responsible for transporting all samples to the McMaster field lab in Honey Harbour within 8 hours of collection.

All EC and TP samples would be processed with the same methods used by McMaster for nearshore waters in the coastal zone of TGB between 2020 and 2022 (see Vinden 2023). Briefly, instead of using Coliplates, samples for EC and TC would be analyzed with the Tecta B16 analyzer (IDEXX Laboratories). The McMaster team would also freeze the TP samples and bring them back to McMaster University for processing by trained senior thesis students at the end of the summer. During early September, the McMaster team would sample each lake at deep sites with a multi-parameter probe (In situ Aqua Troll 600) to determine depth profiles for temperature, DO and TURB. To facilitate comparison with historic data, we also proposed to collect samples from the epilimnion and hypolimnion for TP.

We proposed to conduct a long-term assessment by assembling all available historic information from Schiefer and Schiefer (2010; 2001 to 2008) and from the program coordinated by Wiancko (2012 to 2022). This database will be analyzed by Senior thesis students during the 2023-2024 academic year. Lake physical profiles and effect of stratification on internal loading of P will also be assessed. Long-term trends in trophic states for each lake will be interpreted based on basic lake morphometric information, sources of human disturbances (modified land along the shoreline), and watershed features. Because all nutrient/CHL samples were analzyed by undergraduate students who were not remunerated, and the salary of summer technicians in 2023 (Karolina Charczynska, Jacqui Vinden, Milo vanden Hoven) were paid through other projects/funding sources, the cost of this project was relatively low and only covered the cost of chemicals, disposables and Tecta cartridges used, as well as some of the operating costs of the truck and boat.

An interim report was produced that detailed the 2023 fecal bacteria and TP data and submitted to the TGB in January 2024. This document is the final report that includes updated results for 2023 including TP, TC and EC data, as well as levels of TN, total nitrate N (TNN), and CHL during the September sampling.

METHODS

STUDY SITES

The eight water bodies in this study are located within the TGB (see **Figure 2**) and were sampled at various times from late June to early September in 2023 (**Table 2**). To be consistent with past monitoring efforts, we asked volunteers to be available to collect water samples five times between late June and end of August.

- **Galla Lake** (**Appendix 1a**)**:** Galla Lake, with an area of 50 ha is the second smallest lake we sampled, but has a relatively deep basin in the southeastern end with a maximum depth of 27.0 m (**Table 3**). It is located west of Hwy 400, and does not appear to have heavy cottage development. Despite best intentions, the volunteers only sampled all four stations once during early August. Unfortunately, without appropriate bathymetric maps prior to the sampling and lacking local knowledge, we did not know the location of the deep spot in the lake. Instead, we sampled the "Landing" (depth of only 8 m) during September.
- **Gibson Lake** (**Appendix 1b**): Gibson Lake lies to the east of Hwy 400 and is part of the Musquash River Watershed. It has a surface area of 264 ha and has a maximum depth of 14.2 m (**Table 3**). The lake has two deeper areas joined by a relatively narrow and shallow middle portion. There are over 200 cottages on its shoreline as well as a boat launch.
- **Gloucester Pool** (**Appendix 1c**): With a total surface area of 1721 ha and 20 islands, the lake begins at Big Chute (downstream of Severn River), and runs southwest through Little Lake, ending at Lock 45 before emptying into Georgian Bay. Baxter Lake, to the northwest, is connected by a narrow channel. The lake has 5 active marinas, and is home to over 1,500 cottagers, most of whom are seasonal occupants. The deepest portion of the basin is located in the northern portion of the lake, south of White Falls Bay, with a maximum depth of 35 m (**Table 3**).
- **Go Home Lake** (**Appendix 1d**): The Go Home River discharges into the north end of Go Home Lake through a dam, and flows out through a control dam at the south end of the lake into the Musquash River. This is a moderately large lake, with a surface area of 730 ha and a maximum depth of 30 m (**Table 3**). It has the most irregular shoreline of all the lakes in this study. Many of the cottages can only be accessed by boat, and the community is serviced by only one busy marina, the Go Home Lake marina.
- **Myers Lake** (**Appendix 1e**): This is the smallest lake in this study, with a total area of 34 ha. This lake is very shallow, with a maximum depth of only 3.0 m (**Table 3**), and was not stratified in September when we visited it. The shape of the lake resembles a maple seed, with double lobes.
- **Severn River** (**Appendix 1f**): The Severn River connects to Gloucester Pool via Big Chute. This stretch of the river has a series of irregularly shaped indented bays. During 2023, 7 of these bays were sampled. We could not locate any digitized bathymetric data for Severn River in the provincial database and therefore could not produce any bathymetric map for these sites.
- **Six Mile Lake** (**Appendix 1g**): This lake is located just east of Highway 400. It has a popular provincial park that draws thousands of campers each summer. It is part

of the West Basin watershed, and has the second largest surface area in this study of 1475 ha. It is moderately developed with 850 cottages on its shore as well as 2 marinas. It naturally separates into 5 basins, with a maximum depth of 48 m, but its mean depth is only 7.8 m (**Table 3**).

- **Stewart Lake** (**Appendix 1h**): This lake is situated at the far eastern portion of TGB (east of Hwy 400) so that the eastern portion of the lake crosses into the Township of Muskoka. Bordering on the southwestern shore of Stewart Lake is the town of Mactier, where the permanent population is approximately 305 individuals. The shoreline is quite well developed for commercial and residential purposes to the southwest, close to the town. The surface area is 152 ha and the maximum depth is 18.3 m, but the mean depth is only 6.3 m (**Table 3**).

FIELD METHODS

Each Lake association was provided a box with bottles that were clean/sterilized for EC samples or clean/acid-washed for TP samples. To avoid confusion, we used different coloured caps; red were used exclusively for TP while blue were used exclusively for EC. Each volunteer team was provided with sufficient bottles for one sampling trip and additional sterile whirlpak envelopes in case they ran short of bottles. Volunteers were also provided field sheets (on Rite-in-the-Rain paper) that were to be filled out and returned with the samples on each sampling trip. We asked volunteers to use a handheld GPS or a phone to record on the field sheet the geographic coordinates of each site they visited. If we were not provided with coordinates, we used the default geographic coordinates that were extrapolated from maps found in past annual reports and approximated on the Google Earth website.

Rather than collecting water samples from the surface, volunteers were instructed to collect their duplicate samples by plunging the provided containers into the water column as deep as they could manage. They were also asked to sample on rain-free days (<2mm in the past 6 hours) and to phone the Chow-Fraser team (Jacqui or Karolina) to arrange a time to drop off the samples at the Honey Harbour temporary lab (in the library building). All samples were to be labelled with the lake name and site name or site code prior to collection (it is difficult to write on the label when it is wet). On a few occasions, the cap of the sampling bottle was not screwed on tightly and we lost the sample during transportation. All samples were to be stored in a cooler with ice paks and kept below 10°C and delivered to the Honey Harbour temporary lab near the Township Dock within 6-8 hours of collection.

Although a tentative schedule of dates for each lake was given to the volunteers, many schedule changes had to be made throughout the summer, and all these were arranged by contacting members of the McMaster team via texts and/or phone. In September, Kelton Adderley-Heron, Ph.D candidate, and Karolina Charczynska sampled each lake at the deep stations (from September 5 to September 8) to obtain vertical depth profiles of physico-chemical parameters, and to collect water at the epilimnion and hypolimnion for TP and TNN, and at the epilimnion for planktonic CHL. Although all volunteers were offered the opportunity to sample with the team, Simon Edwards was the only volunteer who indicated an interest and participated in the September sampling.

As indicated in the Introduction, Wiancko modified sampling protocols for TP from 2012 to 2022. Instead of collecting water samples 2-3 m below the thermocline in the hypolimnion, he collected water approximately 1 m off the sediment surface (Wiancko 2012). During the 2023 season, we collected samples within a meter of the sediment surface to be consistent with Wiancko's protocol so that our datasets are directly applicable. Sometimes, volunteers collected samples at additional sites and asked us to analyze them, but whenever possible, we ensured that samples were also collected at locations consistent with those in past monitoring programs.

LABORATORY METHODS

As mentioned in the Introduction, the most traditional method to enumerate EC density is by filtering water samples and growing any EC colonies on the filters using selective media. The Coliplate™ method uses defined substrate to simultaneously screen for the amount of β-D-galactosidase enzyme present in all TC, and for β-D-glucoronidase, an enzyme that is present only in EC, which will react with 4-methylumbelliferyl-β-D-glucoronide (MUG) to produce a product (MU) that fluoresces under UV light. The defined substrate targeting these enzymes are supplied in 96 wells. After 24 hours of incubation at 35-37°C, wells that are positive for TC will turn blue, and of these, a subset will fluoresce under UV light to indicate they are positive for EC. To quantify densities, the number of positive wells is compared to a Most Probable Number (MPN) table, which has a minimum density of <3, and a maximum density of >2424. Since there is no zero value in the MPN table, we converted all "zero" entries in historic datasets to 1.5, given that the lowest value in the table is <3, and half of this value is an acceptable detection limit.

The McMaster lab analyzed EC/TC samples with the Tecta B-16, which was developed in Kingston, ON (formerly sold by Endetec and Pathogen Detection Systems and currently sold by IDEXX Laboratories). It is an automated system approved by USEPA for enumerating EC/TC and FC. It simultaneously analyzes up to 16 samples of EC/TC in under 18 hours. The system requires the use of single-use cartridges containing proprietary pre-measured growth media and metabolic substrates specific to the target microbe. For EC, a glucuronic acid conjugate is used as the substrate to detect the β-D-glucoronidase enzyme. When present, the EC acts on the substrate and releases a hydrophobic, fluorescent metabolite which forms a polymer bead in the bottom of the cartridge where fluorescence is detected by the instrument. This overcomes the problem with interference from suspended solids in the raw water. The amount of time required to lead to detection of fluorescence reflects the concentration of target microbes; extremely high counts could be detected within 2 hours, whereas no detection after 18 h of incubation should be interpreted as being below 1 CFU/100 mL. As with the Coliplate method, values <1 is typically transformed to half the detection level (i.e. 0.5) for statistical analyses.

We installed the Tecta in the temporary lab space in Honey Harbour so that all EC samples could be processed within 2 hours of samples being received volunteers. As recommended by the manufacturers, we performed calibrations at the start of each week before the first set of tests were run. To analyze EC samples, we poured 100 mL of raw water into an unused cartridge and gently swirled it to dissolve all reagents. This would take several minutes. The cartridge was then placed inside one of 16 chambers. The steps were repeated until all samples were placed into chambers. The machine automatically incubates for up to 18 hours once the correct incubation temperature is reached (35°C), and the results are stored on the Tecta and can be retrieved at any time for reporting purposes.

All TP samples were frozen and then transported in a cooler back to McMaster at the end of the summer and then kept in a -20 freezer until they were processed by the thesis students. As was the case for TP samples collected prior to 2010 (analyzed by Maxxam Analytics in Mississauga), lakewater was analyzed whole; by contrast, samples collected by Wiancko were analyzed by the Dorset lab, and water samples were first filtered through 80-µm Nitex mesh before they were analyzed. Although it was not explicitly written in the reports, the reason for this step was likely to remove zooplankton or debris in the water that might have led to elevated readings. The water samples were thawed overnight and analyzed once they reached room temperature. We first added persulfate to 50-mL of raw water and then placed the sample in an autoclave to digest the contents. After the sample was cooled, we used the molybdenum blue method of Murphy and Riley (1962) to quantify the concentration of TP in the digested samples. It is possible that without filtration through the 80-µm mesh, TP concentrations in the 2023 samples may be more erratic than those sampled by Wiancko.

INDIVIDUAL CONTRIBUTION OF THESIS STUDENTS

Four thesis students had been recruited for this project, but one decided to pursue other interests. Dr. Chow-Fraser therefore assigned the lakes to the three remaining students as follows, and arranged to have the remaining samples processed by hired undergraduate assistants:

Karolina Charczynska:	Gloucester Pool and Myers Lake
Jessica Stevens:	Gibson Lake and Six Mile Lake
Soroya Rosli:	Go Home Lake and Stewart Lake

The thesis students calculated morphometric indices based on lake bathymetry and entered historic data into a database for long-term assessments. Bathymetry is the study of the depth contours of water bodies; a bathymetric map is a useful way to visualize lake contours, which are lines joining the same depths in a lake basin (see Appendix 1a to 1h). Such a map is required to calculate morphometric indices such as lake volume or mean depth, which provide useful information on lake productivity. All else being equal, a shallow lake will tend to be more productive than a deep lake, and this inverse relationship between depth and primary productivity is foundational to our current understanding of how lakes can be classified according to their trophic status (Rawson 1952).

MORPHOMETRIC INDICES

The government of Ontario has digitized a number of bathymetric maps and have made them downloadable through the Ontario Geohub (Bathymetry, Line https://geohub.lio.gov.on.ca/datasets/mnrf::bathymetry-line/about. Files for Gibson Lake, Gloucester Pool (minus Little Lake), Stewart Lake and Myers Lake were imported into QGIS v. 3.28.2-Firenze (QGIS) and students measured Lake Area (A), Lake Perimeter (P), Maximum Depth (Z_{max}), Maximum Length (L_{max}) and Maximum Breadth (B_{max}) for each lake (**Table 2**). Volume (V) for each stratum can be calculated with **Eq. 1**, and the sum of all strata volumes is the lake volume. Mean Depth can then be calculated with **Eq. 2**,

Volume (V) was calculated as: $V = 1/3H(A_1 + A_2 + \sqrt{A_1 \times A_2})$
where A_1 is the surface area (m^2) of the top of a stratum, A_2 is the surface area (m^2) of the bottom of a stratum and H is the stratum depth (m) (Eq. 1)

Mean depth (Z_{mean}) was calculated as: $Z_{mean} = V/A$
where V is the volume (m^3) and A is the surface area (m^2) (Eq. 2)

There were no digital bathymetric data for Little Lake (part of Gloucester Pool), Galla Lake, Six Mile Lake, Go Home Lake or Severn River. There were, however, bathymetric maps for all lakes except for those sites in the Severn River (https://geohub.lio.gov.on.ca/datasets/mnrf::historic-bathymetry-maps-1/about). Therefore, students assigned to these lakes downloaded the bathymetric maps and used QGIS or ArcGIS to create a GIS, with which they could then calculate all the morphometric indices. Unfortunately, we encountered problems with Six Mile Lake and could not include the finished bathymetric map in this report. Instead, the morphometric information for Six Mile Lake were taken from Ministry of Natural Resources Lake Fact Sheet (https://bracebridgerealty.ca/Lakes/Lake-Fact-Sheets.php?l=Six_Mile_Lake.pdf)

HISTORICAL DATA and FOCAL AREAS

In total, 4,371 entries of EC and 862 entries of TP were separately assembled from all historic and current sources dating back to 2001 for EC and 2005 for TP. These entries were only identified by names or site codes and were not associated with geographic coordinates. Locations of most sites could be approximated from maps included in the annual reports, but a substantial number of sites were not shown on maps (e.g. Galla Lake and Myers Lake), and in some cases, the labels only included a site number or were named “Temporary location” or “Temporary Site #”. We contacted past volunteers and were able to affix an approximate location to some sites, but in many cases, current volunteers did not know the exact location of historic sites. There were also inconsistencies in where EC and TP were collected historically—in some cases, TP samples were collected at a site that had not been sampled for EC and vice versa. Another problem was that some sites were sampled only once or twice over the past 20 years, while others were sampled consistently throughout the two decades.

To deal with these inconsistencies, we decided to use “focal areas” by lumping together sampling stations located in close proximity to each other (or assumed to be located in close proximity based on their names and land marks). Whenever possible, we used natural features such bays or lake basins to combine stations. When we had geographic coordinates, we calculated a mean value for latitude and longitude for each focal area; when we did not have any geographic coordinates, we arbitarily chose a location in the middle of the feature. Together, we created 11 focal areas in Gloucester

Pool (including 2 in Little Lake, 1 in Little Go Home Bay and 1 in Baxter Lake), 7 in Severn River, 6 in Six Mile Lake, 3 in Gibson Lake, 6 in Go Home Lake, 3 in Galla Lake and 3 in Myers Lake (see **Figure 3**).

STATISTICAL ANALYSES

All statistical and graphical analyses were performed with JMP 17.0 software (JMP Statistical Discovery LLC; Cary, N. Carolina). Since historical EC densities were estimated with Coliplates and current EC densities were measured with the Tecta, we used **Eq. 3** to standardize the data so they could be compared through time. The data for Eq. 3 were collected by Vinden and Chow-Fraser at various sites in coastal Georgian Bay and in inland lakes sampled between 2020 to 2023 (see **Figure 4**).

$$log_{10}ECTecta = 1.049 \times log_{10}ECColiplate - 0.1333 \qquad \text{(Eq. 3)}$$

We generated geometric mean of EC and arithmetic mean of TP for each focal area for long-term comparisons. We used non-parametric statistical tests in all cases because of the known variation in data that would make it difficult for data to meet assumptions of parametric tests. We used a Kendall's Tau (α=0.05) to determine significant long-term temporal trends in EC and TP for all focal areas, and Wilcoxon signed rank to compare epilimnetic and hypolimnetic TP concentrations. We also calculated the Trophic State Index (TSI(TP); Carlson 1977) score using **Eq. 4** for each focal area or water body.

$$TSI(TP) = 14.42\ln(TP) + 4.15 \qquad \text{(Eq. 4)}$$

where TP is mean TP (μg/L) for the area

RESULTS and DISCUSSION

CURRENT STATUS

Results reported in this report supercede those from the previous interim report prepared in January 2024. The McMaster team and volunteers sampled the eight water bodies in this study a combined total of 323 times between June 22 and September 7 (**Table 2**). Due to circumstances beyond our control, Galla Lake was only sampled at 4 stations once during the summer (August) and at the Landing once in September. At the other extreme, Gloucester Pool was sampled up to 8 times because EC samples from the two July trips were ruined by two power outages (that interrupted the incubation period); therefore when we replaced the EC samples, we also collected additional TP samples. Gloucester Pool was also the largest and most complex water body we sampled, essentially consisting of three adjoining lakes (Baxter Lake, Gloucester Pool and Little Lake); therefore, we established a larger number of sites in that lake compared to the other water bodies. As well, the volunteers identified other sites of interest and collected samples for us to analyze.

Fecal indicators

EC is one of two recommended indicators of fecal contamination for primary contact recreation (Health Canada 2023). Health Canada currently uses the Beach Action Value (BAV) of 235 CFU/100 mL which applies to a single sample rather than to multiple samples as was the case when geometric means were used. Managers are encouraged to make day-to-day beach management decisions rather than wait at least five days to calculate an average. Every exceedance of the BAV should trigger a management action that may include issuing a swimming advisory, or an immediate resampling of the site, especially if the results are atypical. Such an approach requires that processing times for EC samples be minimized (within a day) and that all exceedances be communicated promptly to the lake managers for action.

In this study, EC densities only exceeded the BAV on two occasions during the entire summer, at **Wahta** (Gibson Lake; 2624 CFU/100 mL) on August 4, 2023 and at **Little Lake Centre** (Gloucester Pool; 4178) on August 8, 2023 (see **Figure 5**). These values were atypical for these sites given that at other months, densities were all below 10 CFU/100 mL. Such a pattern could be due to sampling too soon following a storm or too close to waterfowl, that are known to be a source of EC. We did not find any significant differences among means for June, July, August or September data. The results were the same when we compared monthly data on a lake-by-lake basis or for the pooled dataset (Kruskal-Wallis test).

EC densities measured at the same site can vary greatly over a season, and atypically high counts can skew the seasonal means. Rather than excluding these atypically high values, we can minimize their influence over the remaining data by calculating a geometric mean rather than an arithmetic mean. It is good practice to use geometric means rather than arithemetic means to compare data across time for the same lake, or across many different sites. Based on geometric means of EC sampled during 2023, only three sites, **Wahta** in Gibson Lake (12.73 CFU/100 mL), **White Falls Marina** in Gloucester Pool (13.41 CFU/100 mL), and **Go Home Lake Marina** in Go Home Lake (23.52 CFU/100 mL) exceeded the GBWQO (**Figure 6** middle panel; **Figure 7**; **Table 4**). More importantly, for over 90% of the sites, the geometric mean EC densities were well below the GBWQO.

Total Coliform

Total coliform (TC) has been used as an indicator of environmental contamination in *drinking-water* sources (i.e. wells and water treatment facilities). For that purpose, the current maximum acceptable concentration of total coliforms in water leaving a treatment plant and in non-disinfected groundwater leaving the well is zero detectable colonies per 100 mL (Health Canada 2020). In 1994, the Province of Ontario recommended that the geometric mean density of TC in a "series of water samples" should not exceed 1000 CFU/100 mL. In this study, three sites had very high individual TC densities that exceeded 200,000 CFU/100 mL measured during the month of August. These were **Island Beach** on August 10, 2023, **Little Lake Centre** on August 8, 2023, and the **Landing** in Gibson Lake on August 10, 2023. As was the case for EC, calculating a geometric mean of all data helps to smooth out the extreme seasonal variation.

Of the 61 sites sampled, more than half (34 sites) had a geometric mean TC density that exceeded 1,000 CFU/100 mL, while 6 exceeded 3,000 CFU/100 mL (**Figures 6 and 8**). **Prism Island** (in Gloucester Pool) had a high value that exceeded 20,000 CFU/100 mL (**Table 4**). It is important to note, however, that there is no current guideline for TC densities in surface water. Additionally, Health Canada does not recommend using TC as an indicator of fecal contamination because total coliforms are present in both fecal and non-fecal environments. "Consequently, monitoring total coliforms in raw surface water…does not provide information on the quality of the source water from the perspective of (human) health risk" (Health Canada 2020). What is more germane to this study is that we did not find any statistically significant correlation between EC and TC data (Spearman test; $P>0.05$). Therefore, there is *no scientific basis for using TC data in routine monitoring programs meant to detect fecal contamination*, and the Township should not continue to report on TC densities for this purpose.

<u>Nutrients</u>

Mean seasonal TP in 2023

From an ecosystem health perspective, the more serious concern is the high prevalence of TP concentrations exceeding the GBWQO (<10.0 µg/L). More than half of the sites (31 of 61) sampled in 2023 had *arithmetic mean* seasonal TP concentrations that exceeded the GBWQO (solid bars in right panel of **Figure 6).** All but three of these means were calculated from 5+ samples collected during the summer, and are therefore representative of the sites. Of particular concern are sites that have exceeded 15 µg/L, which include **Big Chute** in Severn River (15.5 µg/L), **Copp Bay** in Severn River (15.7 µg/L), **Landing** in Gibson Lake (18.1 µg/L), and **Dam G** (18.8 µg/L) in Gloucester Pool (**Figure 9 and 10**). These sites may already be or will become associated with symptoms of cultural eutrophication such as poor water clarity and reduced hypolimnetic dissolved oxygen content. Galla Lake was the only water body without exceedances in 2023 (**Figure 10**); we should keep in mind, however, that Galla Lake had only been sampled at all four sites once during August. For all other water bodies, at least one station exceeded the GBWQO for TP.

During the summer, individual measurements at seven stations (Gloucester Pool, Myers Lake, Severn River and Six Mile Lake) had elevated TP concentrations above the PWQO (i.e. < 20 µg/L) and these occurred in each of the summer months (**Figure 9**). In fact, except for Gibson Lake and Severn River, TP concentrations did not vary significantly among months (**Figure 11**). TP concentrations were significantly higher during June than at any other month during the summer in Gibson Lake and Severn River. The July, August and September means did not differ significantly for Gibson Lake, but for Severn River, mean TP was significantly lower in August compared with those in July and September. The higher June concentrations may be related to inputs from spring freshet and should be investigated further with a repeat monthly sampling program beginning in mid-June. The following sites are those in which mean 2023 **TP concentrations** ≥ 10 µg/L:

Gibson Lake:	Hiawartha
	Island Beach
	Landing
	North River Outlet
	South Lake
	Wahta
Gloucester Pool:	Baxter Lake
	Big Chute
	Black River Channel
	Centre Pool
	Dam G
	Little Go Home Bay
	Narrows Marina
	Prism Island
	White Falls Marina
Go Home Lake:	Go Home Lake Marina
	Heart Bay
Myers Lake:	Crisco Bay
	East Side
Severn River:	Big Chute
	Copp Bay
	Coulter's Bay
	Pretty Channel
Six Mile Lake:	Hungry River
	Near the Six Mile Lake Marina
	Six Mile Lake Provincial Park
	Wawautosa Government Dock
Stewart Lake:	Bear Bay
	Buckeye Bay
	North Bay
	South Kilty Bay

TP concentrations by lake stratum

During the September sampling trip, we collected water samples at both the epilimnion and at the hypolimnion for nutrient analyses. In productive lakes that are stratified, hypolimnetic TP concentrations are expected to be significantly higher than those in the epilinion because of internal loading as discussed earlier (**Figure 12**). Indeed, when data for all water bodies were combined, the hypolimnetic TP concentrations were significantly higher than corresponding epilimnetic TP concentrations (Wilcoxon Matched Pair Test; $P<0.0293$), with mean difference of 2.93 ± 1.39 SD µg/L across all matched sets. In Heart Bay, epilimnetic TP concentrations were more than double the hypolimnetic TP values. In most cases, the hypolimnetic TP concentrations exceeded the GBWQO, while TP concentrations in two sites, **Middle Lake** and **Centre Pool** actually exceeded the PWQO (<20.0 µg/L), further supporting the hypothesis that internal loading is likely occurring in these lakes.

There were no significant differences in TN concentrations between lake strata ($P=0.0774$) although mean hypolimnetic concentrations were generally higher than epilimnetic concentrations (1.067 vs 0.886 mg/L, respectively). By contrast, the hypolimnetic TNN concentrations were significantly higher than the epilimnetic concentrations (0.033 vs 0.015 mg/L , respectively; $P=0.0407$). Normally, we would not expect to see higher hypolimnetic levels of TNN, especially when there is low dissolved oxygen (DO) condition in the bottom of the lake. That said, the concentrations of TNN in both the epilimnion and hypolimnion are relatively low for surface waters, and would not threaten aquatic ecosystem health.

Water Clarity

Light attenuates predictably below the water surface and if lake water is not highly coloured and has low algal biomass and suspended sediment, sunlight should be able to penetrate to 4.5 to 5.0 m depth in oligotrophic lakes (see **Table 1**). As the lake becomes more productive, however, the algae tend to interfere with light penetration. The Secchi disk can be used to track how deep the light can penetrate, and this information is useful for inferring how productive the lake is. There is quite a bit of subjectivity associated with Secchi depth measurements and it is not uncommon for two individuals to come up with quite different numbers for the same lake. To reduce this observer-bias, the same person should take readings for all lakes in a study, but in a volunteer-based program this is impractical.

The Secchi depths in 2023 ranged from a low of 2.1 m at Middle Lake in Gibson Lake to a high of 5.5 m at Little Lake Centre in Gloucester Pool (**Figure 13**); over half of the values were above 4.0, indicating oligotrophic conditions (**Table 1**). Sites with Secchi depths between 2 m and 4 m (indicated by the two dashed lines) suggest they are mesotrophic (**Table 1**), and include Galla Lake, all sites in Gibson Lake, all sites except Four Seasons Bay in Go Home Lake, Myers Lake, Russian Bay, Long Lake and Stewart Lake. As discussed above, Secchi depth readings can be very subjective and any assessment should be based on seasonal means of data collected at least monthly during the summer. Therefore, we will not use Secchi depth readings for trophic status assessment in this report. They are useful in a general way to show improving or deteriorating trends in lakes, provided that readings have been taken by the same individual. CHL values ranged from 0.05 to 1.38 µg/L, levels that are consistent with oligotrophic lakes (0 to 2.6 µg/L, Carlson & Simpson (1996); **Table 1**). By comparison, turbidity values ranged from 0.557 to 5.367 NTU, but majority (29 of 35 values) were < 2.0 NTU, and this is typical of lakes in this region (Chow-Fraser, unpub. data).

Algal CHL is the primary variable responsible for reduced water clarity, unless the lake is shallow and boating activites resuspend sediment into the water column. But CHL is difficult to be measured by volunteers and therefore, many volunteer monitoring programs use the Secchi disk. We collected parallel CHL, turbidity and Secchi data to provide empirical relationships that could be used in the future to relate Secchi or

Turbidity readings to CHL. We regressed 1/Secchi and $\log_{10}$ Turbidity separately against $\log_{10}$ CHL and found statistically significant relationships for both sets of variables (**Figure 14**). The Turbidity-CHL relationship was much stronger than the Secchi-CHL relationship. Because of the subjectivity involved with taking Secchi readings, a turbidimeter is a good option that is relatively inexpensive and easy to use. Samples of water can be collected and brought to a central location for measurement, or turbidimeters may be loaned out to volunteers.

<u>Temperature and DO depth profiles</u>

We prepared depth profiles for Gibson Lake and Gloucester Pool (**Figure 15**), Go Home Lake and Myers Lake (**Figure 16**), and Six Mile Lake and Stewart Lake (**Figure 17**). Unfortunately, as explained, we did not sample the deep basin in Galla Lake, and we have not yet processed the profiles for the sites in Severn River (although we have them available). The two sites in Myers Lake and Little Lake Centre were too shallow to stratify, and DO levels did not diminish much with depth at these sites. All other lakes were sufficiently deep to stratify and were either weakly or strongly stratified. All sites in Go Home Bay, including Bay of Many Winds, the deepest site sampled in 2023, were well oxygenated throughout the hypolimnion. At two sites (Four Seasons Bay and Go Home Lake Marina), there was only a slight reduction in DO levels in the hypolimnon until the probe neared the sediment. By contrast, all sites in Gibson Lake exhibited hypolimnetic anoxia, and at Gloucester Pool (South Centre Pool), where there was strong stratification, DO levels dropped to anoxic conditions below 12 m. By comparison, the hypolimnion at Baxter Lake only showed modest reduction in DO below the thermocline. Therefore, hypoxia (<3 mg/L) or anoxia (<1 mg/L) developed at all sites except those in Go Home Lake and Myers Lake.

Hypolimnetic oxygen depletion is a serious ecosystem health problem because it reduces fish habitat and can contribute to internal P loading that makes the lakes even more productive. Therefore, we recommend that monitoring programs in the future retain the depth profiling component to track the extent of hypoxia and anoxia in these lakes and the degree of internal P loading during the late summer and fall. If possible, there should be biweekly depth profiling at several of the "hotspots" throughout the summer to more fully characterize the onset of thermal stratification and the development of anoxia in the lakes.

LONG-TERM TRENDS

We will first present an overview of EC temporal trends for focal areas in each water body, followed by similar analysis for the corresponding TP data. This analysis makes use of all available data from annual reports as well as data that we collected in 2023. Year-to-year differences in EC and TP are not unusual, and it is rarely possible to discern increasing or decreasing trends by just visually examining a plot of the data. Here, we used Kendall's τ (tau), a non-parametric statistic similar to the correlation coefficient, that is commonly used to determine significant increases (+ve values) or decreases (-ve values) through time. Unless the P-value associated with τ is < 0.05, we must conclude that there is no evidence of a significant temporal trend, and the long-term geometric mean could be indicative of the site's current conditions. If there is a significant increasing or decreasing trend, however, the long-term geometric mean is meaningless and should not be used to infer current conditions.

Fecal indicators

To enable valid long-term comparisons, we first converted all historic Coliplate EC densities to TECTA-equivalent EC densities using **Eq. 3** (see Methods). We then calculated a geometric mean EC density for each focal area to determine which sites exceeded the GBWQO (<10 CFU/100 mL) (**Figure 18**). None of the sites in Galla Lake, Myers Lake, Severn River, Six Mile Lake or Stewart Lake exceeded the GBWQO. In Go Home Lake, the **Go Home Lake Marina** exceeded the guideline 50% of the time, notably more in recent years than in years prior to 2015. Only the **North site** in Gibson Lake showed exceedances in 2005 and 2012. By contrast, 8 of the 13 sites in Gloucester Pool had exceedances in at least one year between 2001 and 2023. There were exceedances in 8 of 11 years at **Black River Channel** and in 5 of 20 years at **Lower Little Lake**.

Besides determining exceedances, we also wanted to determine if there were significant temporal trends. Given that EC is an indicator of fecal contamination, a significant decreasing trend is desirable, whereas a significant increasing trend is undesirable. For the three smaller lakes, we combined all sites to increase statistical power and found significant decreasing trends for both **Myers** and **Stewart** Lakes, but not for Galla Lake (**Table 5; Figure 18**). For the other 41 stations in the six remaining lakes, we found 10 significant temporal trends. Only one site, **Go Home Bay Marina** had a significant temporal increase in EC densities. This significant increase was unique because in all other cases, we found a signficant decrease with time including **South Lake** in Gibson Lake, **Lower Little Lake** and **The Narrows** in Gloucester Pool, **Hungarian Bay** and **Lost Channel** in Severn River, **Crooked Bay**, **Hungry River**, **Main Lake** and **Provincial Park** in Six Mile Lake.

We also calculated the long-term geometric mean for all sites (**Table 4**). Readers should keep in mind that this value is meaningless if there is a significant temporal trend because it represents an average condition over the past 15-20 years that may be a lot lower or higher than current conditions. As an example, the long-term geometric mean for the Go Home Lake Marina was 9.24 CFU/100 mL, which is almost three times lower than the 2023 density of 23.52 CFU/100 mL (**Table 4**), suggesting that conditions have worsened considerably in recent years. Except for **Black River Channel,** long-term geometric mean EC densities were below the GBWQO and well below the BAV of 235 CFU/100 mL. The geometric mean at Black River Channel was 13.46 CFU/100 mL, which was only slightly elevated. There were few exceedances associated with Six Mile Lake, Severn River, Myers Lake and Stewart Lake. Of note is that EC densities in many sites in Go Home Lake exceeded the GBWQO after the year 2020. One possible explanation for this may be related to cottagers choosing to spend the COVID-19 lock-down period at the cottage in 2020 and 2021.

Nutrients

Seasonal mean TP (2001-2023)

We calculated long-term mean TP concentration for each focal area to determine which sites exceeded the GBWQO (<10 µg/L) over the past 2 decades (**Figure 19**). We only used September data for this comparison since TP concentrations had been measured only in September prior to 2023. The difference between EC and TP trends is immediately obvious; relative to EC, there were many more exceedances of TP across the lakes. None of the eight lakes were exempt from exceedances, although they were less prevalent in the three smaller lakes. There has been no exceedances in Galla Lake since 2015 and Myers Lake had its first exceedance in 2023. This contrasts the situation in Gibson Lake, where all three stations had exceedances except in 2013, 2019 and 2022. In fact, across all lakes, concentrations were uniformly depressed in 2019 and 2022 and uncharacteristically, there were no exceedances at all in 2022 for any lake. Convesely, a high proportion of sites had elevated TP concentrations in both 2020 and 2021, even in lakes that did not normally show exceedances such as Stewart Lake. Further investigation should be carried out to see if these patterns of reduced and elevated TP concentrations were widespread throughout the District of Muskoka. If so, the increased TP concentrations in 2020 and 2021 may further support the hypothesis that cottagers opted to spend the COVID-19 province-wide lock down at their cottages rather than in cities.

We only found two significant temporal trends for TP (**Table 7**). When all data were combined for Galla Lake, we found a significant decrease in TP concentrations through time. This is consistent with the observation that there has been a steady decline in TP concentrations in **Galla Lake** since 2015 (**Figure 19**). We also determined a significant decrease in TP through time when all sites were combined for **Stewart Lake** (**Table 7**; **Figure 19**). For all other sites in the remaining lakes, there were no significant temporal trends. Therefore, the long-term TP means calculated for these sites is a useful indication of their current status. The following sites are those in which **long-term TP concentrations** ≥ 10 µg/L:

Gibson Lake:	North Lake
	Middle Lake
	South Lake
Gloucester Pool:	Baxter Lake
	Little Go Home Bay
	Big Chute
	Black River Channel
	Upper Little Lake
	Lower Little Lake
Go Home Lake:	Go Home Lake Marina
Myers Lake:	Crisco Bay
Severn River:	Russian Bay
	Wood Bay
	Copp Bay
Six Mile Lake:	Hungry River

TP concentrations by lake stratum

We also compared long-term mean TP concentrations by lake stratum from 2005 to 2023 (**Figure 20**). In this graph, we have highlighted all values that exceeded 10.0 µg/L (GBWQO) in both the epilimnion and hypolimnion. Consistent with earlier observations, hypolimnetic concentrations were generally higher than epilimnetic concentrations. Using data from 95 site-years, we confirmed that the mean hypolimnetic concentration (17.337 µg/L) was significantly higher than the epilimnetic concentration (8.838 µg/L) by a factor of ~2 to 1 (Wilcoxon Signed Rank test; $P<0.0001$). These data again support the hypothesis that internal P loading has been occurring in these lakes.

Trophic State Index Scores

According to Carlson (1977), TSI scores above 40 correspond to mesotrophic lakes, and since lakes in this region are naturally oligotrophic, we should aim to keep TSI(P) scores below 40. Based on long-term means and the 2023 scores (**Table 8**), the following sites are on the watch list:

Gibson Lake:	South Lake
	Wahta
Gloucester Pool:	Black River Channel
	Main Pool
Myers Lake	Crisco Bay
	East Bay
Severn River:	Big Chute
	Copp Bay
	Russian Bay
	Wood Bay
Six Mile Lake:	Six Mile Lake Provincial Park

We also reviewed the annual TSI scores to determine if there were significant trends. **Stewart Lake** was the only lake with significantly decreasing trend (see **Figures 21 and 22**). Recent TSI scores for the three smaller lakes have generally stayed below 40 except for Crisco Bay, which we noted had an extremely high TP concentration during September. Scores for the other water bodies have fluctuated around the threshold of 40, suggesting that they are at the cusp of mesotrophy.

HOTSPOT IDENTIFICATIONS and RECOMMENDATIONS

Fecal indicators

We have assessed the influence of anthropogenic pollutants on the current and past water quality of many focal areas within the eight water bodies. One of the most important findings is that contamination by fecal bacteria (i.e. EC) is currently not a major concern. Two sites, **Wahta** and **Little Lake Centre** exceeded the BAV (single sample ≥ 235 CFU/100 mL) once during the season but these readings were deemed atypical of the sites. Sources of EC at these were likely from waterfowl, but can be confirmed through microbial source tracking (MST). But this would require extensive effort which includes sampling immediately following storm events throughout the summer, confirmation from lab results that EC concentrations > 400 CFU/100 mL, as well as transporting contaminated samples to a lab for genetic analyses within 6 hours of collection. The cost of such analyses can be expensive; we arranged for samples to be analyzed at cost by a retired McMaster Professor ($100/sample) but this option may not be available in the future. Based on the experience from the coastal GB sampling program in 2023, we do not recommend going this route unless repeatedly high measurements have been obtained over the summer at a site, so that reliably contaminated samples can be collected for the MST.

Only three sites in 2023 had geometric mean EC densities that exceeded the GBWQO (see **Table 9**), but not by very much (<20 CFU/100 mL). These were **Wahta**, **White Falls Marina**, and **Go Home Lake Marina**. In addition, analysis of long-term data revealed that there have been significant decreases in EC densities through time for Myers and Stewart Lakes, and about a quarter of the remaining stations monitored (see **Table 5; Figure 18**). **Go Home Lake Marina** was the only site of major concern because it was associated with a significant increasing trend. The long-term geometric mean for **Black River Channel** was 13.46 CFU/100 mL and should be monitored; unfortunately, that was not one of the stations we included in the program during 2023.

RECOMMENDATION: Sample at Wahta, White Falls Marina, Go Home Marina and Black River Channel minimum 5 times during the season. For all other focal areas (see **Table 10**), sample once monthly or twice during the summer. Use Coliplates and volunteer power to measure EC densities

Trophic indicators

Based on seasonal mean concentrations, over half of the sites sampled in 2023 had elevated TP concentrations (**Table 4**). The only lake that was exempt was Galla Lake, but this was also the lake that had been sampled only once. Therefore, it is premature to draw conclusions about Galla Lake. Given the current widespread prevalence of exceedances, as well as historic exceedances (**Figure 19**), we make the following recommendation.

RECOMMENDATION: Sample at all focal areas (see **Table 10**) once between mid June to end of June and then monthly in July, August and September. Arrange to have vertical profiling performed at all deep stations in focal areas (indicated with asterisk in Table 10) and collect hypolimnetic samples for TP analysis during September. In Gloucester Pool, establish a deep station south of Whites Bay where the depth is maximum. Once the Six Mile Lake bathymetric map is available, it may be prudent to adjust the location of sampling stations to ensure that the deeper areas are being sampled.

Some logistical considerations:

Water samples can be collected by volunteers at their convenience and then brought to a central location in Honey Harbour at an appointed time at the end of the season. TP samples do not require any filtration in the field and can be stored samples without preservatives in a -20 freezer (regular freezer in most homes/cottages). These samples can be stored this way for at least 3 months prior to analysis. These samples can be sent to a commercial lab for analysis or if the cost is prohibitively expensive, then an option might be to have these samples analyzed by university students as part of internships or thesis (such as in the current project). The cost of the chemicals and disposables is modest (~$1K).

It is more difficult to have volunteers conduct the September depth profiling. TGB must either supply a multiparameter probe ($5-6K minimum) or rent it (probably $1K each week), and provide training. With a modest grant ($2K) to cover cost of travel and accommodation for the week in September, McMaster would be able to use our equipment to complete the sampling in all lakes at the specified stations. This would provide a great learning opportunity to students and samples will be processed and data will be analyzed at a relatively low cost for the TGB.

FURTHER RESEARCH

Further research projects are being planned to use the large volume of information assembled for this study. One is to relate exceedances of EC and TP to metrics of human disturbance such as land-use modifications near the shoreline, cottage density, road density or boating activity. Thesis students did not have sufficient time in 2023 to properly examine the effect of land use-land cover classes in watersheds, and this is something that will be pursued in the future. We intend to complete the digitization of the Six Mile Lake bathymetric map and will share all GIS databases with the TGB for future use.

In 2023, we carried out a pilot Periplate bioassay program in some of these lakes and there have been very promising results. This method allows naturally occurring algae that grows on rocks and sediment surfaces to incubate on glass slides over a 2-week period. The amount of algal biomass accumulated (based on fluorescence of extracted photosynthetic algal pigments) should indicate short-term nutrient availability at the site. The approach is volunteer-friendly and may be an additional tool for cottagers to use to track nutrient enrichment in their lakes. Based on information we have collected in 2022 and 2023, Periplates data were useful in ordinating sites that agreed with perceived degree of human disturbances (see **Figure 23**). The plan going forward is to use the data from this study to choose additional sites to carry out more bioassays and to develop a scientific way to quantify level of human activities.

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Table 1: Characteristics of lakes associated with three trophic state categories and corresponding range of Trophic State Index (TSI) scores. Modified from the North American Lake Management Society website for volunteer monitoring programs (https://www.nalms.org/secchidipin/monitoring-methods/trophic-state-equations/)

Range of TSI scores	CHL (µg/L)	Secchi (m)	TP (µg/L)	Trophic state	Characteristics
<30	<0.95	8	6	Oligotrophic	Clear water, well oxygenated in the hypolimnion throughout year; hypolimnia of shallower lakes may become anoxic
30-40	0.95-2.6	8-4	6-12		
40-50	2.6-7.3	4-2	12-24	Mesotrophic	Moderately clear, increased probability of hypolimnetic anoxia during summer
50-60	7.3-20	2-1	24-48	Eutrophic	Anoxic hypolimnia, possible colonization of nuisance aquatic macrophytes
60-70	20-56	0.5-1	48-96		Blue-green algal dominance, algal scums and colonization of nuisance aquatic macrophytes

Table 2: List of sites sampled from the first date (Date began) to the last (Date ended) in 2023. N refers to number of sampling times. Duration refers to the number of days between start and end of sampling for each site.

Lake Name	Code	Description of Site	N	Latitude	Longitude	Date began	Date ended	Duration	Volunteers
Galla Lake	GA01	South Bay	1	45.0584510	-79.8533870	08-05-2023	08-05-2023	0	Mark Manna
	GA02	Lot 7	1	45.0615690	-79.8619290	08-05-2023	08-05-2023	0	
	GA03	Landing	2	45.0633940	-79.8654980	08-05-2023	09-06-2023	32	
	GA04	Lot 29	1	45.0641940	-79.8707420	08-05-2023	08-05-2023	0	
Gibson Lake	GB01	South Lake	6	44.9487738	-79.7223460	06-24-2023	09-05-2023	73	Richard Renshaw
	GB02	Landing	6	44.9490360	-79.7326607	06-24-2023	09-05-2023	73	
	GB03	Middle Lake (Control)	7	44.9601830	-79.7475857	06-24-2023	09-05-2023	73	
	GB04	Island Beach	6	44.9618939	-79.7494215	06-24-2023	09-05-2023	73	
	GB05	Hiawartha	6	44.9754837	-79.7600553	06-24-2023	09-05-2023	73	
	GB06	Wahta	6	44.9874760	-79.7673630	06-24-2023	09-05-2023	73	
	GB07	North River Outlet	6	44.9826550	-79.7699950	06-24-2023	09-05-2023	73	
Gloucester Pool	GL01	Big Chute	7	44.8819073	-79.6785430	06-22-2023	08-23-2023	62	Cindy Gilmour, Cat Graydon, Mitra Doherty, Steve Zammit, Michele Sexsmith & Cheryl Elliot Fraser
	GL02	Six Mile Channel	7	44.8820965	-79.6870209	06-22-2023	08-23-2023	62	
	GL03	White Falls	7	44.8769157	-79.7201610	06-22-2023	08-23-2023	62	
	GL04	Little Go Home Bay	7	44.8669490	-79.7380570	06-22-2023	08-23-2023	62	
	GL05	Centre Pool	8	44.8506483	-79.7024830	06-22-2023	09-05-2023	71	
	GL05S	South Centre Pool	1	44.8447116	-79.6975313	09-05-2023	09-05-2023	0	
	GL06	Black River	7	44.8147586	-79.6745816	06-22-2023	08-23-2023	62	
	GL07	Narrows Marina	7	44.8197696	-79.6949190	06-22-2023	08-23-2023	62	
	GL08	Little Lake Centre	8	44.8184350	-79.7123058	06-22-2023	09-05-2023	75	
	GL09	Lock 45	7	44.8042471	-79.7200447	06-22-2023	08-23-2023	62	
	GL10	Dam G	7	44.8044607	-79.7293783	06-22-2023	08-23-2023	62	
	GL11	Baxter Lake	7	44.8848512	-79.7577515	06-22-2023	08-23-2023	62	
	GL12	White Falls Marina	8	44.8760930	-79.7175150	06-22-2023	09-05-2023	75	
	GL13	Prism Island	2	44.8412890	-79.7079160	07-18-2023	08-22-2023	28	
	GL14	Floating Cottages	7	44.8237943	-79.7015657	08-03-2023	08-23-2023	20	

Table 2: (continued)

Lake Name	Code	Description of Site	N	Latitude	Longitude	Date began	Date ended	Duration	Volunteers
Go Home Lake	GH01	Four Seasons Bay	5	44.9983315	-79.8542677	06-24-2023	09-07-2023	75	Simon Edwards, Steve Predko
	GH02	Heart Bay	5	45.0054861	-79.8582605	06-24-2023	09-07-2023	75	
	GH03	Bay of Many Winds	5	45.0058536	-79.8456476	06-24-2023	09-07-2023	75	
	GH04	Pike Bay	3	45.0072800	-79.8329684	06-24-2023	08-19-2023	56	
	GH05	Bay of Many Winds Campsite	3	45.0114865	-79.8435004	06-24-2023	08-19-2023	56	
	GH06	Go Home Lake Marina	5	44.9860830	-79.8263780	06-24-2023	09-07-2023	75	
Myers Lake	ML01	Crisco Bay	7	45.0949163	-79.7492873	06-23-2023	09-06-2023	75	Pam and Cliff Jordan
	ML02	Lake in Swamp	6	45.0955527	-79.7515475	06-23-2023	08-16-2023	54	
	ML03	Creek Outflow	6	45.1021855	-79.7514702	06-23-2023	08-16-2023	54	
	ML04	Heids Bay	6	45.0970198	-79.7424990	06-23-2023	08-16-2023	54	
	ML05	East Side	1	45.0992080	-79.7459960	09-06-2023	09-06-2023	0	
Severn River	SR01	Russian Bay	5	44.8660358	-79.5589226	07-06-2023	09-06-2023	62	Sue Marshall, Debbie Bang, Julia Hale, Carolyn St. Louis
	SR05	Severn Falls	5	44.8737000	-79.6013500	07-06-2023	09-06-2023	62	
	SR06	Woods Bay	4	44.8925350	-79.6135800	07-06-2023	08-16-2023	41	
	SR08	Coulter's Bay	5	44.8986700	-79.6456600	06-25-2023	08-16-2023	52	
	SR09	Copp Bay	5	44.8970079	-79.6565500	06-25-2023	08-16-2023	52	
	SR10	Pretty Channel	5	44.8934856	-79.6727600	06-25-2023	08-16-2023	52	
	SR11	Big Chute	5	44.8867380	-79.6733630	06-25-2023	08-16-2023	52	
Six Mile Lake	SM01	White Falls above dam	5	44.8803520	-79.7229790	07-11-2023	09-06-2023	57	Kristian Graziano
	SM02	Six Mile Lake Marina	5	44.8819380	-79.7381410	07-11-2023	09-06-2023	57	
	SM03	Six Mile Lake Prov Park	5	44.8914240	-79.7518690	07-11-2023	09-06-2023	57	
	SM04	Long Lake	5	44.9114970	-79.7536320	07-11-2023	09-06-2023	57	
	SM05	Wawautosa Govt Dock	5	44.9219830	-79.7644010	07-11-2023	09-06-2023	57	
	SM06	West Crooked Bay	5	44.9329360	-79.7641130	07-11-2023	09-06-2023	57	
	SM07	East Crooked Bay	5	44.9348420	-79.7521920	07-11-2023	09-06-2023	57	
	SM08	Hungry River	5	44.9261660	-79.7984130	07-11-2023	09-06-2023	57	
	SM09	South Hungry Bay	5	44.9141660	-79.7126410	07-11-2023	09-06-2023	57	
	SM10	Lost Channel	5	44.9054530	-79.6983160	07-11-2023	09-06-2023	57	
	SM11	Near the SML Marina?	2	44.8830230	-79.7419810	08-11-2023	09-06-2023	26	

Table 2: (continued)

Lake Name	Code	Description of Site	N	Latitude	Longitude	Date began	Date ended	Duration	Volunteers
	SL01	South Kilty Bay	5	45.1340640	-79.7620880	06-23-2023	08-17-2023	55	
	SL03	North Bay	5	45.1501000	-79.7767830	06-23-2023	08-17-2023	55	
Stewart Lake	SL04	Bear Bay	5	45.1478090	-79.7670160	06-23-2023	08-17-2023	55	Roch Beaulieu
	SL05	Buckeye Bay	5	45.1419810	-79.7563910	06-23-2023	08-17-2023	55	
	SL06	Big Bay	6	45.1418107	-79.7628136	06-23-2023	09-06-2023	75	

Table 3: Comparison of morphometric characteristics for 6 lakes in this study. There were no data for Galla Lake and sites in Severn river. All data except those for Six Mile Lake were determined from digitized maps and calculated in GIS or with formulas (see Methods). The sources for Six Mile Lake were Ministry of Natural Resources, Parry Sound District, Lake Fact Sheet for Six Mile Lake (see Methods).

Characteristics	Galla Lake	Gibson Lake	Gloucester Pool	Go Home Lake	Myers Lake	Six Mile Lake	Stewart Lake
Surface Area (ha)	50.42	264.1	1720.8	730.0	33.7	1475.0	152.0
Volume (10^6 m^3)	7.4	16.0	81.4	195.0	7.5	115.1	9.6
Max Length (km)	1.6	6.7	7.0	5.3	1.1	---	3.1
Max Breadth (km)	0.5	0.8	2.8	1.3	0.6	---	1.1
Mean Depth (m)	14.7	6.1	4.7	26.7	2.2	7.8	6.3
Max Depth (m)	27.0	14.2	35.0	30.0	3.0	48.0	18.3
Lake Perimeter (km)	6.47	26.4	155.4	79.9	4.3	126.5	10.9

Table 4: Mean and standard error (SE) of total phosphorus (TP) concentrations, geometric mean (GM) and arithmetic mean (Mean) and SE of *E. coli* (EC) and GM and Mean of Total Coliform (TC) calculated by site in 8 water bodies sampled from late June to early September in 2023. All exceedances of the GBWQO are highlighted in red.

Lake name	Focal Area	n	TP	SE (TP)	EC_{GM}	EC_{Mean}	SE (EC)	TC_{GM}	TC_{Mean}	SE (TC)
Galla Lake	Landing	4	3.2	2.06	5.53	9.0	4.00	2168	2178	152
	Lot 7	2	6.4	0.00	1.00	1.0	0.00	1638	1638	0
	Lot 29	2	6.4	0.00	2.00	2.0	0.00	920	920	0
	South Bay	2	7.0	0.00	1.00	1.0	0.00	464	464	0
Gibson Lake	Hiawartha	6	**11.6**	1.40	0.76	0.9	0.29	1357	5534	4856
	Island Beach	7	**12.8**	2.18	3.34	**13.7**	9.20	2670	40651	39194
	Landing	6	**18.1**	4.45	0.76	0.8	0.12	4840	251610	248635
	Middle Lake (Control)	7	9.8	0.99	1.28	2.1	1.23	803	997	267
	North River Outlet	6	**11.8**	1.43	1.00	1.4	0.66	649	891	420
	South Lake	8	**13.1**	1.12	1.89	8.3	7.33	2221	8073	5691
	Wahta	8	**11.8**	0.80	**12.73**	**447.1**	435.42	4520	11134	7367
Gloucester Pool	Baxter Lake	8	**12.1**	3.34	1.00	1.0	0.00	1130	1331	376
	Big Chute	7	**15.5**	4.78	0.94	1.7	1.08	2067	2315	513
	Black River	7	**15.0**	1.79	4.35	6.2	2.27	2054	2114	236
	Centre Pool	8	**10.3**	1.80	0.59	0.6	0.13	319	351	70
	Dam G	7	**18.8**	7.57	2.00	2.4	0.68	2432	3161	1277
	Floating Cottages	7	6.8	0.69	2.43	3.5	1.50	2076	2190	400
	Little Go Home Bay	7	**10.4**	5.05	1.15	1.2	0.20	768	912	227
	Little Lake Centre	8	8.9	1.65	4.02	**836.2**	835.45	3279	139843	138926
	Lock 45	7	7.3	1.23	3.94	8.1	3.33	1324	1415	289
	Narrows Marina	7	**10.8**	1.29	0.76	0.8	0.12	1233	1251	102
	Prism Island	2	**11.6**	0.13	1.00	1.0		22832	22832	
	Six Mile Channel	7	6.7	0.75	1.74	7.1	6.23	3810	4892	1584
	South Centre Pool	1	4.9							
	White Falls	7	6.2	0.61	6.75	15.2	9.61	2557	3269	1077
	White Falls Marina	8	**11.0**	0.97	**13.41**	**22.0**	7.49	674	852	263
Go Home Lake	Bay of Many Winds	5	8.3	1.45	1.63	4.3	3.27	2419	13354	12473
	Bay of Many Winds Campsite	3	9.5	1.35	1.71	2.3	1.33	1004	1277	476
	Four Seasons Bay	5	7.5	0.85	2.89	9.8	8.42	539	565	105
	Go Home Lake Marina	5	**11.4**	1.69	**23.52**	**25.8**	6.22	3248	3635	941
	Heart Bay	5	**11.3**	1.61	1.92	7.4	6.54	1776	4892	4040
	Pike Bay	3	8.4	1.15	1.14	1.5	0.76	404	449	137

Table 4 (continued)

Lake name	Focal Area	n	TP	SE (TP)	EC_{GM}	EC_{Mean}	SE (EC)	TC_{GM}	TC_{Mean}	SE (TC)
Myers Lake	Creek Outflow	6	8.1	1.46	1.43	2.0	1.00	457	519	95
	Crisco Bay	7	**10.9**	1.46	1.95	3.8	2.56	161	250	105
	East Side	1	**13.4**							
	Heids Bay	6	7.2	0.44	1.43	2.0	1.00	273	399	202
	Lake in Swamp	6	8.9	1.80	1.43	5.4	4.65	202	258	93
Severn River	Big Chute	6	**14.8**	3.59	2.25	6.8	5.55	2679	3090	830
	Copp Bay	6	**15.7**	6.49	1.00	1.1	0.24	1309	1494	430
	Coulter's Bay	5	**12.2**	3.20	3.11	**13.2**	11.23	2246	2520	542
	Pretty Channel	5	**10.5**	3.48	1.25	5.3	4.68	2351	2482	428
	Russian Bay	7	8.2	1.57	1.66	2.3	0.99	1572	1706	303
	Severn Falls	7	6.6	0.60	3.47	5.1	1.77	2294	2446	356
	Woods Bay	4	7.2	2.03	0.84	0.9	0.13	1399	1777	627
Six Mile Lake	East Crooked Bay	6	9.3	1.00	0.57	0.6	0.10	565	745	276
	Hungry River	5	**11.4**	1.03	0.87	0.9	0.10	2312	2569	614
	Long Lake	6	8.8	1.22	1.15	1.2	0.20	1241	1297	193
	Lost Channel	5	9.9	1.19	1.00	1.4	0.66	924	1373	680
	Near the SML Marina	2	**10.4**	0.33	1.73	2.0	1.00	1628	1629	51
	Six Mile Lake Marina	5	10.0	0.13	1.41	9.5	8.88	1257	1492	432
	Six Mile Lake Prov Park	5	**14.3**	1.75	1.81	8.5	7.63	2168	2977	921
	South Hungry Bay	5	9.9	0.26	2.10	4.1	2.00	661	793	246
	Wawautosa Govt Dock	6	**10.1**	0.94	0.76	0.8	0.12	476	563	157
	West Crooked Bay	5	7.9	0.76	0.76	0.8	0.12	604	823	278
	White Falls above dam	5	8.9	1.00	0.76	0.8	0.12	1437	1885	795
Stewart Lake	Bear Bay	5	**10.5**	0.76	1.08	1.8	1.06	982	1765	907
	Big Bay	6	8.0	1.28	0.66	0.7	0.12	395	462	115
	Buckeye Bay	5	**10.8**	1.66	1.70	2.4	1.17	627	769	240
	North Bay	5	**14.1**	2.07	1.19	1.3	0.25	1157	1228	216
	South Kilty Bay	5	**10.1**	1.26	1.52	3.9	3.03	930	1529	896

Table 5: Mean total phosphorus (TP; µg/L), total nitrogen (TN; mg/L), total nitrate-N (TNN; mg/L), and planktonic chlorophyll-a (CHL; µg/L) concentrations and turbidity (TURB; NTU) calculated by site in 8 water bodies sampled in September 2023.

Lake Name	Focal Area	Date sampled	Stratum	Depth	Secchi	TP	TN	TNN	CHL	TURB
Galla Lake	Landing	09-06-2023	E	3	2.3	3.81	1.20	0.01	1.38	0.96
Gibson Lake	Middle Lake	09-05-2023	E	3	2.1	**11.42**	0.67	0.01	0.26	1.07
		09-05-2023	H	9		**21.18**	0.96	0.02		3.56
	South Lake	09-05-2023	E	3	2.9	**14.68**	0.94	0.01	0.62	1.83
		09-05-2023	H	8		**14.68**	2.04	0.01		1.42
	Wahta	09-05-2023	E	3	2.4	**13.37**	0.67	0.02	0.92	1.00
		09-05-2023	H	8		**18.58**	0.70	0.02		3.00
Gloucester Pool	Baxter Lake	09-05-2023	E	3	4.6				0.12	0.86
		09-05-2023	H	8		9.47	1.31	0.02		2.92
	Centre Pool	09-05-2023	E	3	4.9	**13.37**	1.30	0.01	0.34	3.14
		09-05-2023	H	8		**21.83**	1.32	0.01		0.82
	Little Lake Centre	09-05-2023	E	3	5.5	**10.12**	1.46	0.01	0.31	1.01
	South Centre Pool	09-05-2023	E	3	4.9	4.91	1.39	0.01	1.02	1.57
		09-05-2023	H	13		8.82	1.15	0.02		1.08
Go Home Lake	Bay of Many Winds	09-07-2023	E	6	3.8	6.21	0.48	0.02	0.55	1.13
		09-07-2023	H	16		6.21	0.97	0.10		1.52
	Four Seasons Bay	09-07-2023	E	7	4.5	6.86	0.70	0.02	0.33	0.90
		09-07-2023	H	16		**12.72**	1.45	0.12		1.05
	Go Home Lake Marina	09-07-2023	E	6	3.1	7.52	1.28	0.02	0.33	1.14
	Heart Bay	09-07-2023	E	3	3.7	**12.07**	0.92	0.02	0.45	1.41
		09-07-2023	H	8		4.91	0.85	0.03		1.22
Myers Lake	East Side	09-06-2023	E	2	2.9	**13.37**	2.09	0.01	0.22	0.78
	South Side	09-06-2023	E	3	3.0	**31.60**	0.71	0.01	0.26	1.15
Severn River	Big Chute	09-08-2023	E	4	4.7	**15.33**	1.91	0.02	0.28	0.84
	Buckskin Island	09-06-2023	E	5	4.3	9.47	1.40	0.01	0.34	0.89
	Copp Bay	09-08-2023	E	5	4.4	**10.12**	1.31	0.02	0.30	0.93
	Russian Bay	09-06-2023	E	5	3.2	**12.07**	4.74	0.01	0.93	1.47
Six Mile Lake	East Crooked Bay	09-07-2023	E	5	5.1	**14.02**	0.75	0.02	0.05	0.56
		09-07-2023	H	15		**12.07**	0.67	0.01		1.68
	Long Lake	09-07-2023	E	3	4.1	**11.42**	0.91	0.02	0.05	0.82
		09-07-2023	H	15		**18.58**	0.74	0.01		5.37
	Wawautosa Govt Dock	09-07-2023	E	5	3.5	**14.68**	0.91	0.02	0.60	0.79
		09-07-2023	H	13		**16.63**	0.77	0.04		0.78
Stewart Lake	Big Bay	09-06-2023	E	3	4.9	4.26	1.00	0.01	0.15	0.66
		09-06-2023	H	13		6.21	1.20	0.04		2.37

Table 6: Long-term geometric mean *E. coli* densities (EC; CFU/100 mL) calculated for lakes by focal areas for all available years (see Figure 3). Prob>|τ| < 0.05 indicates a significant decrease (-ve Kendall's τ; green) or increase (+ve Kendall's τ; red) in concentrations through time. EC density that did not meet the GBWQO is highlighted.

Water body	Focal Area	n	EC	Site-years	Kendall's τ	Prob>|τ|
Galla Lake	Cottages (locations	15	4.40	---	---	---
	Landing	45	2.25	10	---	---
	Lot 7	38	1.92	8	---	---
	Lot 29	38	2.39	8	---	---
	South Bay	32	2.46	7	---	---
	All sites (excludes East Bay)	168	2.36	36	-0.1925	0.1116
Gibson Lake	North Lake	216	2.50	18	-0.3168	0.0683
	Middle Lake	198	2.01	18	-0.2508	0.1490
	South Lake	198	**2.13**	18	**-0.3697**	**0.0334**
Gloucester Pool	Baxter Lake	20	1.95	3	-0.3333	0.6015
	Big Chute	86	3.07	18	-0.2098	0.2251
	Black River Channel	61	**13.46**	18	-0.3072	0.0750
	Floating Cottages	7	2.43	1	---	---
	Little Go Home Bay	73	3.11	20	-0.2642	0.1096
	Lower Little Lake	122	**5.64**	20	**-0.2420**	**0.0003**
	MacLean Lake	36	3.43	9	---	---
	Main Pool	108	1.75	20	-0.2878	0.1007
	The Narrows	68	**3.25**	20	**-0.4022**	**0.0145**
	Upper Little Lake*	69	3.01	20	-0.1789	0.2798
	White Falls Bay	32	3.46	11	+0.2455	0.3046
	White Falls Marina	12	9.79	2	--	--
	White's Bay	72	3.17	8	-0.5000	0.0833
Go Home Bay Lake	Bay of Many Winds	94	1.89	14	+0.0769	0.7016
	Bay of Many Winds Campsite	92	1.91	14	-0.0778	0.7007
	Four Seasons Bay	94	2.44	14	+0.3187	0.1124
	Go Home Lake Marina	94	**9.24**	14	**+0.4725**	**0.0186**
	Heart Bay	95	2.77	14	-0.0884	0.6609
	Pike Bay	92	1.74	14	-0.2210	0.2728
Myers Lake	East Bay	50	3.45	6	---	---
	North Bay	31	2.26	5	---	---
	South Bay	69	3.08	6	---	---
	All sites	150	**3.00**	6	**-0.8667**	**0.0146**

Table 6 continued

Water body	Focal Area	n	EC	Site-years	Kendall's τ	Prob>|τ|
Severn River	Big Chute	57	2.23	11	-0.2000	0.3918
	Cherry Creek	93	2.67	16	-0.3500	0.0586
	Control	74	1.76	14	-0.1326	0.5106
	Copp Bay	92	1.83	17	-0.3259	0.0694
	Coulter's Bay	91	2.61	17	-0.0735	0.6804
	Hungarian Bay	79	**2.53**	15	**-0.4095**	**0.0333**
	Lost Channel	86	**2.38**	16	**-0.5833**	**0.0016**
	Pretty Channel	68	1.79	13	-0.1868	0.3853
	Russian Bay	93	1.87	17	-0.0735	0.6804
	Severn Falls	93	2.12	17	-0.0441	0.8048
	Woods Bay	95	1.95	17	-0.3495	0.0521
Six Mile Lake	Crooked Bay	222	**2.14**	19	**-0.6765**	**0.0002**
	Hungry River	120	**2.20**	19	**-0.5333**	**0.0040**
	Long Lake	52	2.30	19	-0.3596	0.1508
	Main Lake	213	**2.05**	19	**-0.5588**	**0.0017**
	Provincial Park	270	**2.66**	19	**-0.6324**	**0.0004**
Stewart Lake	Bear Bay	15	1.78	3	-1.000	0.1172
	Big Bay	35	**1.28**	4	**-1.000**	**0.0415**
	Cottages	119	2.44	9	-0.3333	0.2109
	Kilty Bay Beaver Dam	26	2.70	5	-0.4000	0.3272
	Near Town	53	2.59	7	-0.0476	0.8806
	North	38	**1.66**	7	**-0.6831**	**0.0334**
	South Bay	28	2.22	6	-0.6000	0.0909
	All sites	314	**2.18**	11	**-0.4909**	**0.0356**

* Includes data from Little Lake Centre

Table 7: Long-term mean±SE epilimnetic total phosphorus (TP; µg/L) concentrations in focal areas of inland lakes (see Figure 3) collected during September of each year. Statistically significant (P<0.05) decrease (negative Kendall's τ; green) or increase (positive Kendall's τ; red) in concentrations through time are bolded. Dashes indicate that no correlation could be run because of insufficient data. All bolded TP concentrations indicate they did not meet the GBWQO (<10 µg/L).

Lake name	Focal Area	Site-years	TP	Kendall's τ	Prob>|τ|
Galla Lake	East Bay	14	7.47 ± 1.027	---	---
	Lot 7	14	7.23 ± 1.257	---	---
	Outlet Bay	14	6.93 ± 0.964	---	---
	All sites (including Landing)	45	7.034 ± 0.595	**-0.2982**	**0.0060**
Gibson Lake	North Lake	24	**11.29 ± 1.061**	+0.0969	0.5336
	Middle Lake	24	**11.6 ± 1.031**	-0.0650	0.6709
	South Lake	24	**11.56 ± 0.961**	+0.0243	0.8734
Gloucester Pool	Baxter Lake	16	**10.22 ± 1.477**	-0.0481	0.8041
	Little Go Home Bay	21	**10.00 ± 1.153**	+0.0535	07386
	Big Chute	34	**11.162 ± 0.903**	-0.1570	0.2082
	White Falls Bay	18	9.49 ± 0.690	+0.1056	0.5434
	Main Pool	23	8.77± 0.650	+0.2667	0.0800
	Black River Channel	21	**13.17 ± 1.338**	+0.1676	0.3117
	Upper Little Lake	22	**11.26 ± 1.381**	+0.2539	0.1058
	Lower Little Lake	20	**10.46± 0.988**	+0.1035	0.5343
Go Home Bay Lake	Pike Bay	3	8.38 ± 1.148	---	---
	Bay of Many Winds	22	8.24 ± 0.922	+0.1432	0.3626
	Heart Bay	22	9.63 ± 0.963	+0.0489	0.7547
	Four Seasons Bay	22	7.61 ± 0.658	-0.0133	0.9321
	Bay of Many Winds Campsite	3	9.47 ± 1.355	---	---
	Go Home Lake Marina	22	**10.0 ± 0.928**	-0.0311	0.8424
Myers	North Bay	5	5.90 ± 1.503	---	---
	Crisco Bay	6	**10.55 ± 4.377**	---	---
	East Bay	5	6.30 ± 2.087	---	---
	All Sites	16	7.77 ± 1.805	+0.1475	0.4586

Table 7 continued

Lake name	Focal Area	Site-years	TP	Kendall's τ	Prob>|τ|
Severn River	Russian Bay	19	**12.82 ± 1.116**	-0.0595	0.7254
	Wood Bay	16	**12.77 ± 1.174**	+0.0336	0.8568
	Lost Channel	16	9.08 ± 1.258	-0.0251	0.8925
	Copp Bay	17	**12.91 ± 1.010**	-0.1402	0.4334
	All sites	68	**11.95 ± 0.590**	-0.0448	0.5992
Six Mile Lake	Crooked Bay	47	8.09 ± 0.543	+0.0846	0.4835
	Hungry River	30	**10.39 ± 1.114**	+0.1133	0.4136
	Long Lake	30	7.04 ± 0.744	+01864	0.1914
	Main Lake	55	8.84 ± 0.739	-0.0486	0.6315
	Provincial Park	31	9.77 ± 1.107	+0.0823	0.5448
Stewart Lake	Bear Bay	10	6.69 ± 0.844	---	---
	Big Bay	11	6.71 ± 1.254	---	---
	North Bay	10	6.97 ± 1.330	---	---
	South Kilty Bay	10	6.29 ± 0.969	---	---
	All Sites	41	6.67 ± 0.543	**-0.2333**	**0.0396**

Table 8: Long-term mean (2005-2023; LT mean) Trophic State Index (TSI(TP)) scores for stations in the eight water bodies.

Water body	Focal Area	# years	LT Mean	2023
Galla Lake	Whole lake	11	28.39	
	Landing	1	--	29.48
Gibson Lake	Island Beach	1	--	38.42
	Middle Lake	18	38.23	39.27
	North Lake	17	37.46	--
	South Lake	18	38.20	**40.65**
	Wahta	1	--	**40.41**
Gloucester Pool	Baxter Lake	16	35.22	--
	Big Chute	17	36.70	--
	Black River Channel	17	**40.53**	--
	Little Go Home Bay	17	36.59	--
	Little Lake Centre	1	--	37.52
	Lower Little Lake	16	36.54	--
	Main Pool	18	35.71	**41.54**
	South Centre Pool	1	--	27.10
	Upper Little Lake	17	37.90	--
	White Falls Bay	17	35.38	--
	White Falls Marina	1	--	39.27
Go Home Lake	Bay of Many Winds	18	32.14	27.77
	Four Seasons Bay	18	31.41	29.52
	Go Home Lake Marina	18	34.42	39.24
	Heart Bay	18	33.94	34.89
Myers Lake	Crisco Bay	6	32.86	**53.94**
	East Bay	5	26.99	**41.54**
	North Bay	5	26.27	--
Severn River	Big Chute	1	--	**43.51**
	Buckskin Island	1	--	36.57
	Copp Bay	17	**40.23**	37.52
	Lost Channel	16	33.68	--
	Russian Bay	17	**40.49**	37.05
	Severn Falls	1	--	35.54
	Wood Bay	16	**40.09**	--
Six Mile Lake	Crooked Bay	19	31.75	36.64
	Hungry River	19	35.59	38.40
	Long Lake	19	29.74	34.88
	Lost Channel	1	--	28.90
	Main Lake	18	32.11	--
	Near the SML Marina	1	--	37.52

Table 8 (continued)

Water body	Focal Area	# years	LT Mean	2023
Six Mile Lake (continued)	Six Mile Lake Provincial Park	19	33.96	**47.73**
	Six Mile Lake Marina	1	--	36.57
	Wawautosa Govt Dock	1	--	39.21
	White Falls above dam	1	--	34.43
Stewart Lake	Bear Bay	10	30.12	--
	Big Bay	11	28.34	25.05
	North Bay	10	28.82	--
	South Kilty Bay	10	28.02	--

Table 9: Summary of exceedances of water-quality objectives and/or indicated symptoms of eutrophication based on 2023 data. EC_{BAV} = single sample ≥235 CFU/100 mL; EC_{GBWQO}=seasonal geometric mean EC ≥10 CFU/100 mL; TP_{15} = seasonal mean [TP] ≥15µg/L; TP_{20} = single [TP] ≥20µg/L; TP_{Hypo} = [TP] in hypolimnion ≥20µg/L; TSI= mean TSI scores ≥40 based on long-term mean and current conditions; HYP = [DO] in September <3 mg/L); ANOX = [DO] in September <1 mg/L.

Lake name	Focal Area	EC_{BAV}	EC_{GBWQO}	TP_{15}	TP_{20}	TP_{Hypo}	TSI	HYP/ANOX
Gibson Lake	Wahta	X	X				X	ANOX
	Middle Lake					X		ANOX
	South Lake						X	
	Landing			X				ANOX
Gloucester Pool	White Falls Marina		X					
	Big Chute				X			
	Little Go Home Bay				X			
	Centre Pool					X	X	ANOX
	Little Lake Centre	X						
	Black River Channel						X	
	Dam G			X	X			
Go Home Lake	Go Home Lake Marina		X					
Myers Lake	East Bay						X	
	Crisco Bay				X		X	
Severn River	Big Chute			X	X		X	
	Copp Bay				X		X	
	Wood Bay						X	
	Russian Bay						X	
Six Mile Lake	Government Dock							HYP
	Crooked Bay							HYP
	Long Lake							HYP
	Six Mile Lake Provincial Park				X		X	
Stewart Lake	Whole lake							HYP

Table 10. Proposed location of long-term sites in inland lakes. Asterisk indicates it should be sampled for DO and temperature at meter intervals in September.

Lake name	Site name	Latitude	Longitude
Galla Lake	Lot 29	45.0641940	-79.8707420
	Lot 7	45.0615690	-79.8619290
	South Bay*	45.0584510	-79.8533870
Gibson Lake	North Lake*	44.9845141	-79.7675889
	Middle Lake*	44.9613672	-79.7475634
	South Lake*	44.9495160	-79.7277733
Gloucester Pool	Baxter Lake*	44.8768081	-79.7486812
	Big Chute	44.8819073	-79.6785430
	White's Bay	44.8752132	-79.7186595
	White Falls Marina	44.8760930	-79.7175150
	*New site in deep location**	44.8672600	-79.7132660
	Little Go Home Bay	44.8623550	-79.7342900
	Centre Pool*	44.8525323	-79.7073787
	MacLean Lake	44.8183580	-79.6529640
	Black River Channel	44.8148448	-79.6748843
	The Narrows	44.8197664	-79.6950960
	Upper Little Lake*	44.8231290	-79.7081114
	Lower Little Lake*	44.8053905	-79.7248365
Go Home Lake	Bay Many Winds Campsite	45.0114865	-79.8435004
	Bay of Many Winds*	45.0058536	-79.8456476
	Pike Bay*	45.0072800	-79.8329684
	Heart Bay*	45.0054861	-79.8582605
	Four Seasons Bay*	44.9983315	-79.8542677
	Go Home Lake Marina*	44.9860830	-79.8263780
Myers Lake	North Bay	45.1021855	-79.7514702
	East Bay	45.0970198	-79.7424990
	Crisco Bay*	45.0952350	-79.7504170
Severn River	Russian Bay*	44.8660358	-79.5589226
	Cherry Creek	44.8716070	-79.5884030
	Severn Falls	44.8737000	-79.6013500
	Woods Bay*	44.8929100	-79.6135800
	Coulter's Bay*	44.8986700	-79.6456600
	Copp Bay*	44.8970079	-79.6565500
	Pretty Channel	44.8934856	-79.6727600
Six Mile Lake	Crooked Bay*	44.9310781	-79.7566840
	Long Lake*	44.9092877	-79.7517710
	Provincial Park*	44.8877935	-79.7442860
	Main Lake*	44.8982147	-79.7170530
	Hungry River*	44.9176040	-79.7160790
Stewart Lake	North Bay	45.1501000	-79.7767830
	Bear Bay	45.1478090	-79.7670160
	Buckeye Bay	45.1419810	-79.7563910
	Big Bay*	45.1419510	-79.7618380
	South Kilty	45.1340640	-79.7620880

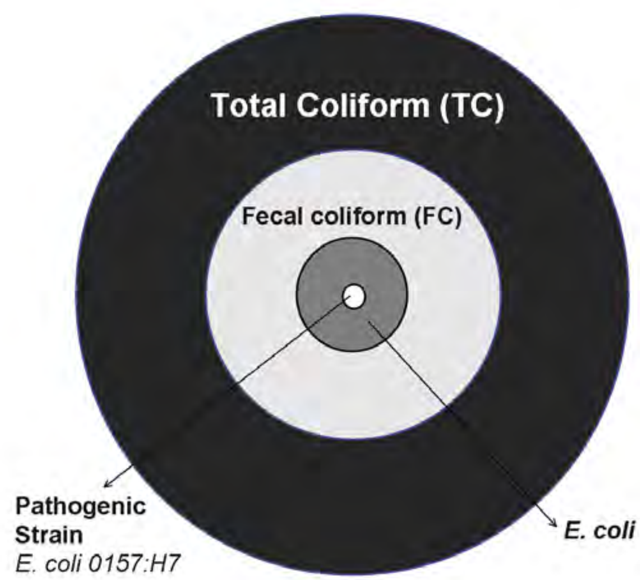


Figure 1: Graphic representation showing the nested relationship among different groups of coliform bacteria. Pathogenic strains of *E. coli* is a subset of *E. coli*, which is a subset of Fecal Coliform, which is a subset of Total Coliform.

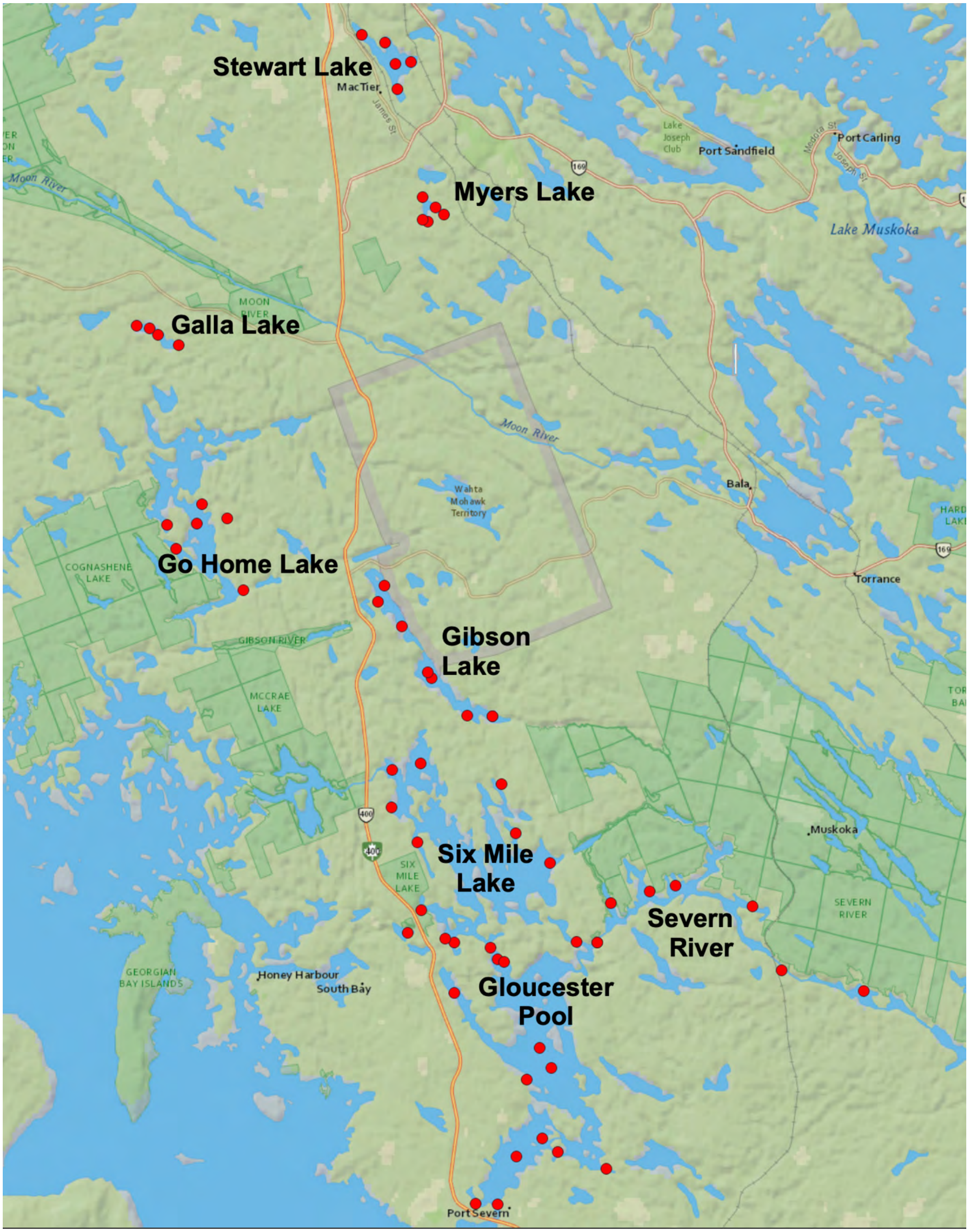


Figure 2: Location of sites where samples were collected by volunteers in the eight water bodies during 2023.

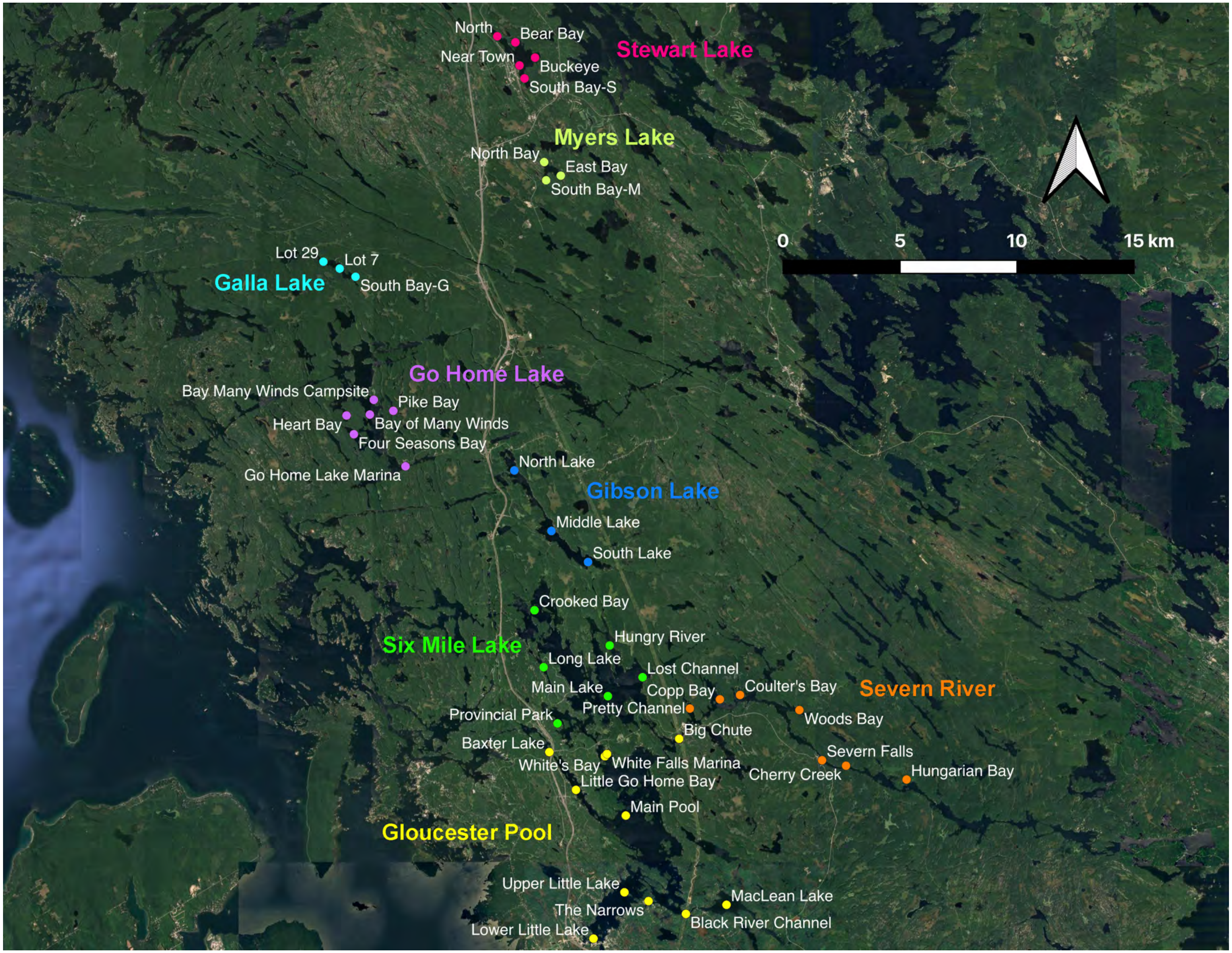


Figure 3: Location of focal areas in each lake used to assess long-term (2001 to 2023) trends in EC and TP in this study.

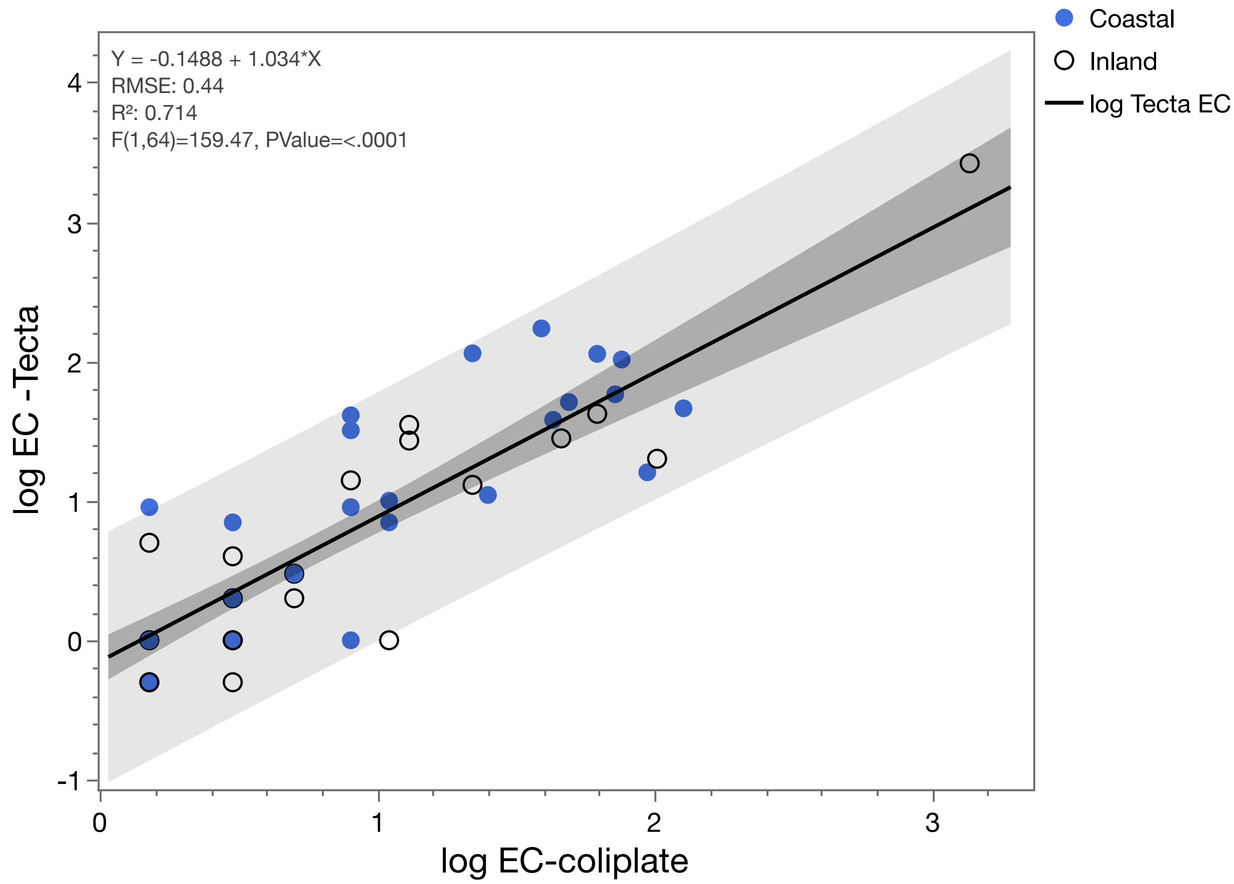


Figure 4: Relationship between $\log_{10}$ EC measured with Tecta B16 and $\log_{10}$ EC measured with Coliplates for parallel water samples collected from nearshore regions of the Coastal zone (Coastal) of the Township of Georgian Bay and in Go Home Lake (Inland).

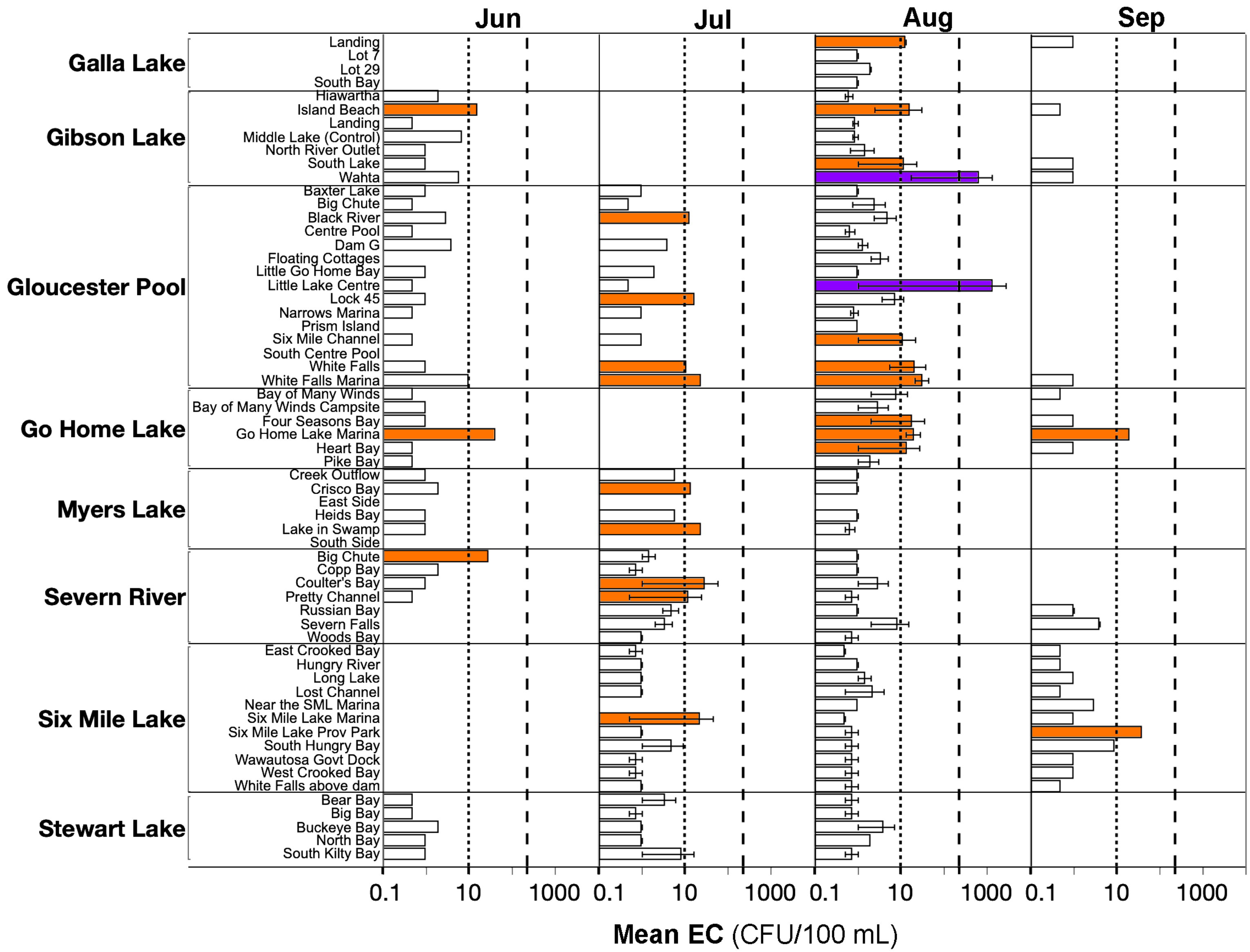


Figure 5: 2023 monthly mean±SE *E. coli* (EC) densities measured at sampling stations in the eight water bodies. The dotted black lines correspond to 10 CFU/100 mL (Georgian Bay Water Quality Objective) while the dotted red lines correspond to the Beach Action Value of 235 CFU/100 mL. Orange bars indicate means have exceeded the GBWQO whereas purple bars indicate they have exceeded the BAV.

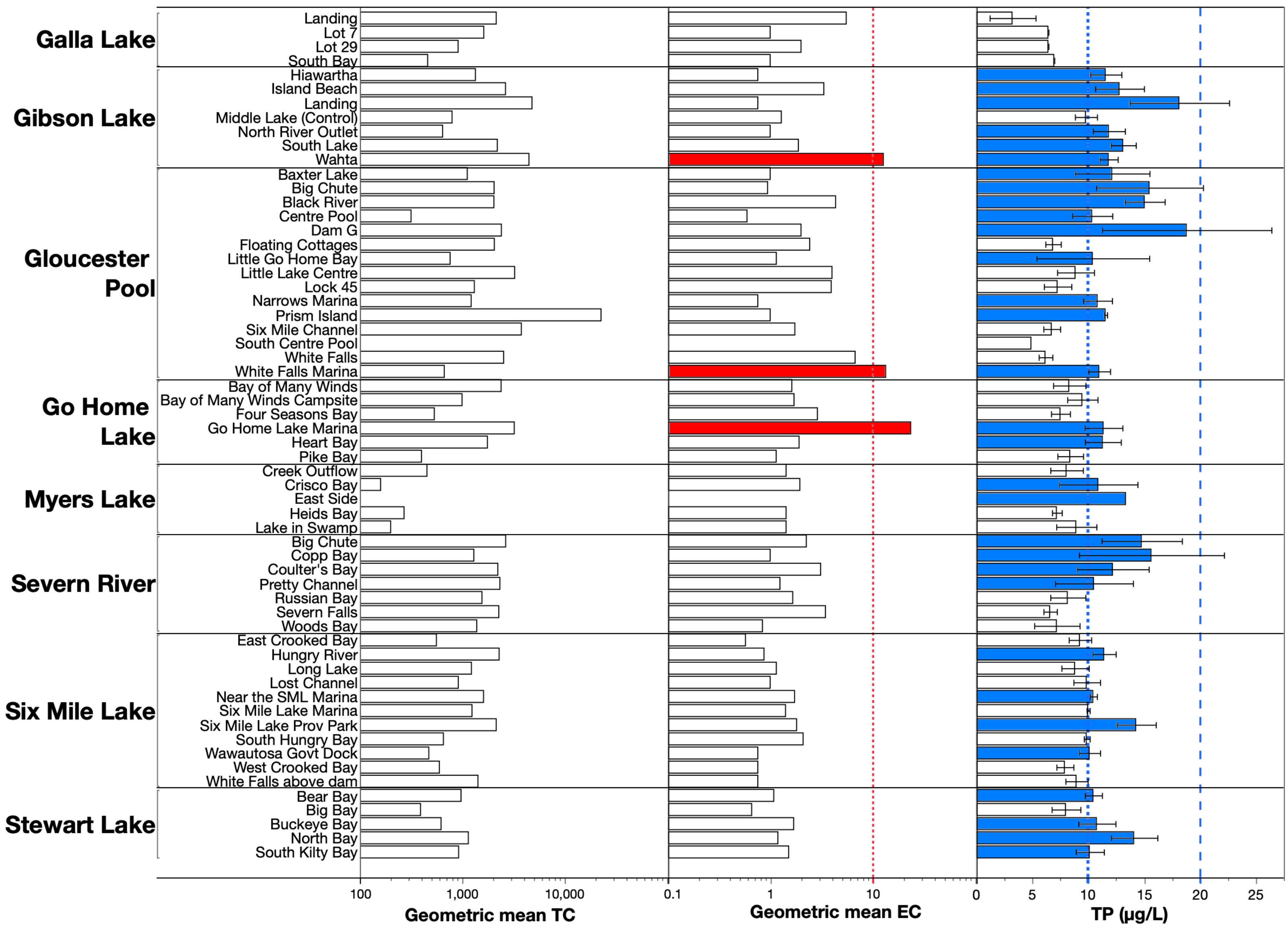


Figure 6: 2023 geometric mean Total Coliform (TC), geometric mean *E. coli* (EC)densities, and mean±SE total phosphorus (TP) concentrations measured at sampling stations in the eight water bodies in this study. Short dashed red and blue lines indicate the GBWQO for EC and TP, respectively. Long dashed blue line indicates the PWQO for TP. All solid bars correspond to sites that exceeded the GBWQO.

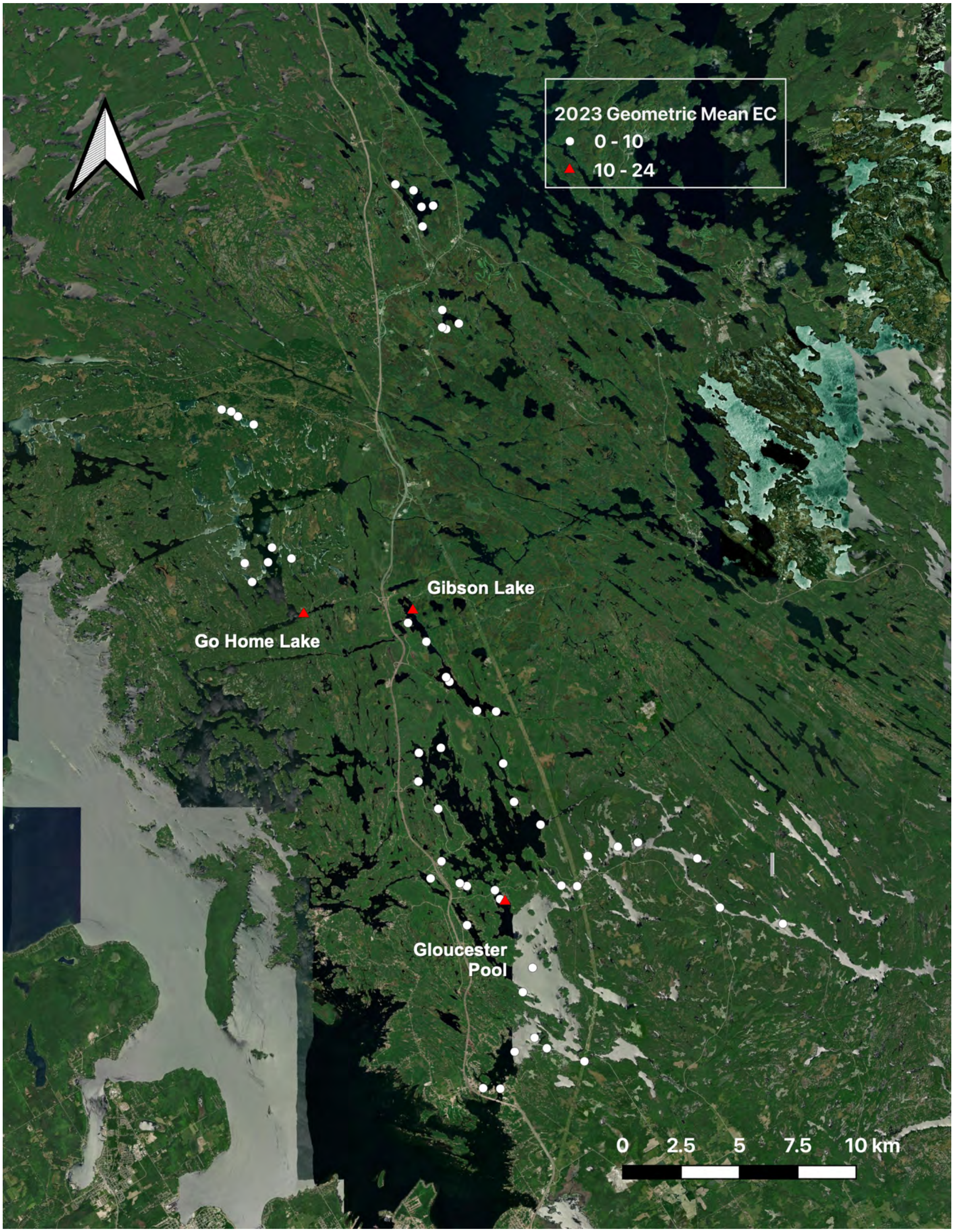


Figure 7: Distribution of geometric mean EC densities in samples collected during 2023 in all eight water bodies. Names of lakes associated with mean densities exceeding the GBWQO are provided.

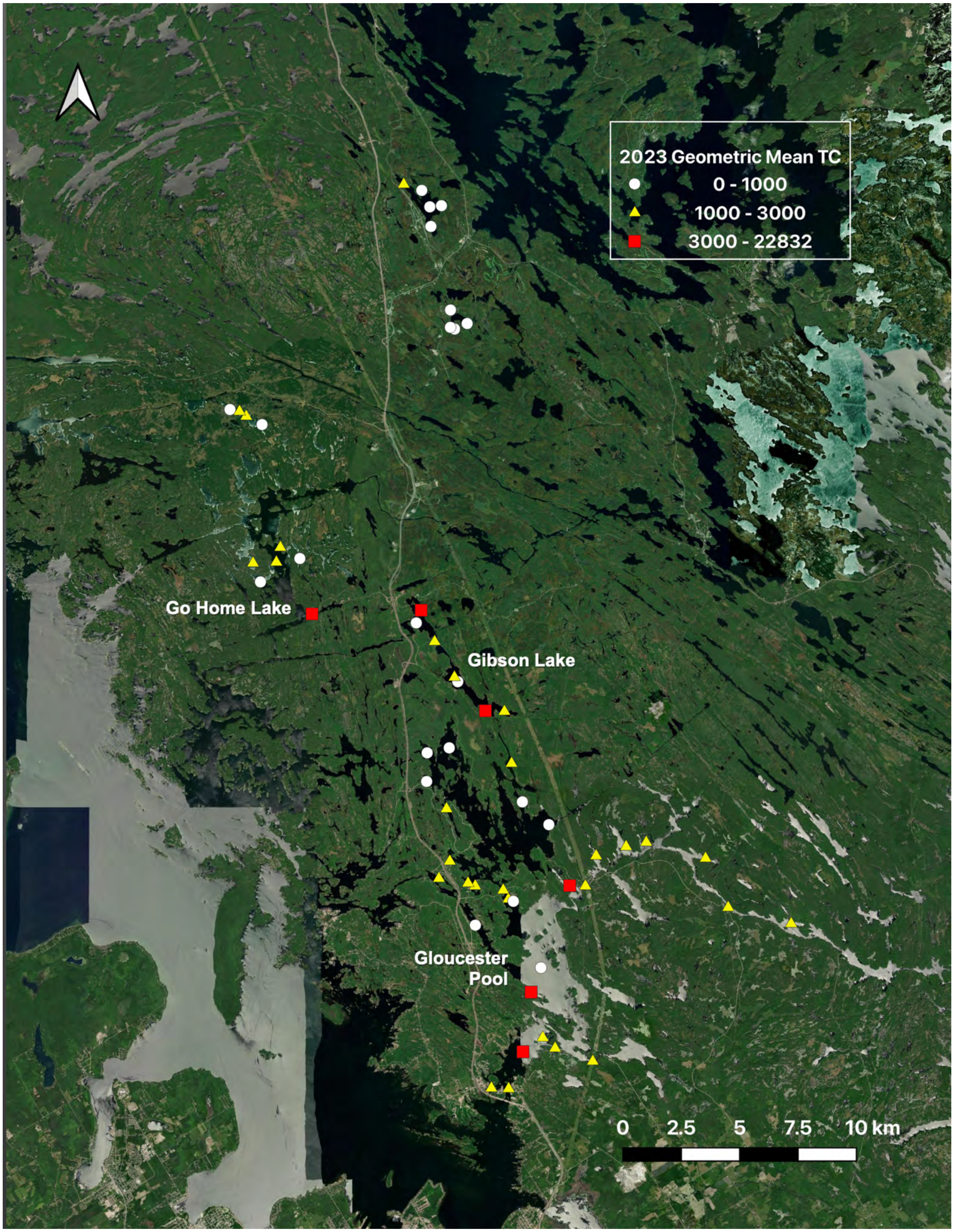


Figure 8: Distribution of geometric mean TC densities in samples collected during 2023 in all eight water bodies. Names of lakes associated with mean densities exceeding 3,000 CFU/100 mL are provided.

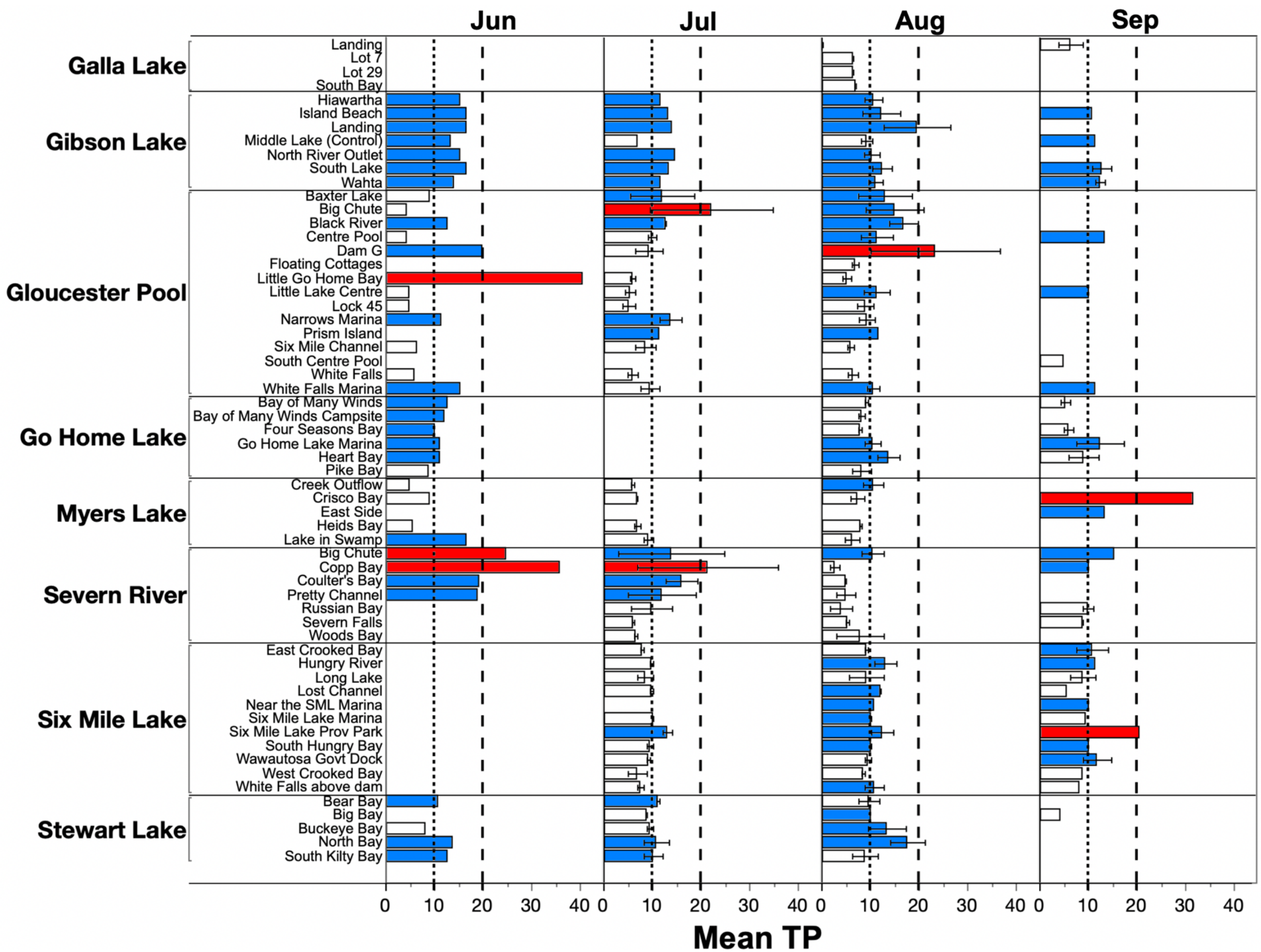


Figure 9: Mean±SE monthly total phosphorus (TP) concentrations at sampling stations during 2023 in the eight water bodies. Short-dashed and long-dashed lines correspond to the GBWQO (10 µg/L) and the PWQO (20 µg/L), respectively. Blue bars indicate means have exceeded the GBWQO whereas red bars indicate they have exceeded the PWQO.

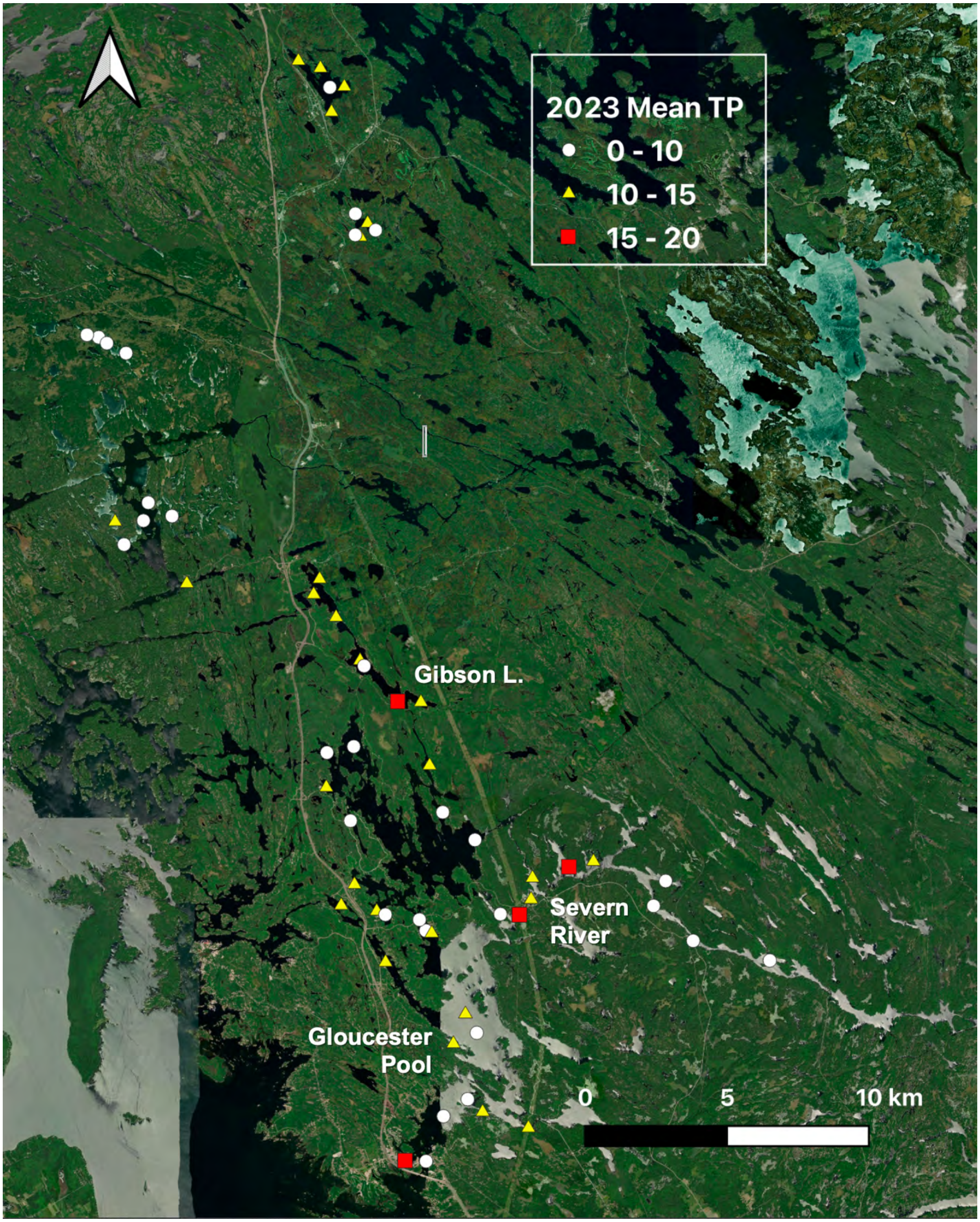


Figure 10: Distribution of mean TP concentrations (µg/L) in samples collected during 2023 in all water bodies. Labelled water bodies are associated with elevated TP concentration.

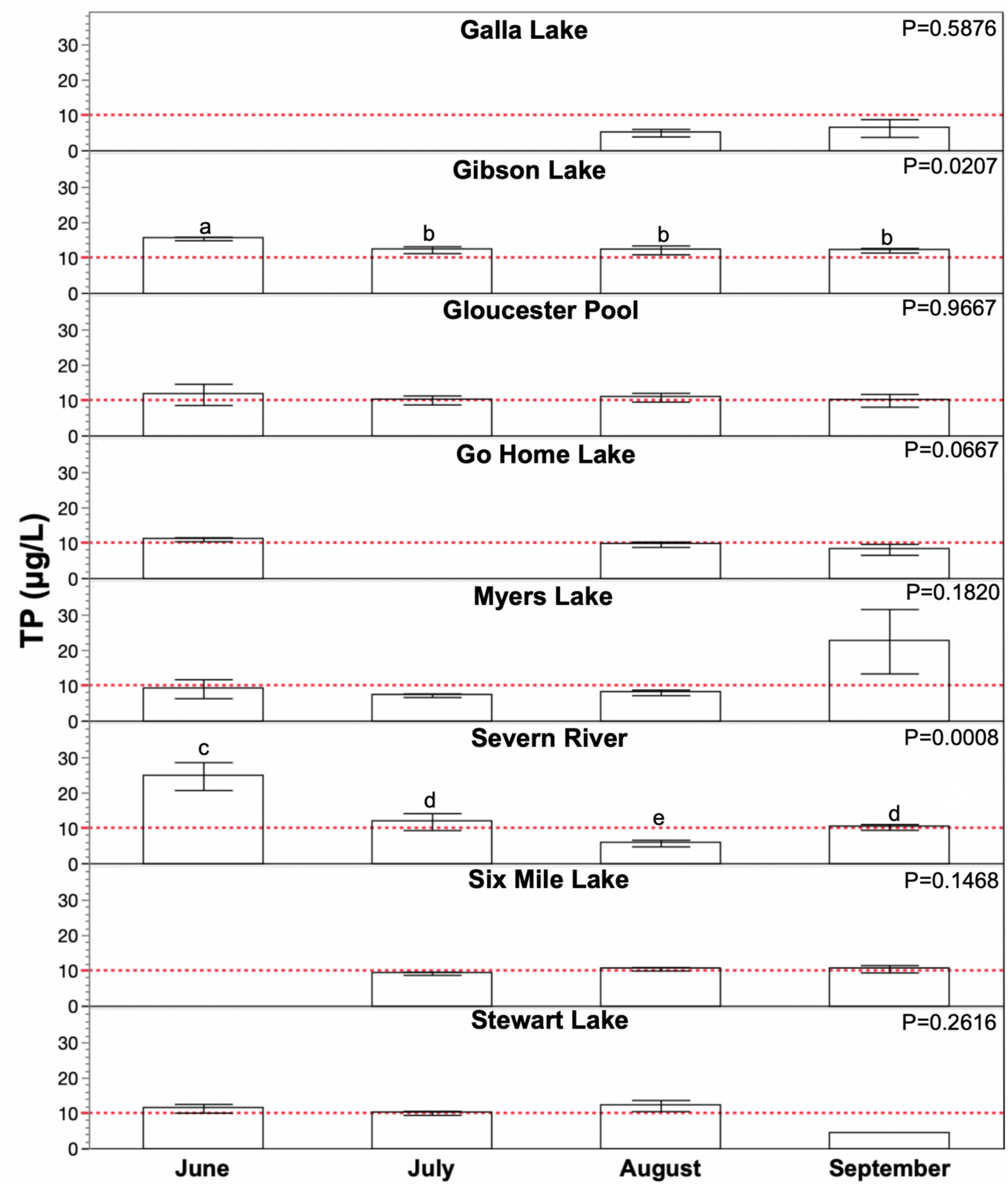


Figure 11: Mean±SE monthly concentrations of total phosphorus (TP) measured in the eight water bodies during 2023. P-values correspond to Kruskal-Wallis Test to detect significant ($P<0.05$) differences among months. Similar letters in panels corresponding to Gibson Lake and Severn River indicate no significant differences in pairwise comparisons.

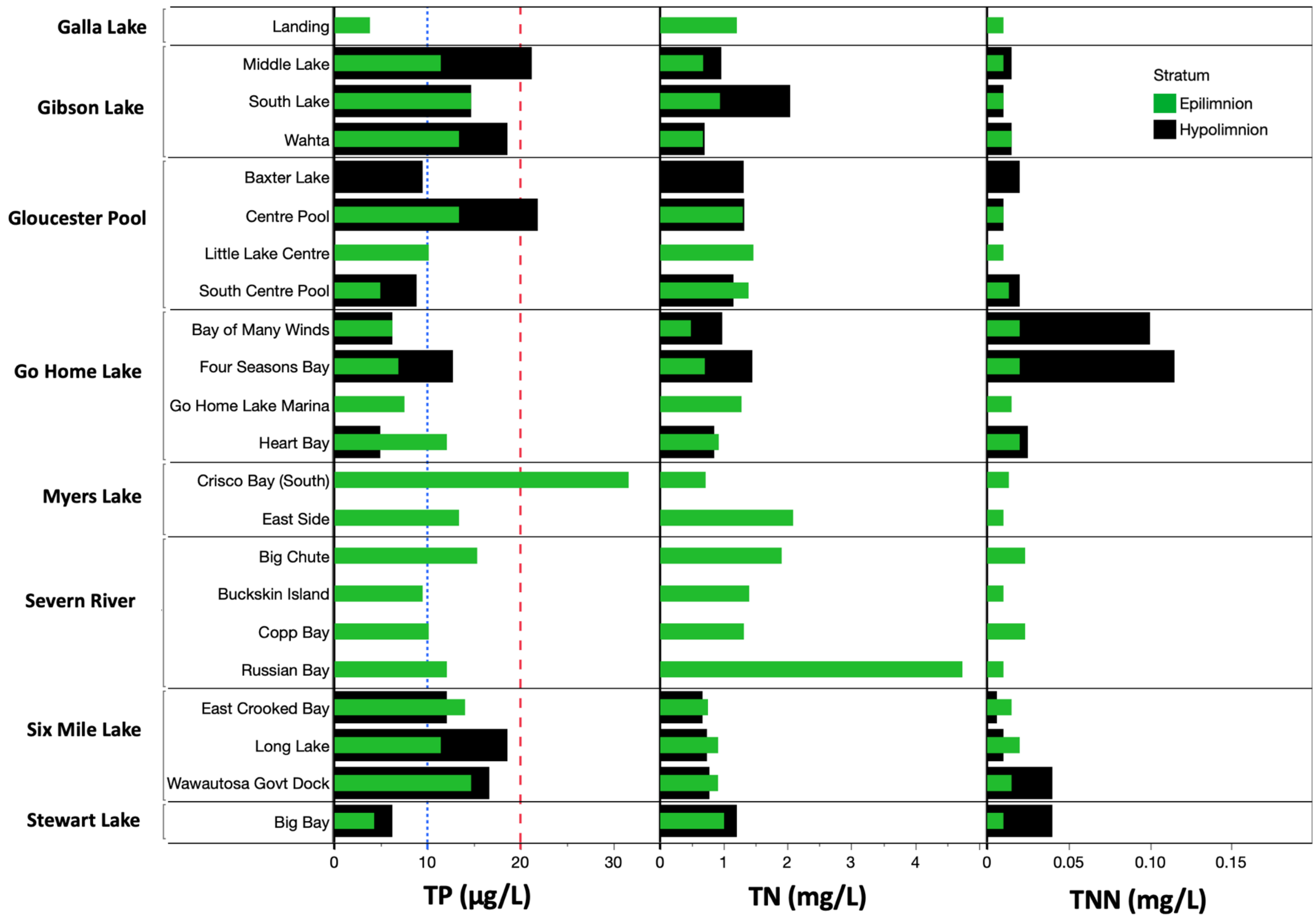


Figure 12: Total phosphorus (TP), total nitrogen (TN), and total nitrate-N (TNN) concentrations in epilimnetic and hypolimnetic samples collected in the eight water bodies during September 2023. No hypolimnetic samples were taken when the site was too shallow to be thermally stratified.

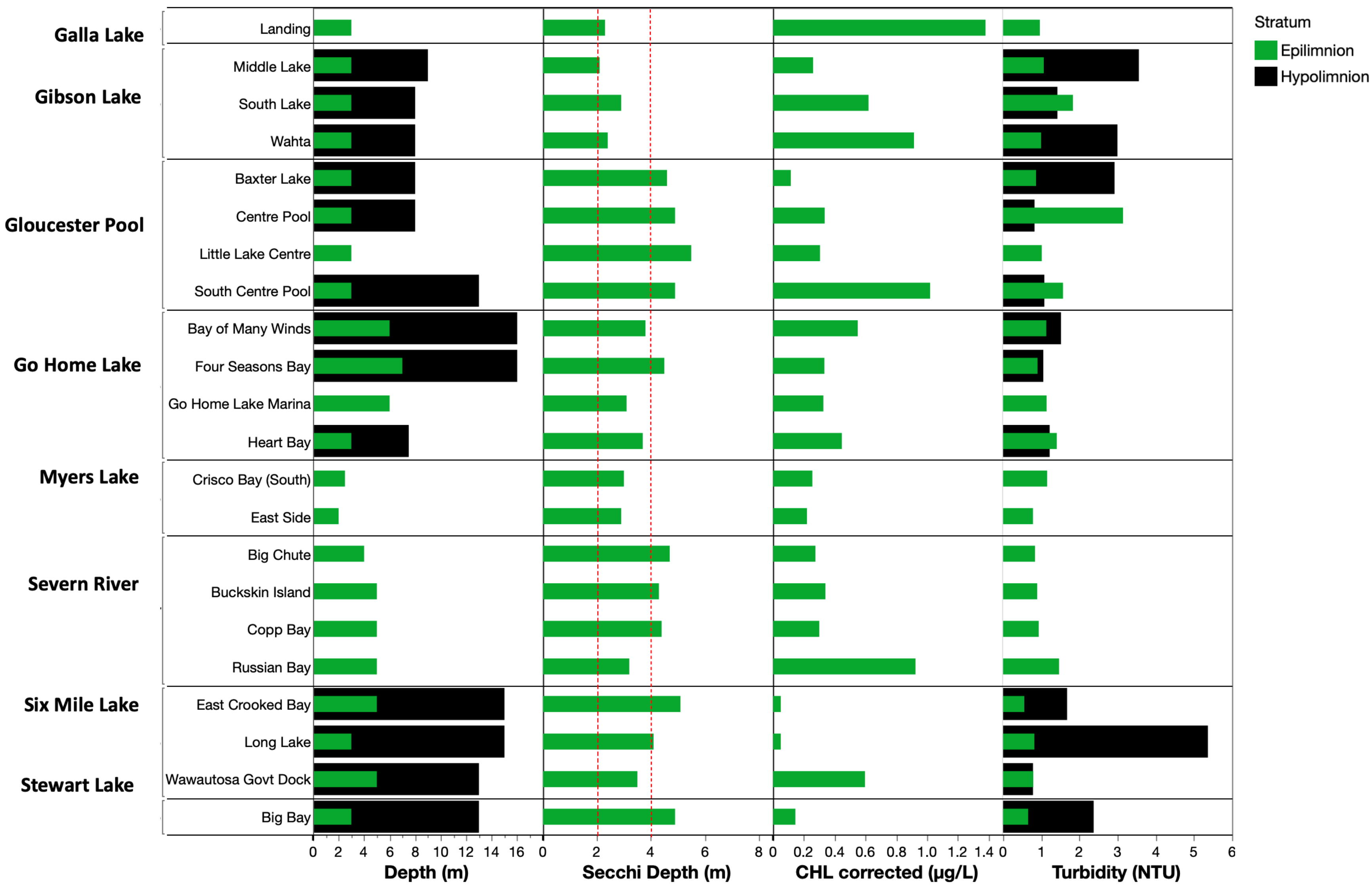


Figure 13: Sampling depths, Secchi depth transparency, planktonic chlorophyll (CHL) and water turbidity measured in the epilimnion and hypolimnion of sites sampled in the eight water bodies during September 2023. No hypolimnetic samples for turbidity were taken when the site was too shallow to be thermally stratified. Secchi depths between the 2 dashed lines indicate that the site is mesotrophic; values >4 indicate they are oligotrophic.

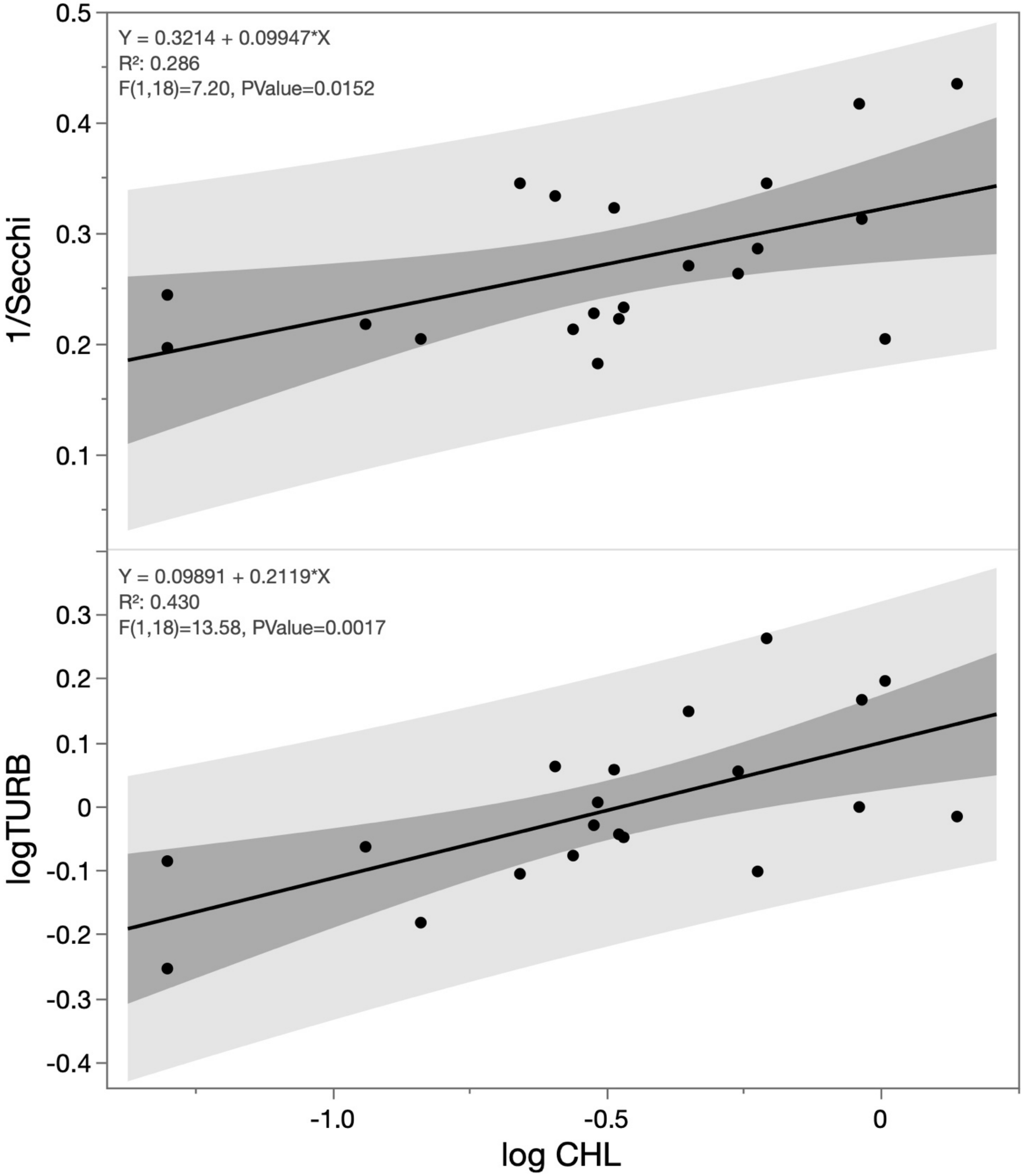


Figure 14: Relationship between Secchi depth (m) and $\log_{10}$ planktonic chlorophyll (CHL) for all sites sampled in September, 2023.

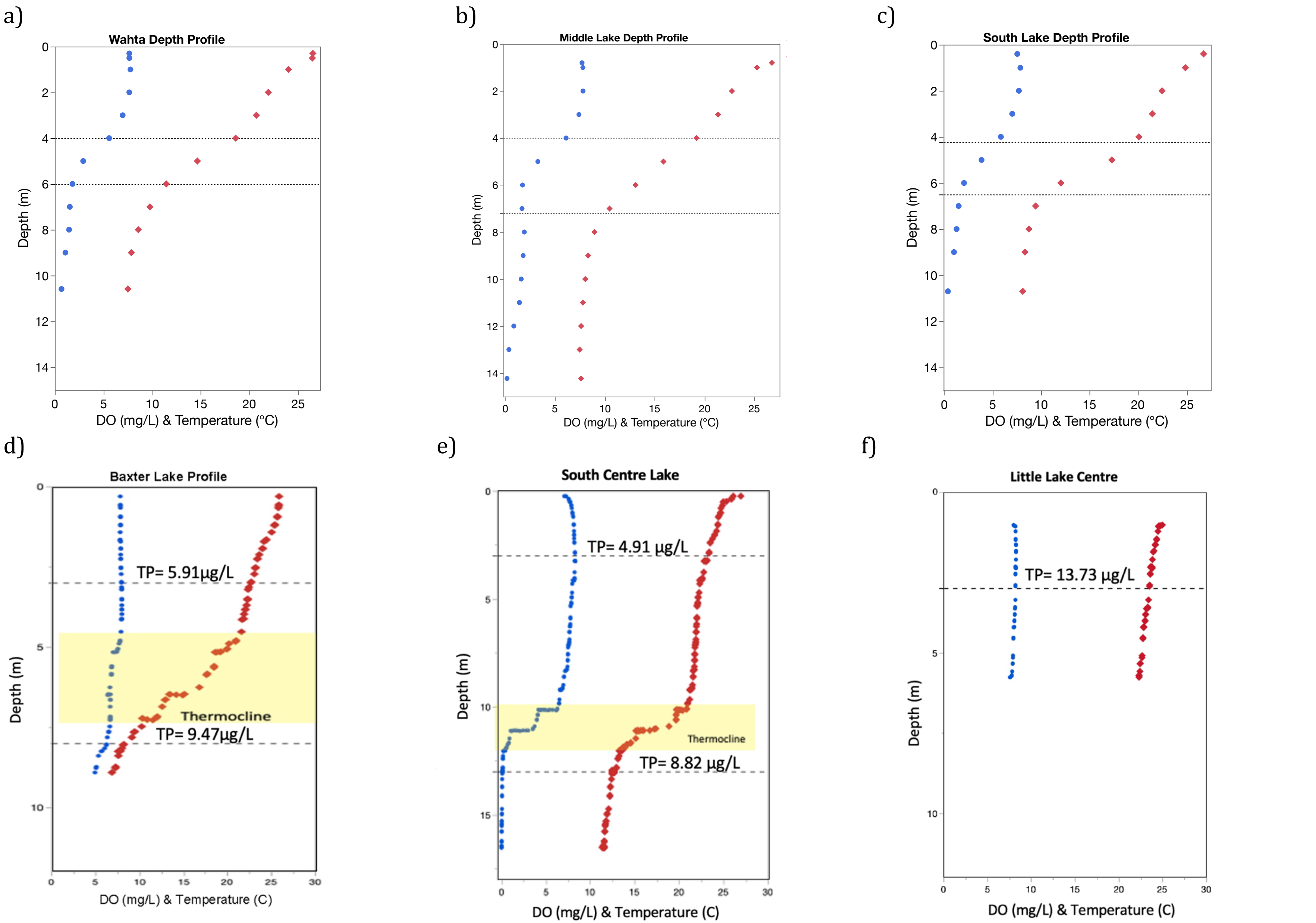


Figure 15: Depth profiles of temperature (red) and dissolved oxygen (DO; blue) for Gibson Lake (a to c) and Gloucester Pool (d to f)

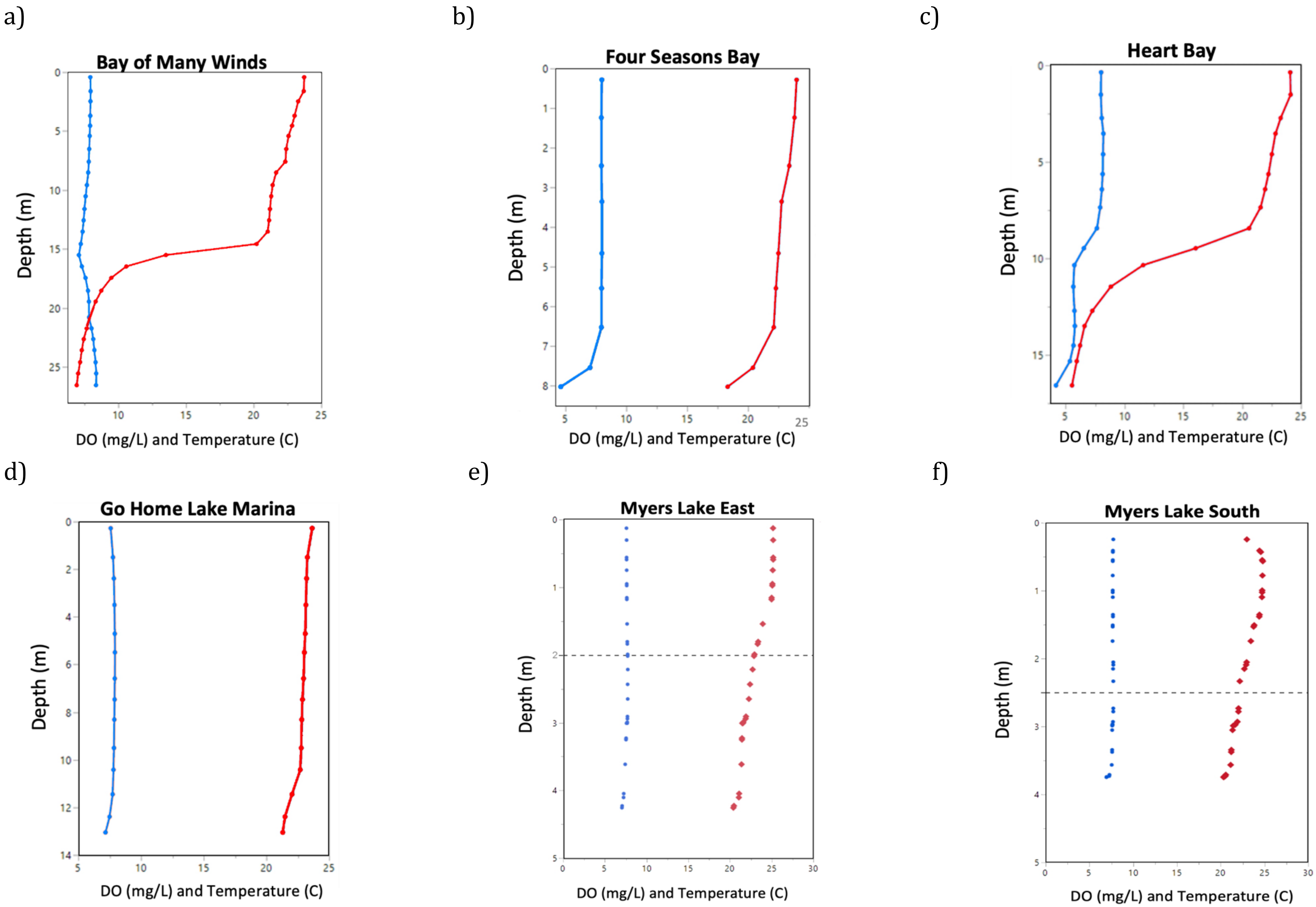


Figure 16: Depth profiles of temperature (red) and dissolved oxygen (DO; blue) for Go Home Lake (a to c) and Myers Lake (d to f). Note that Myers Lake South is synonymous with Crisco Bay

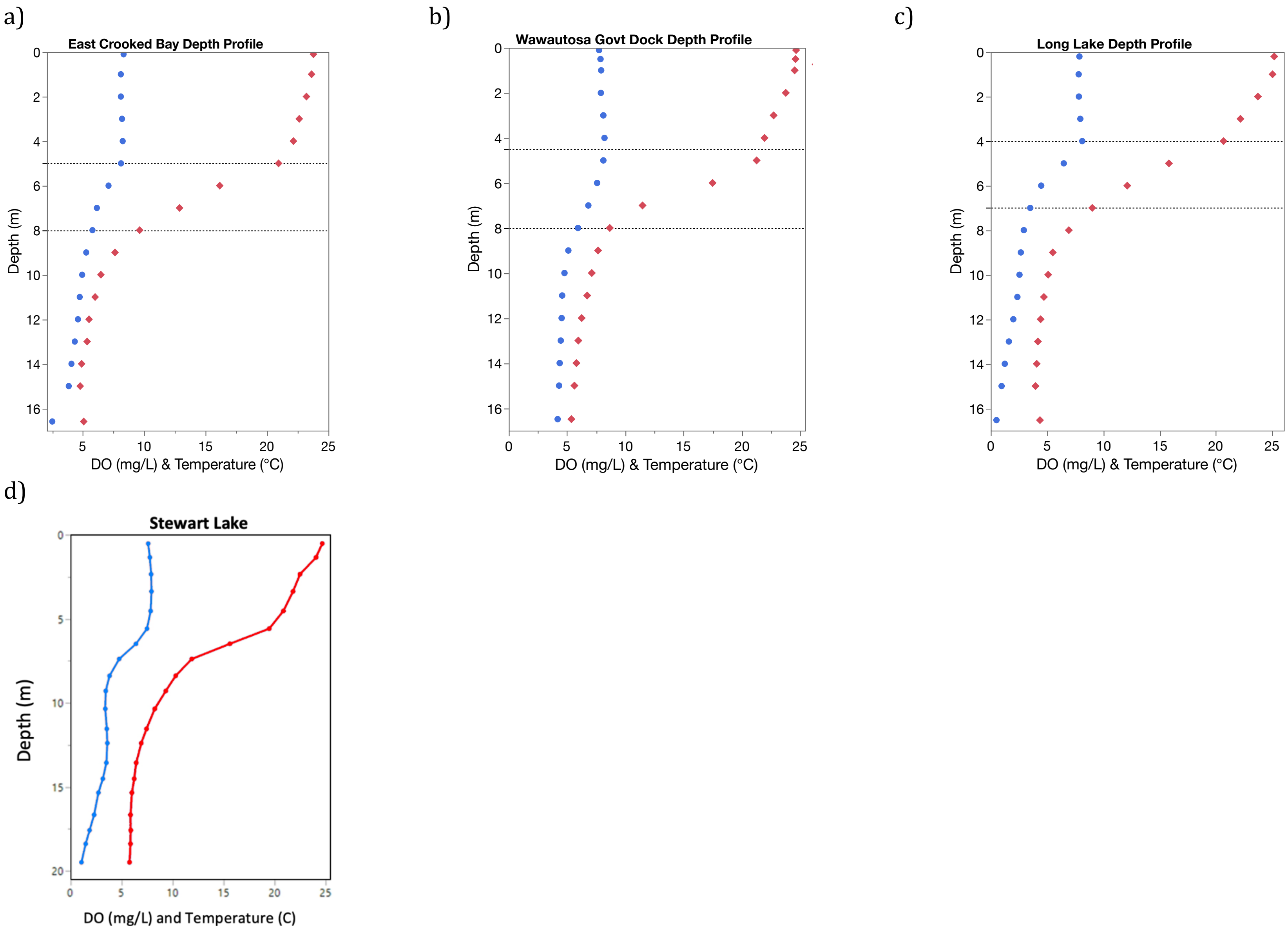


Figure 17: Depth profiles of temperature (red) and dissolved oxygen (DO; blue) for Mile Lake (a to c) and Stewart Lake (d).

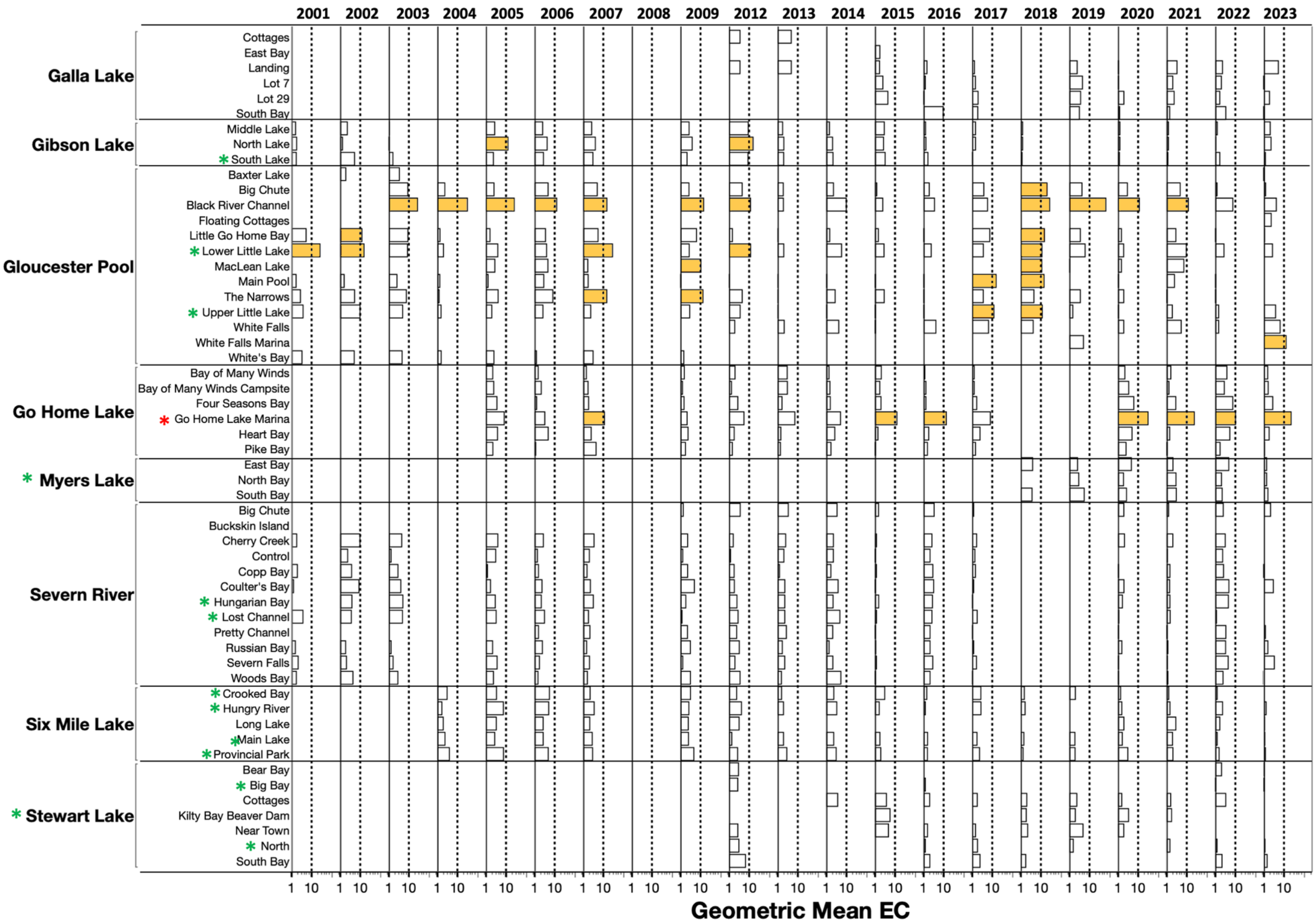


Figure 18: Geometric mean densities of *E. coli* (EC) measured at sampling stations in the eight water bodies. The dotted lines indicate the GBWQO for EC. Solid bars are those that exceed the GBWQO. Green asterisks indicate a significant decrease over time; red asterisk indicate a significant increase over time (see Table 5).

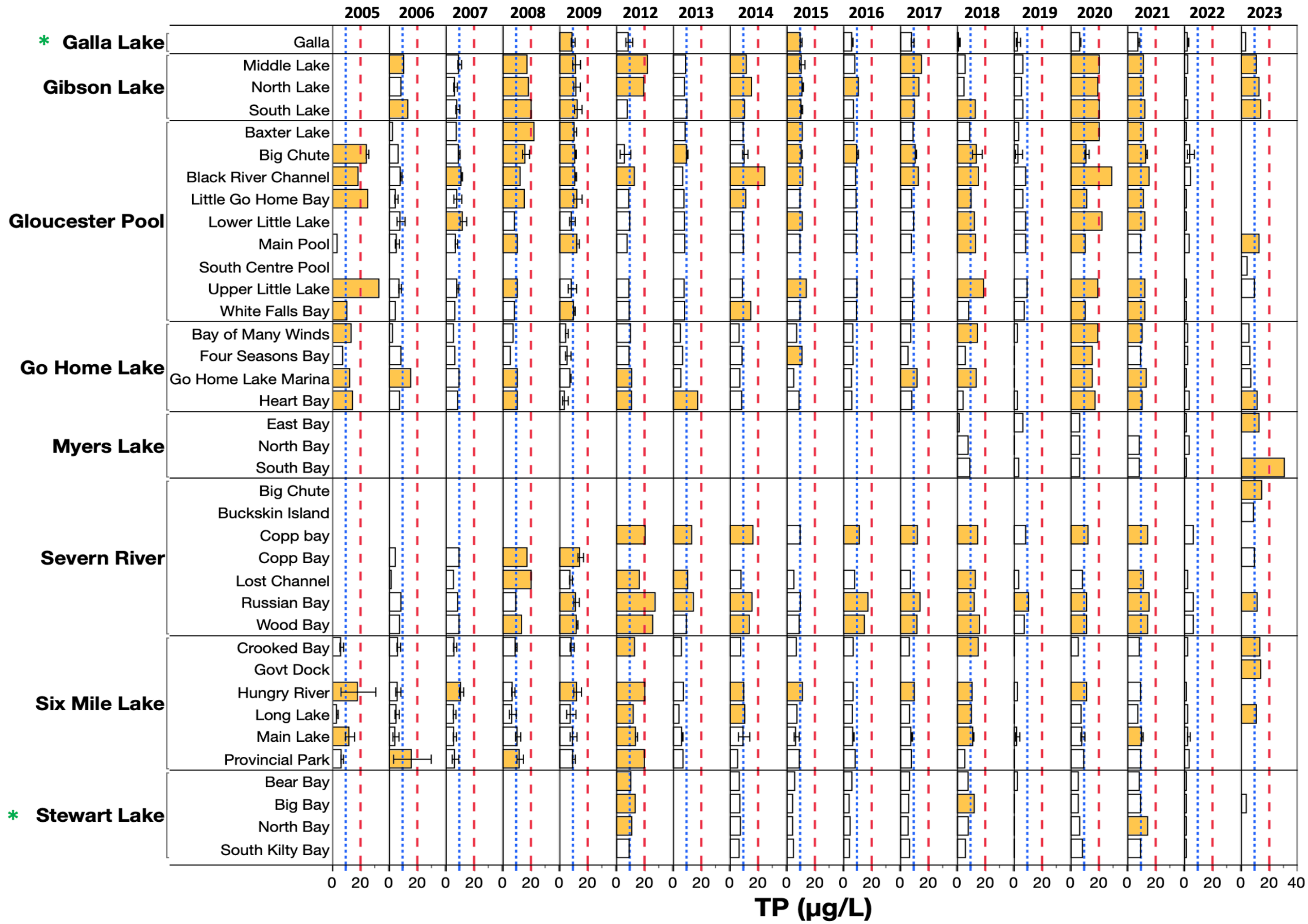


Figure 19: Mean September total phosphorus (TP) concentrations in the eight water bodies. The blue short dashed lines indicate the GBWQO (10 µg/L) for TP, while the red long dashed lines indicate the PWQO (20 µg/L). Solid bars are those that exceed the GBWQO. Green asterisks indicate a significant decrease over time (see Table 6).

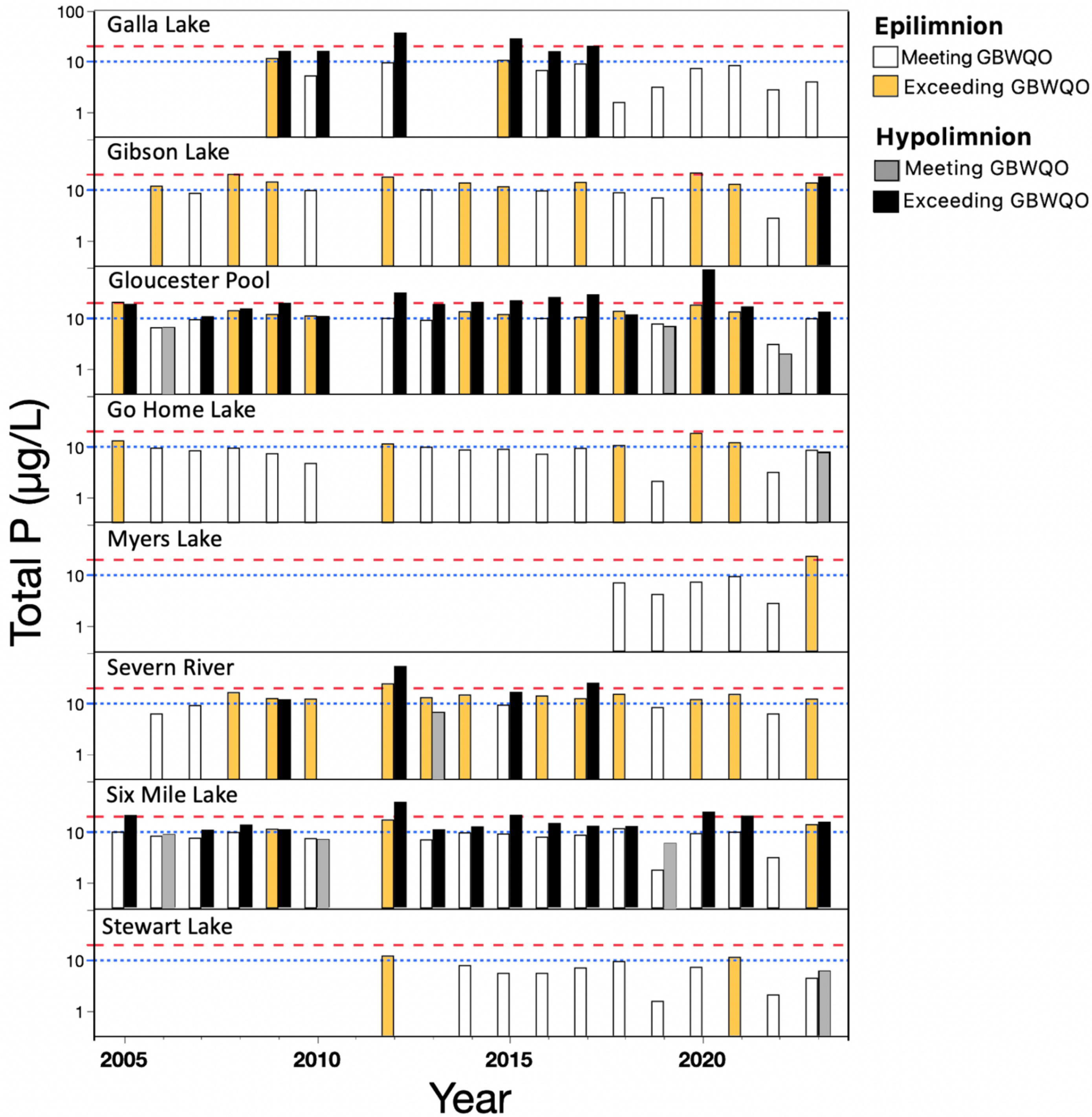


Figure 20: Long-term changes in total phosphorus (Total P) concentrations measured in September for each water body in this study. Hypolimnetic data were not available in the historic database for all water bodies.

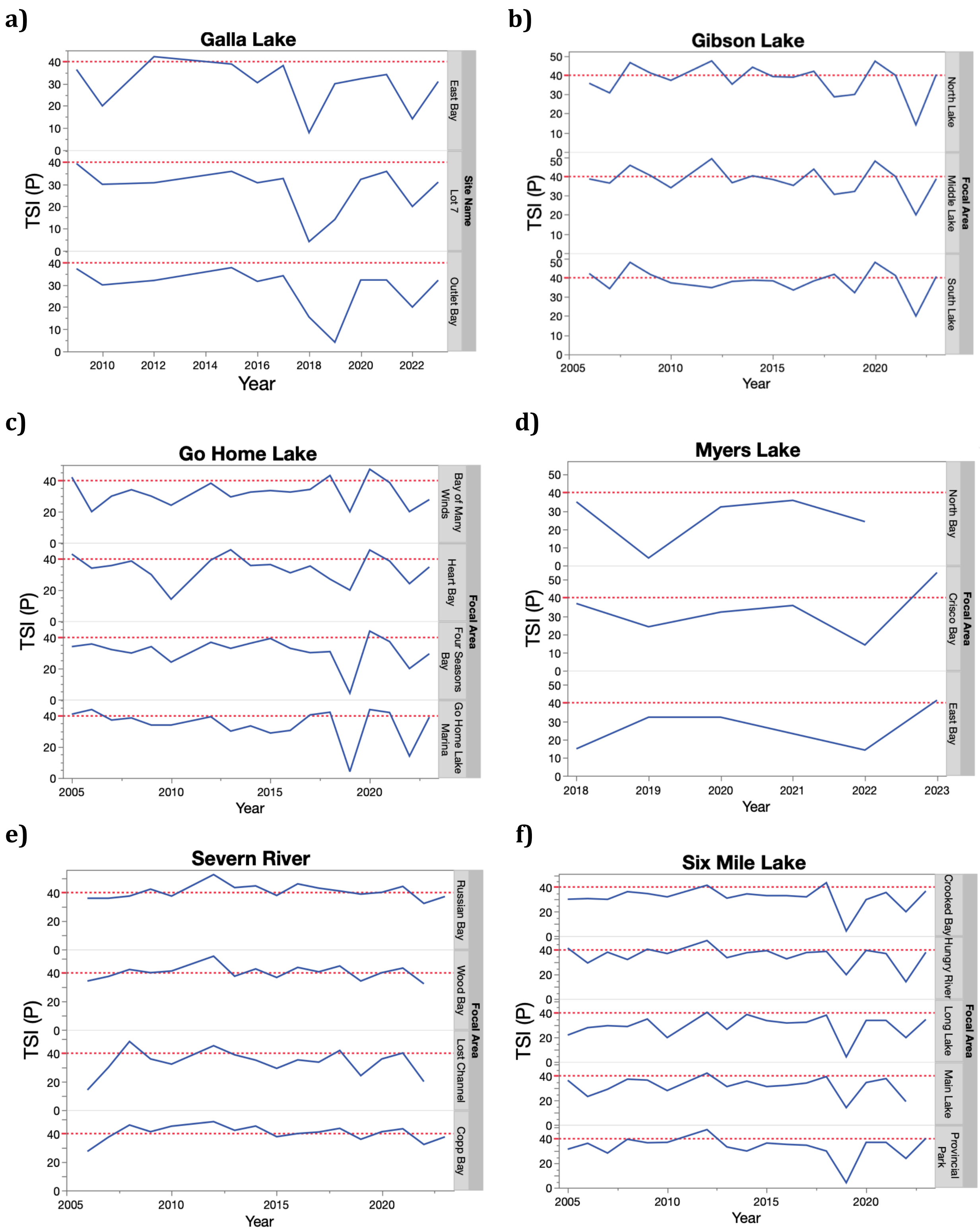
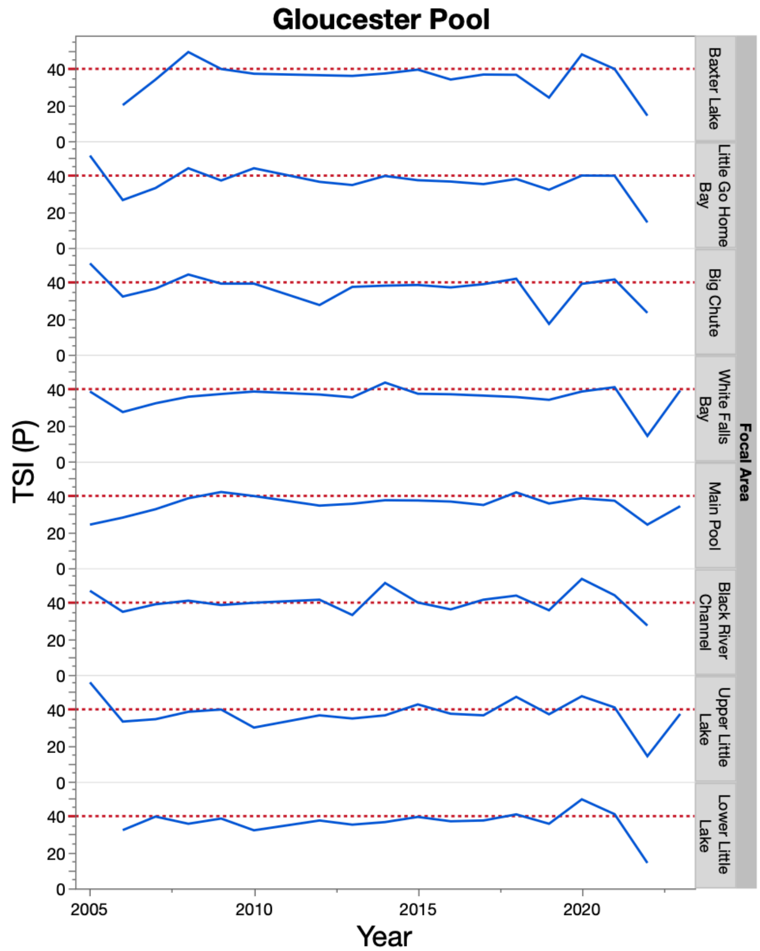


Figure 21: Change in TSI(TP) scores through time for a) Galla Lake, b) Gibson Lake, c) Go Home Lake, d) Myers Lake, e) Severn River and f) Six Mile Lake. Scores calculated with September TP concentrations only.

a)



b)

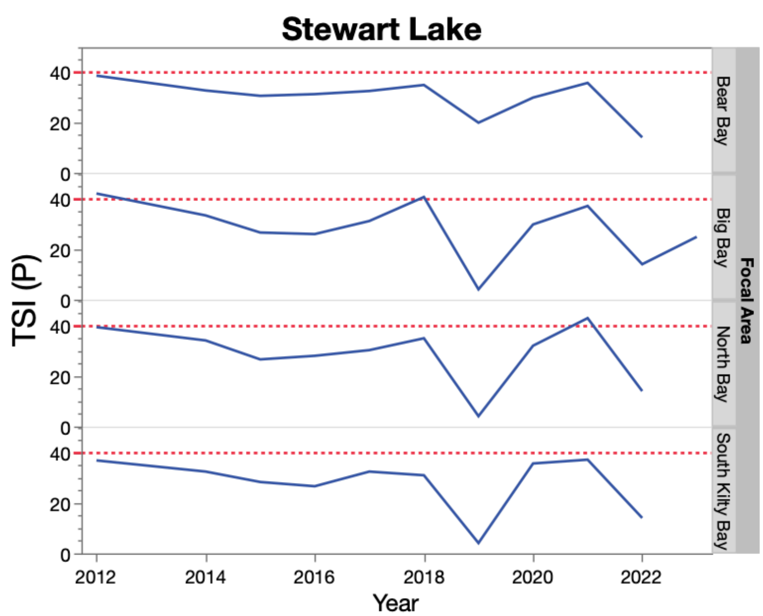


Figure 22: Change in TSI(TP) scores through time for a) Gloucester Pool and b) Stewart Lake. Scores calculated with September TP concentrations only.

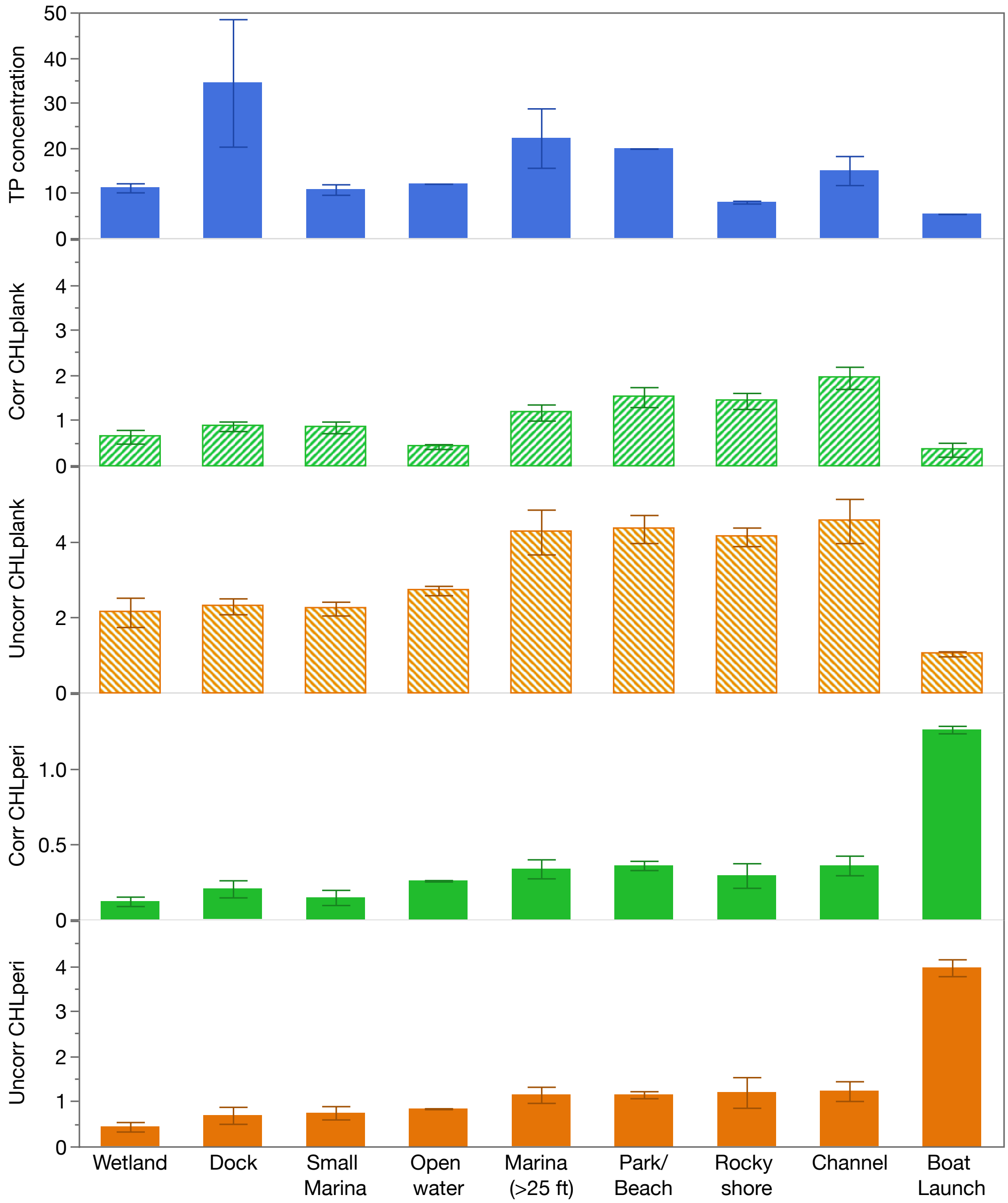


Figure 23: Comparison of mean±SE TP concentrations, photosynthetic planktonic algal pigment (Corr CHLplank), both photosynthetic and inactive planktonic algal pigment (Uncorr CHLplank), photosynthetic periphytic algal pigment (Corr CHLperi) and both photosynthetic and inactive planktonic algal pigment (Uncorr CHLperi) across different categories that reflect degree of human activities at the site. Wetlands were associated with lowest activities while the boat channel and boat launch were assumed to have highest.

Appendix 1a: Bathymetric map of Galla Lake and map of sampling locations

Appendix 1a: Bathymetric map of Gibson Lake and map of sampling locations

Appendix 1a: Bathymetric map of Gloucester Pool and map of sampling locations

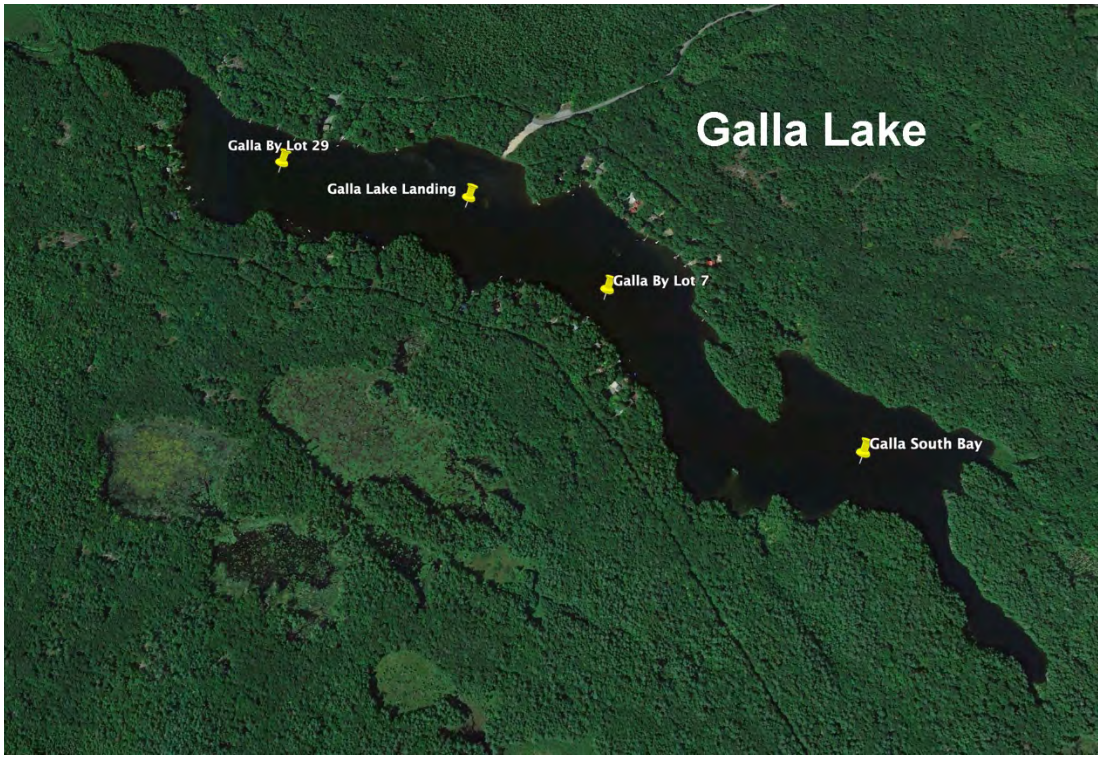
Appendix 1a: Bathymetric map of Go Home Lake and map of sampling locations

Appendix 1a: Bathymetric map of Myers Lake and map of sampling locations

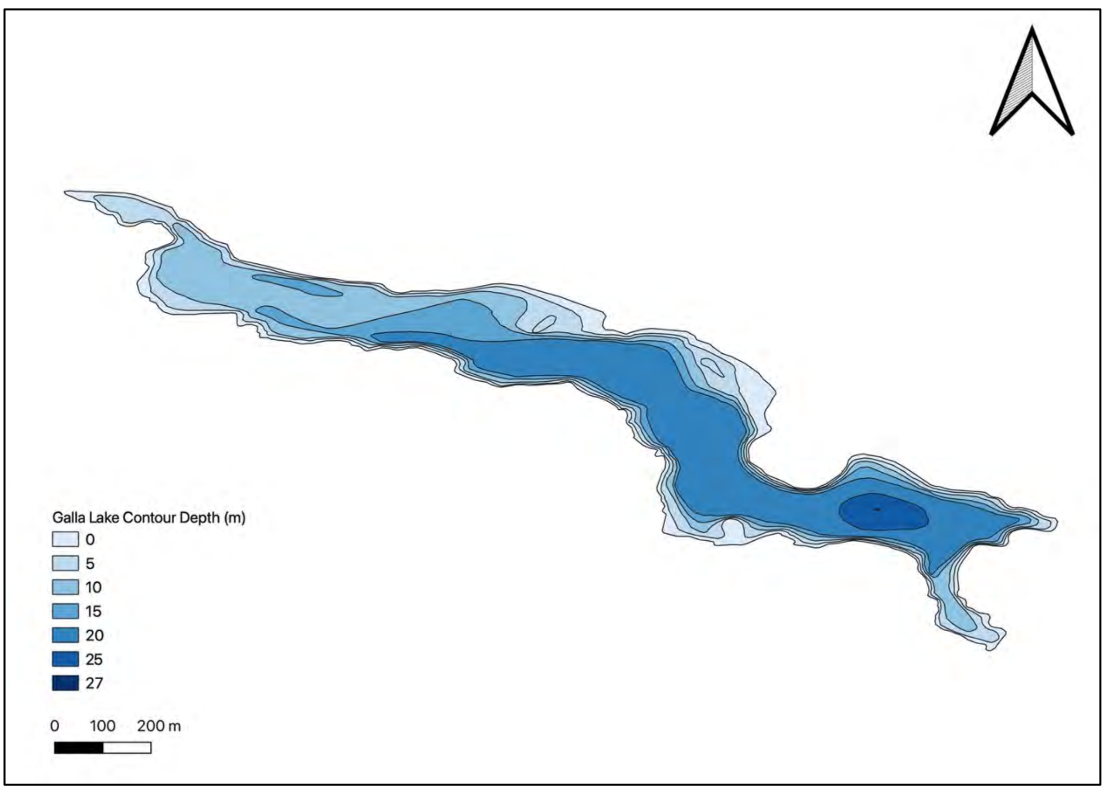
Appendix 1a: Bathymetric map of Six Mile Lake and map of sampling locations

Appendix 1a: Bathymetric map of Severn River and map of sampling locations

Appendix 1a: Bathymetric map of Stewart Lake and map of sampling locations a)

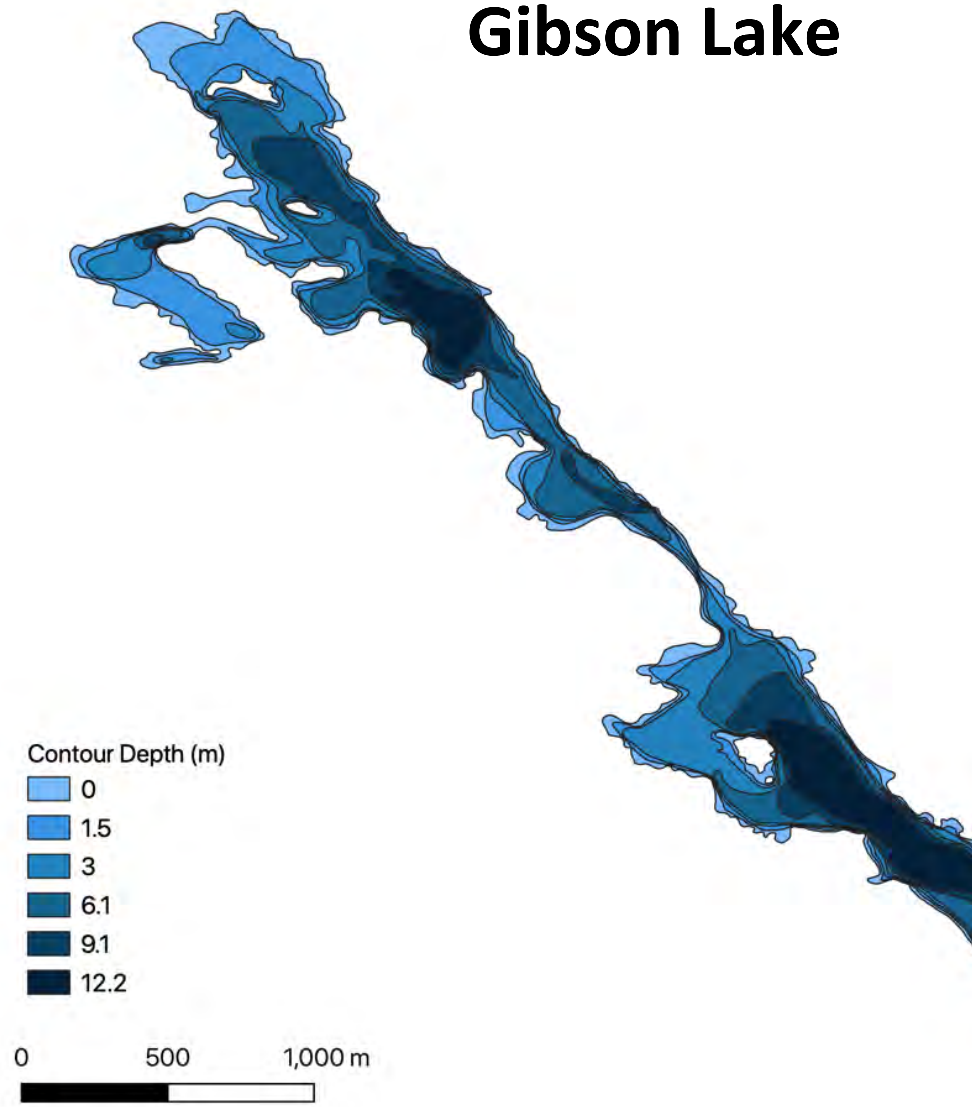


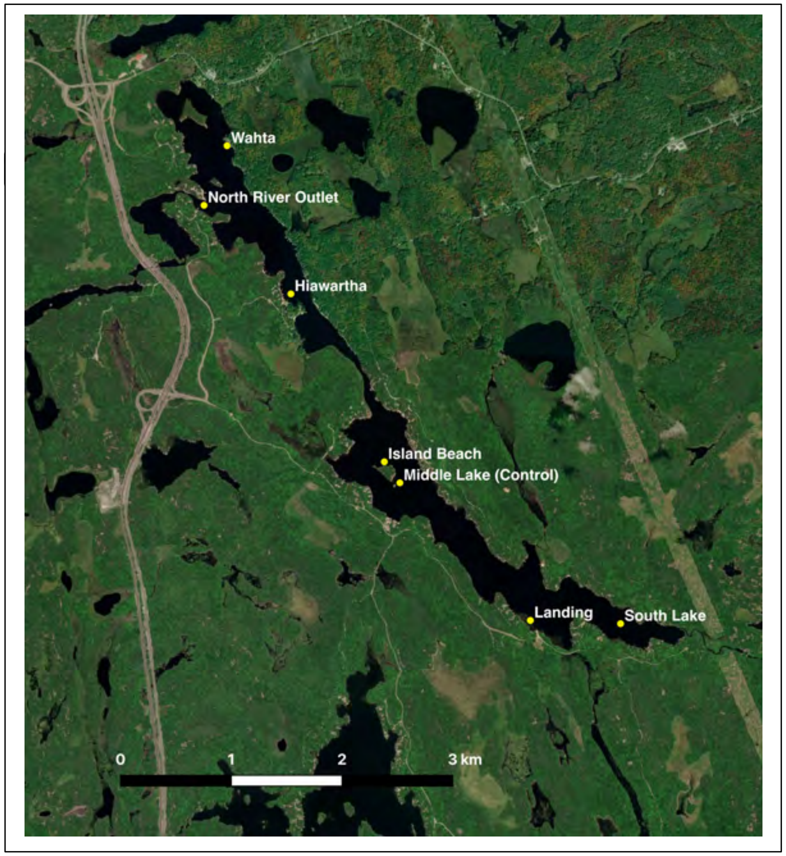
b)



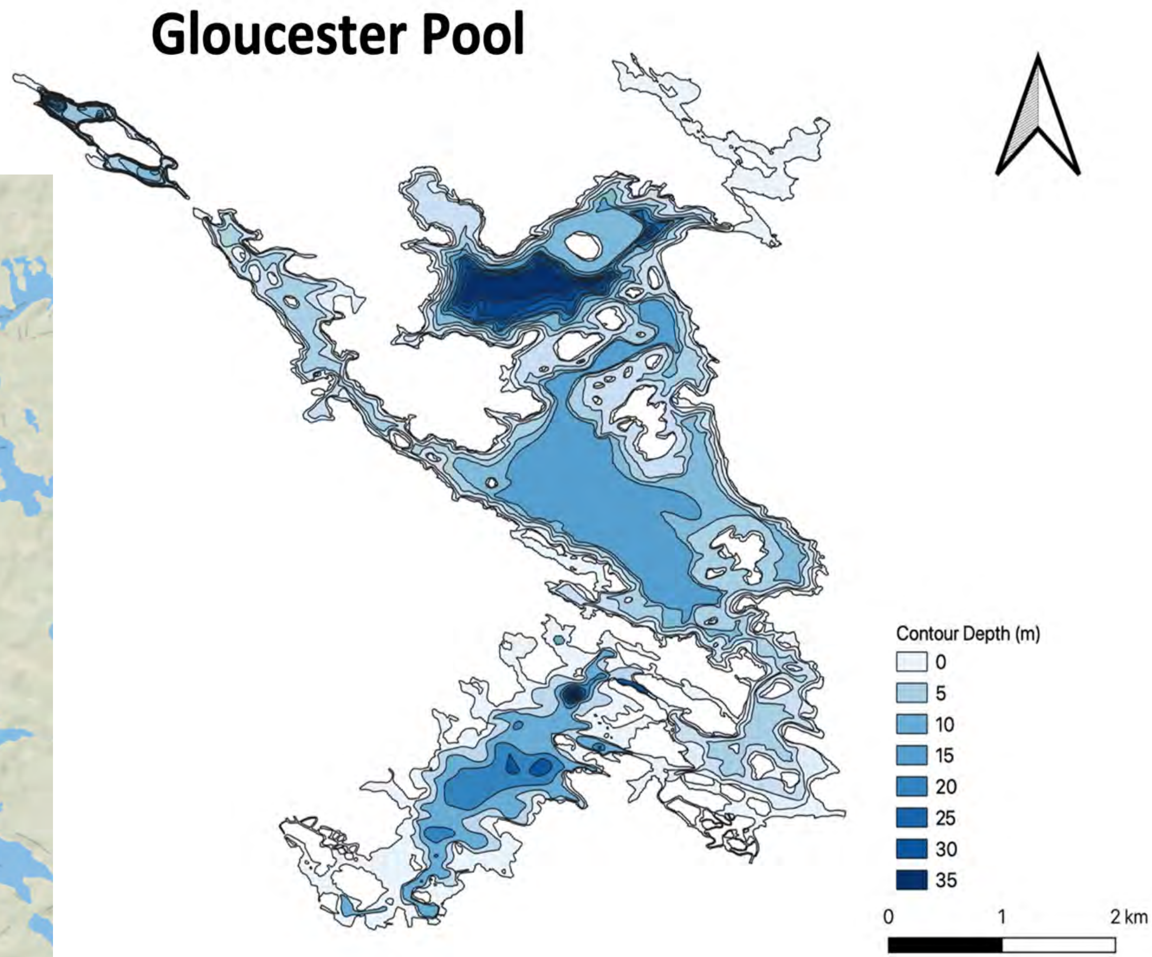
Appendix 1a: Map of Galla Lake, showing a) the 4 sites sampled during 2023 and b) the bathymetric map showing the depth contours.

Gibson Lake

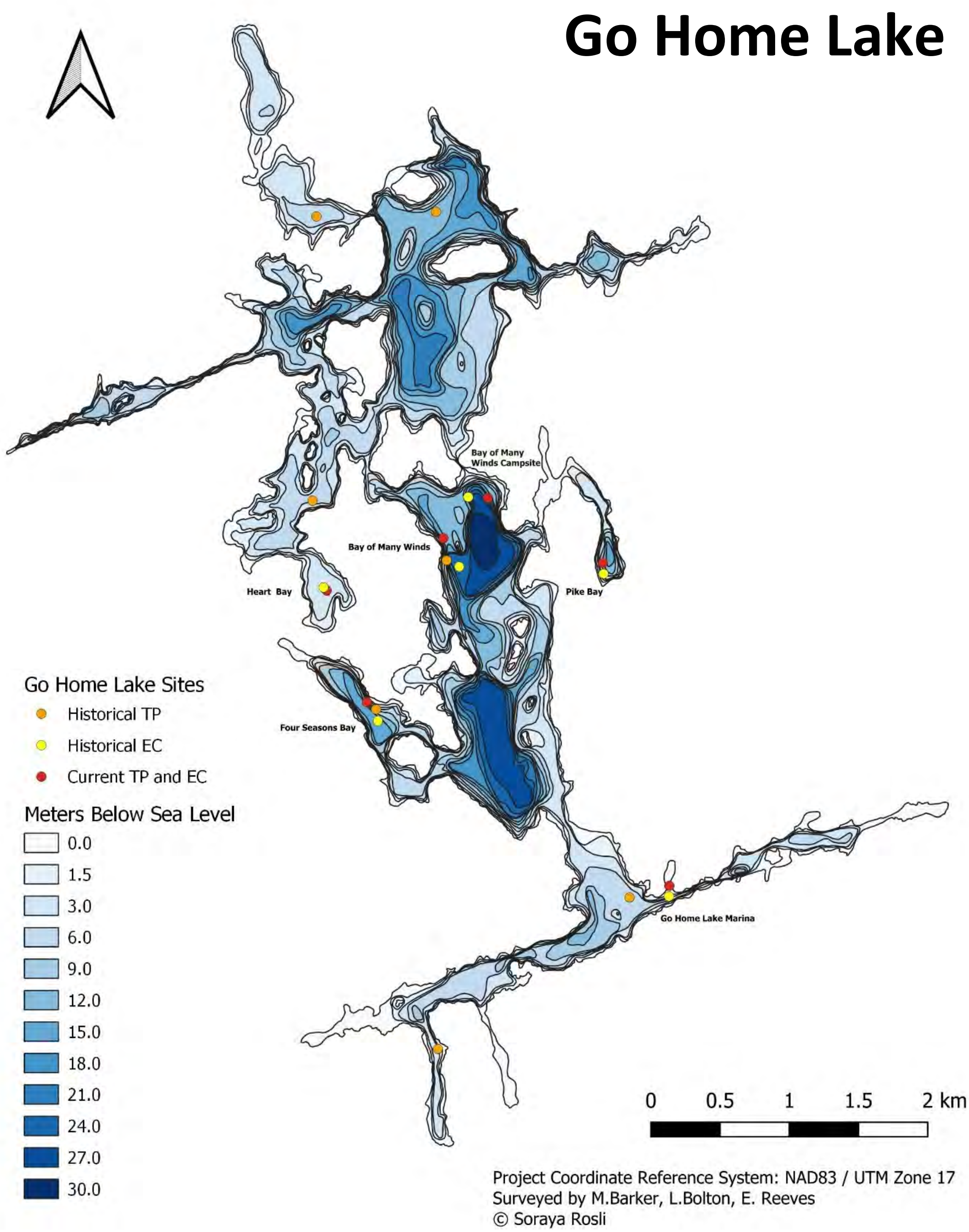




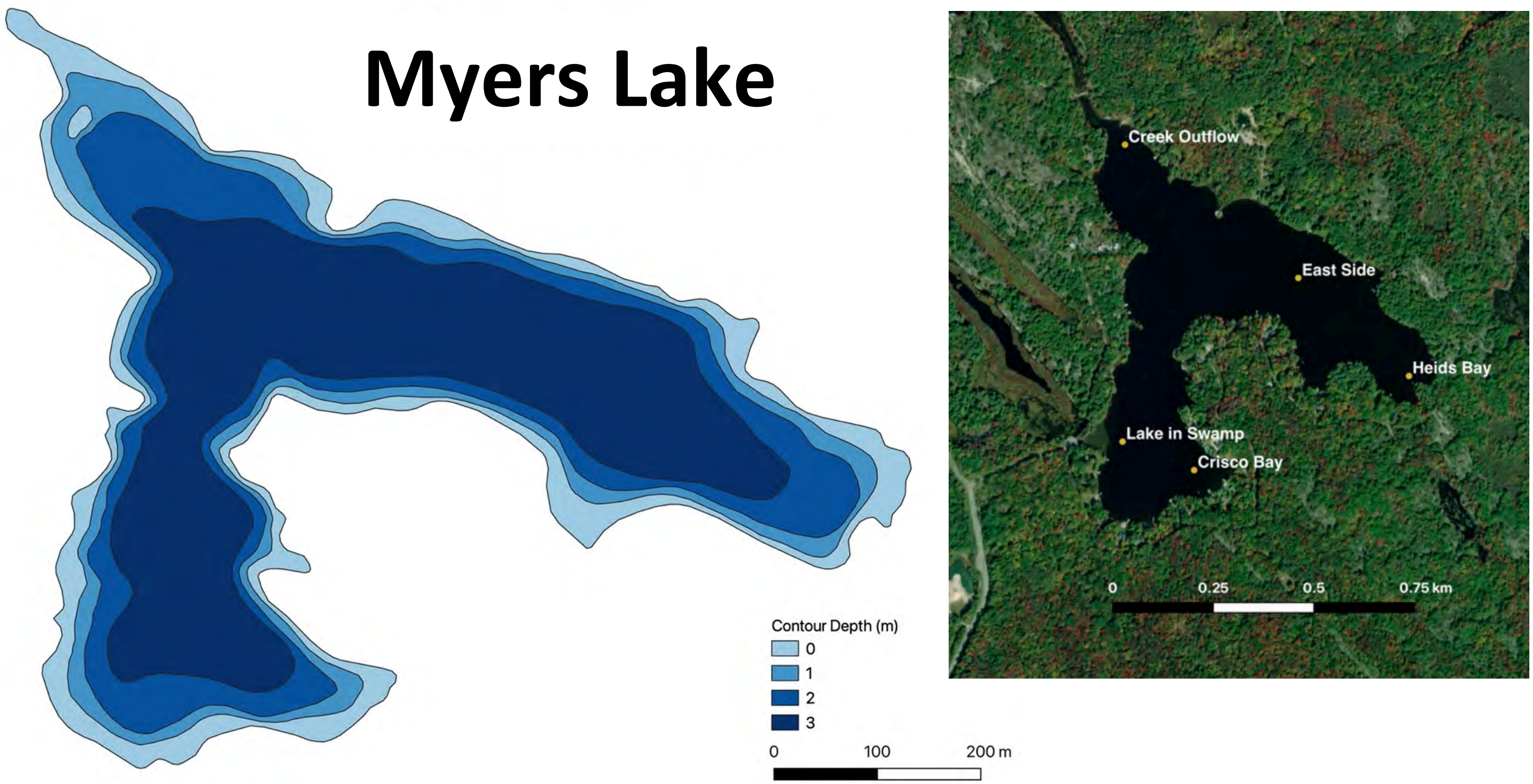
Appendix 1b: Map of Gibson Lake showing the 7 sites sampled during 2023 and the bathymetric map showing the depth contours.



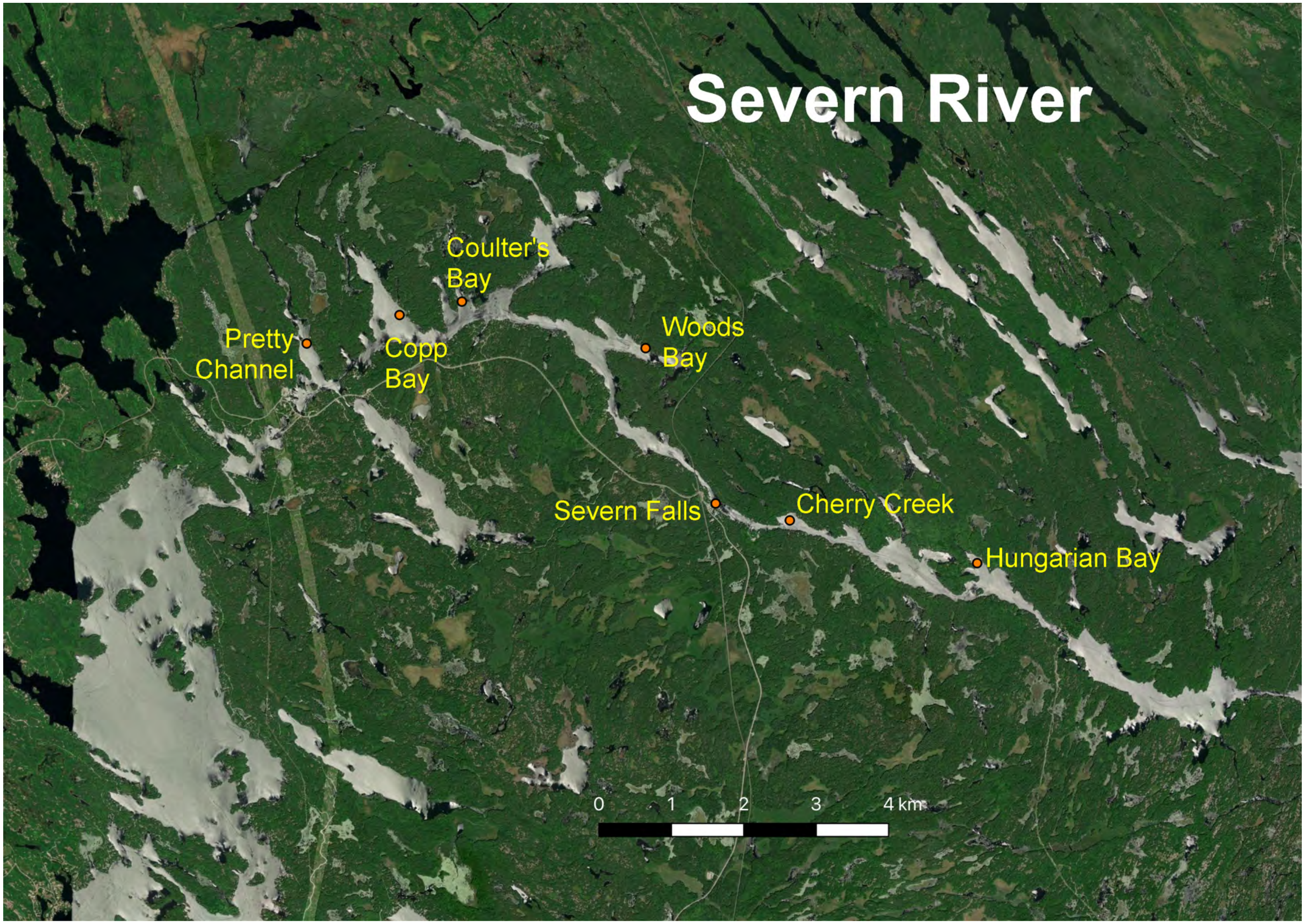
Appendix 1c: Map of Gibson Lake and 15 sites sampled during 2023 and the bathymetric map showing the depth contours.



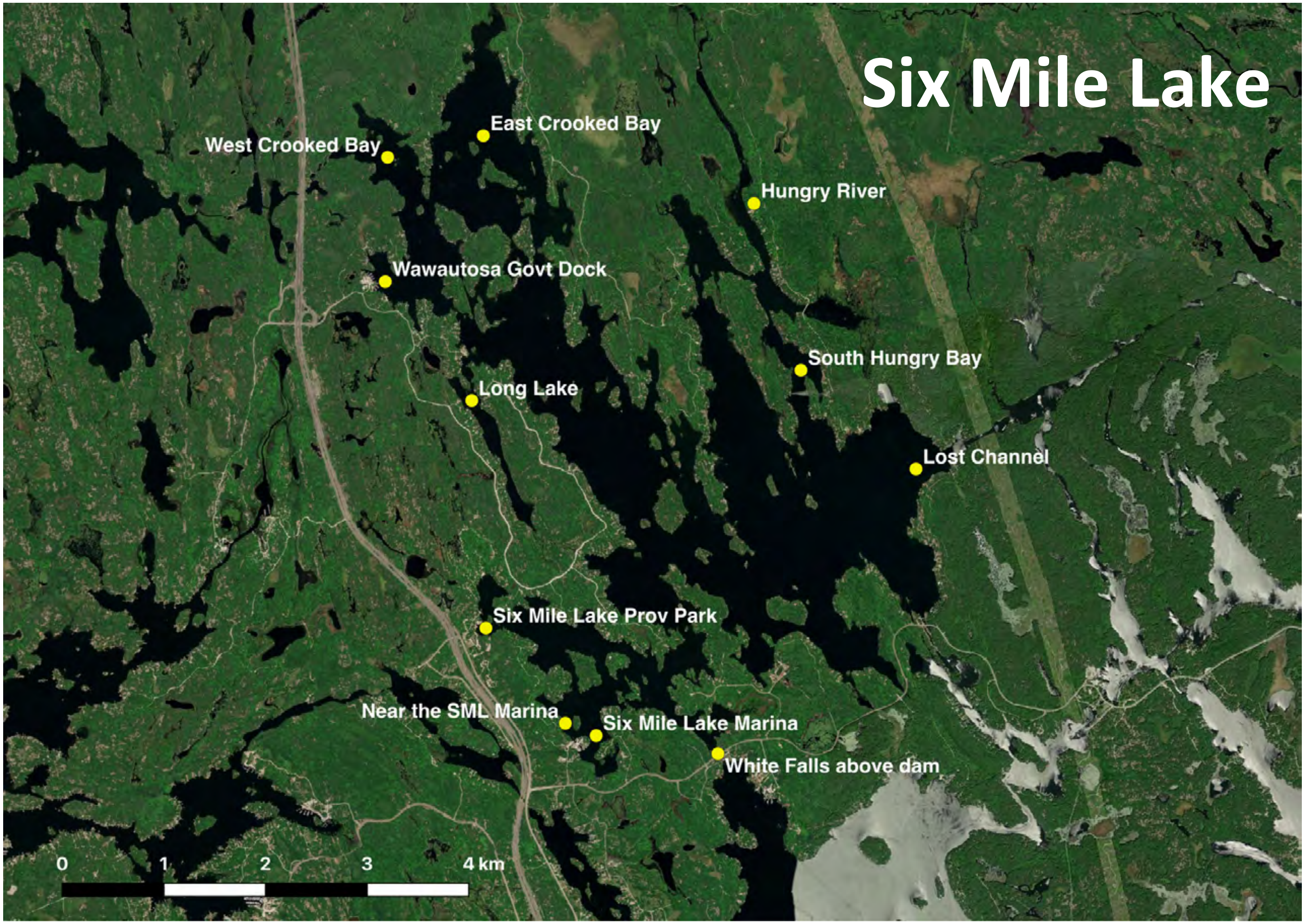
Appendix 1d: Bathymetric map of Go Home Lake, showing the depth contours and locations of the 6 stations that were sampled during 2023 and historically.



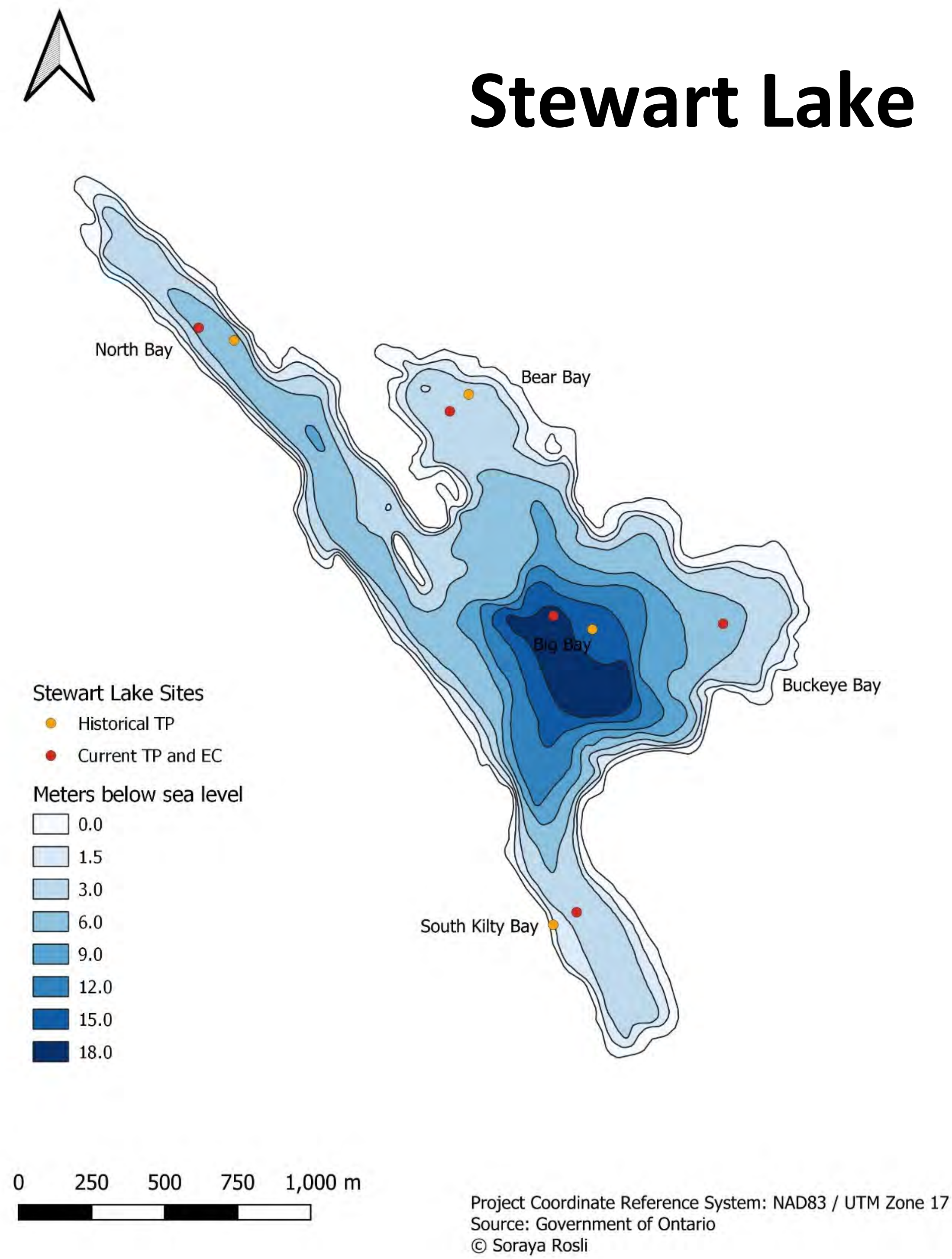
Appendix 1e: Bathymetric map of Myers Lake showing the depth contours and a Google Earth satellite image showing the 5 sampling stations in 2023



Appendix 1f: Map of Severn River and the 7 stations that were sampled regularly during 2023.



Appendix 1g: Map of Six Mile Lake and the 11 stations that were sampled during 2023.



Appendix 1h: Bathymetric map of Stewart Lake and location of the five stations that were sampled during 2023 as well as those sampled historically.