PROJECT CLARITY
2025 Annual Report

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1. Overview

Project Clarity is a large-scale, multidisciplinary, collaborative watershed remediation project aimed at improving water quality in Lake Macatawa. A holistic approach that has included wetland restoration, in-stream remediation, Best Management Practices (BMPs), and community education has been implemented as part of a multimillion-dollar public-private partnership. The project has already reaped numerous economic, social, and ecological benefits – with the ultimate goal of improved water quality in Lake Macatawa.

Lake Macatawa is the terminus of a highly degraded watershed and has exhibited the symptoms of a eutrophic to hypereutrophic lake for more than 40 years (MWP 2012, Holden 2014). Extremely high nutrient and chlorophyll concentrations, excessive turbidity, low dissolved oxygen, and a high rate of sediment deposition have made it one of the most nutrient-rich lakes in Michigan (MWP 2012, Holden 2014). Nonpoint source pollution from the watershed, particularly agricultural areas, is recognized as the primary source of the excess nutrients and sediment that fuel the impaired conditions in Lake Macatawa (MWP 2012).

Because of this nutrient enrichment, Lake Macatawa and all of its tributaries are included on Michigan's 303(d) list of impaired water bodies, prompting the issuance of a phosphorus (P) Total Maximum Daily Load (TMDL) for Lake Macatawa in 2000. The TMDL set an interim target total phosphorus (TP) concentration of 50 µg/L in Lake Macatawa (Walterhouse 1999); a 72% reduction in phosphorus loads from the watershed would be required to meet the TP concentration target (Walterhouse 1999). In the past, monthly average TP concentrations often exceeded 125 µg/L, and at times exceeded 200 µg/L (Holden 2014). Annual mean TP concentrations between 2018 and 2021 started to decline, falling below 90 µg/L. However, over the past two years, annual mean TP concentrations have once again exceeded 100 µg/L. This suggests that while management actions in the watershed have had benefits, improvements in lake water quality have appeared to plateau. These recent data suggest more work is needed. A feasibility study was conducted (Fleis&Vandenbrink 2025) in 2025 to evaluate an alum injection system to reduce phosphorus concentrations entering Lake Macatawa but the cost was considered prohibitive.

The Annis Water Resources Institute (AWRI) of Grand Valley State University, in cooperation with the ODC (Outdoor Discovery Center) Network, the Macatawa Area Coordinating Council, and Niswander Environmental, initiated a long-term monitoring program in the Lake Macatawa watershed in 2013. This effort has provided critical information on the performance of restoration projects that are part of Project Clarity and continues to evaluate the ecological status of Lake Macatawa. This report documents AWRI's monitoring activities in 2025, in combination with data reported previously from 2013-2024. As noted previously, we terminated sampling upstream and downstream of the restored wetlands in April 2019 given the limited value of the information provided. Based on guidance from ODC, our efforts are now focused on Lake Macatawa itself, and the main body of this report provides the latest information on lake water quality. In addition, we have included appendices on the fish community in the lake and the Lake Macatawa water quality dashboard.

The 2025 water quality data are similar to the past few years, indicating a plateau appears to have been reached in terms of water quality improvement. The phosphorus, chlorophyll, and water quality conditions, while somewhat better than pre-Project Clarity concentrations, are still indicative of impaired conditions. There has been some backsliding in terms of phosphorus concentrations, but water clarity has improved and the lake still has low levels of microcystin (the toxin released by cyanobacteria). In order to meet the TMDL for the lake, additional measures will be necessary. Steps are currently being taken to address several concerns. First, the installation of "a lake observatory" in the summer will provide the collection of continuous water quality data, providing a more robust assessment of lake condition in the location of its deployment. Second, a study will be conducted in summer 2026 to assess the sediment phosphorus content in Lake Macatawa, which will help refine the appropriate concentration and location of a chemical treatment to bind phosphorus in the lake.

2. Methods

2.1 Overall site description

The Macatawa watershed (464 km^2/114,000 acres), located in Ottawa and Allegan Counties, includes Lake Macatawa, the Macatawa River, and many tributaries. It is dominated by agricultural (46%) and urban (33%) land uses, which have contributed to the loss of 86% of the watershed's natural wetlands (MWP 2012). The watershed includes the Cities of Holland and Zeeland and parts of 13 townships (MWP 2012). Lake Macatawa is a 7.2 km^2/1,780 acre drowned river mouth lake. It is relatively shallow, with an average depth of 3.6 m/12 ft and a maximum depth of 12 m/40 ft in the western basin. The Macatawa River, the main tributary to the lake, flows into the lake's shallow eastern basin. A navigation channel in the western end of the lake connects Lake Macatawa with Lake Michigan.

2.2 Lake Macatawa: Long-Term Monitoring

Water quality monitoring in the lake was conducted at 5 sites during spring, summer, and fall 2025 (Table 1, Fig. 1). These are the same sampling sites we have used in prior years, and also correspond with Michigan Department of Environment, Great Lakes & Energy (EGLE) monitoring locations to facilitate comparisons with recent and historical data. At each sampling location, general water quality measurements (dissolved oxygen [DO], temperature, pH, specific conductivity, and turbidity) were taken using a YSI EXO V2 sonde at the surface, middle, and near-bottom of the water column. Water transparency was measured as Secchi disk depth. Water samples were collected from the surface and near-bottom of the water column using a Van Dorn bottle and analyzed for SRP, TP, NH_3, NO_3^-, TKN, and chl *a*. Samples also were taken for phytoplankton community composition and archived for future analysis.

Water for SRP and NO_3^- analyses was syringe-filtered through 0.45-µm membrane filters into scintillation vials; SRP was refrigerated at 4°C and NO_3^- frozen until analysis. NH_3 and TKN were acidified with sulfuric acid and kept at 4°C until analysis. SRP, TP, NH_3, NO_3^-, and TKN were analyzed on a SEAL AQ2 discrete automated analyzer (US EPA 1993). Chl *a* samples were filtered through GF/F filters and frozen until analysis on a Shimadzu UV-1601 spectrophotometer (APHA 1992). Any values below detection were reported as ½ the detection limit for the purpose of analysis (U.S. EPA, 2000).

Paired t-tests (for normally distributed data) and Mann-Whitney rank sum tests (non-normal data) were used to detect significant differences in pre- and post-restoration distributions of SRP, TP, and chl *a*. An equal number (n=40) of seasonally corresponding data points from all pre-restoration (summer 2013 – fall 2015) and the most recent post-restoration (summer 2023 – fall 2025) sampling events were incorporated in the analysis, pooling data from all sites (1-5). Statistical significance was set with $\alpha = 0.05$, and testing was performed using R version 4.5.2 (R Core Team 2025).

Additionally, we continued testing for microcystin, which began in 2017. Microcystin is the most common cyanotoxin produced by cyanobacteria (blue-green algae). We used the ELISA QuantiPlate kit for Microcystins High

Sensitivity (Envirologix; Portland, ME), which is commonly used and serves as a useful screening tool if microcystin is present in the lake. Advisories for microcystin consumption have been developed by the World Health Organization (WHO) and US EPA. For drinking water, the WHO advisory is triggered when microcystin concentrations >1 µg/L and the EPA advisory is >1.6 µg/L for adults; for recreational use, WHO is >20 µg/L and EPA is >8 µg/L (US EPA 2021). Since Lake Macatawa is used only for recreation, we applied the latter two criteria.

Table 1. Location and 2025 water column seasonal mean depth at Lake Macatawa long-term monitoring locations (note: these are the same locations used in previous years).

Site	Latitude	Longitude	Depth (m)
1	42.7913	-86.1194	8.0
2	42.7788	-86.1525	5.0
3	42.7872	-86.1474	3.5
4	42.7755	-86.1822	9.7
5	42.7875	-86.1820	4.2

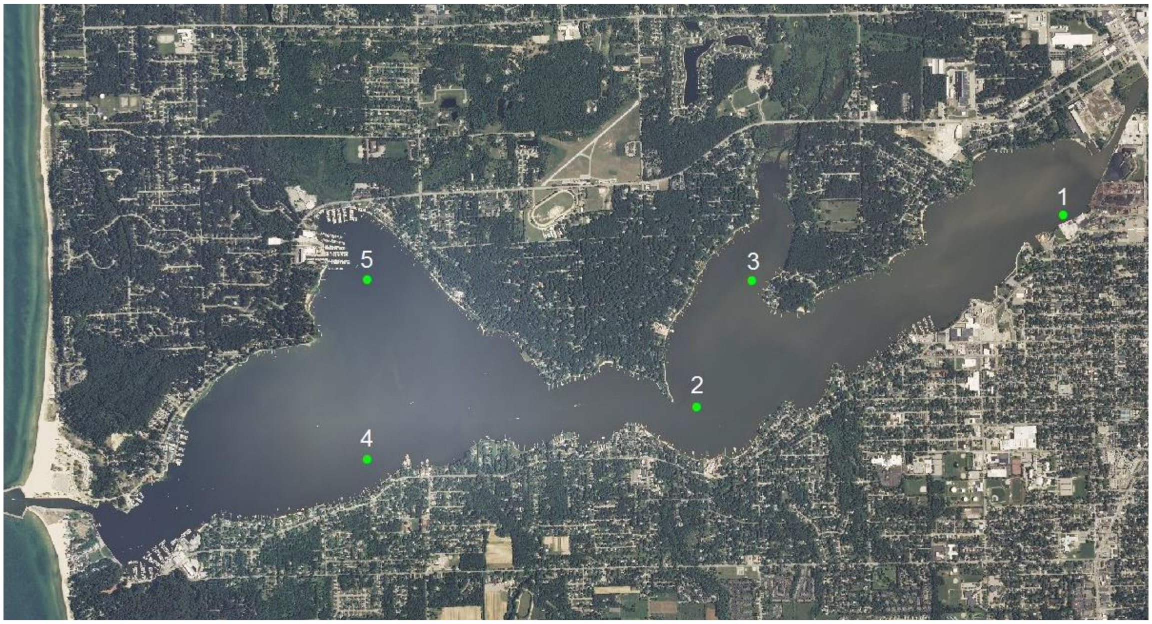


Figure 1. Map of Lake Macatawa showing the 5 sampling locations (green dots) for long-term water quality monitoring.

2.3 Macatawa Watershed Phosphorus – Precipitation Analysis

P concentrations in water bodies are influenced by many variables, but one of the most significant is precipitation because rain and snow events create surface and subsurface runoff from farms and developed areas, which ultimately reach the downstream receiving waters (Baker et al. 2019). In addition, atmospheric deposition can contain significant amounts of P (cf. Brennan et al. 2016). Consequently, it is of interest to know if changes in lake P concentrations are related to precipitation, land use changes, or a combination of the two. This has been shown in the western basin of Lake Erie, where heavy spring rains transported recently applied P fertilizer into the Maumee

River, and eventually Lake Erie, triggering massive harmful algal blooms (Michalak et al. 2013). Hence, years with anomalously good or bad lake conditions may be driven largely by the timing of fertilizer application, tillage practices, and precipitation.

Sophisticated (i.e., computationally intensive) watershed models are often used for this kind of analysis, but developing those models was outside our scope of work. Rather, we took a coarse-level approach to look at how P concentrations in Lake Macatawa compared with precipitation amounts from the weather station at the West Michigan Regional Airport (formerly Tulip City Airport) in Holland using data from NOAA's National Centers for Environmental Information (NCEI, formerly the National Climatic Data Center). Linear regressions on P concentrations and precipitation amounts were conducted in Microsoft Excel. In Lake Macatawa, the relationship between lake TP and precipitation has not been clear-cut. Attempts in previous reporting years to analyze annual precipitation against annual mean TP resulted in trendless data with low statistical power ($R^2<0.01$; Hassett et al. 2025), likely because the annual data set contained so much seasonal variation. In order to control for that seasonal variation, we explored the relationship of Lake Macatawa TP and precipitation using shorter and more closely associated spans of time; daily precipitation from 2013-2025 was summarized into weeks and months of total precipitation prior to each specific sampling date as follows: 1 week, 2w, 3w, 4w (1 month), 2mo, 3mo, 4mo, 5mo, 6mo, 7mo, 8mo, 9mo, 10mo, 11mo, 12mo. Separately for each weekly or monthly summary, total precipitation was regressed against surface and bottom lake-wide average SRP and TP. In 2025, the combined annual data again resulted in trendless data, so annual data were separated into seasons with separate regressions composed of n=11 (spring) or n=12 (summer and fall) seasonal lake means. Outliers in seasonal datasets were identified and removed using multiple sequential Grubbs tests until no outliers were detected in the remaining data.

3. Results and Discussion

3.1 Sampling Year 2025

General water quality followed normal seasonal patterns in Lake Macatawa (Table 2). Dissolved oxygen stratified in both summer and fall. Surface DO concentrations remained high (>7.5 mg/L) at all sites, with higher concentrations in summer and fall than spring (Fig. 2A), most likely associated with greater amounts of algae, which were photosynthesizing. Although mean DO concentrations never became hypoxic (< 2 mg/L), DO dropped to very low levels in the bottom depths at sites 1 (summer and fall: 0.17-1.38 mg/L) and at site 4 (fall: 0.53 mg/L) (Fig. 2B). DO measurements in 2025 were generally highest on the western downstream end of the lake, but well within historic ranges seen since 2013 (Fig. 3). Sites 1 and 4 seem especially susceptible to low DO concentrations in the summer and fall (Fig. 3). Multiyear LOWESS (locally weighted scatterplot smoothing) analysis of summer DO in near-bottom depths indicates considerable variance among years (Fig. 4), with increasing values at most the past two years except site 1, which retains very low hypoxic conditions in deeper areas (Fig. 4).

Mean specific conductivity, total dissolved solids, and turbidity were highest in spring and decreased in summer and fall (Table 2). This is likely a result of spring runoff, carrying sediment into the lake. Indeed, sampling on May 22nd was preceded by a week of wet weather (almost 3 inches of rain). Interestingly, we would have expected Secchi depth to be low in spring due to reduced water clarity from the suspended material, but that was not the case.

Surface SRP concentrations generally were ~50 µg/L in spring at Sites 1-3 and were lower at sites closer to Lake Michigan, as well as declining in summer and fall at all sites (Table 3, Fig. 5A). By fall, SRP concentrations were below detection at all sites. It is likely that the declines in SRP later in the season were due to uptake by algae of this bioavailable form of phosphorus. Near-bottom SRP followed similar trends except for a major spike in the summer at site 1, reaching 169 µg/L (Fig. 5B), corresponding with the previously mentioned hypoxic DO measurement. It is unclear what caused the spike and how long it lasted; given the corresponding spike in TP (Fig. 5D) and that it was confined to the bottom waters, it may have been due to releases from the sediment given the very low DO concentrations at lake bottom at this time (Fig. 2B). Regardless, the concentrations dissipated quickly, as the SRP spike declined almost 4-fold by site 2 (Fig. 5B).

Surface TP measurements exceeded the interim TMDL target of 50 µg/L on all 2025 sampling dates and sites. Indeed, mean surface TP values were 103, 180, and 94 µg/L in spring, summer, and fall (Table 3). The bottom water samples also exceeded the 50 µg/L target, although the TMDL is for surface samples only (Table 3, Fig. 5C-D). On average, both surface and near-bottom TP samples peaked in summer.

Chl *a* continues to trend opposite SRP, supporting the notion that low SRP values are due to uptake by algae. Chl *a* values increased steadily across all sites and seasons in 2025, with surface spring concentrations meeting the 22 µg/L target, but summer and fall concentrations far exceeding that level, reaching a peak of 88 µg/L at site 2 in the fall (Table 3, Fig. 5E-F). Despite the high chlorophyll levels in Lake Macatawa, concentrations of the cyanotoxin microcystin remained very low throughout 2025, far below the EPA guideline of 8 µg/L for recreational waters (Table 3).

Mean nitrate concentrations varied seasonally, being highest in spring, lowest in summer, and slightly increasing in fall (Table 3, Fig. 6A-B). Spring site 1 had the highest concentrations across all samples, ranging 2.4-5.3 mg/L at the surface and near bottom (Fig. 6A-B). These elevated concentrations are most likely associated with agricultural and lawn fertilizer runoff in spring. The spike at site 1, which is fed almost directly from the Macatawa River, suggests that watershed runoff is a more likely source than urban contributions. Ammonia concentrations were <2 mg/L at all sites and depths except during the summer hypoxic event when near-bottom site 1 ammonia spiked to ~10 mg/L (Table 3, Fig. 6C-D). TKN is a measurement of ammonia plus organic ammonia; thus, TKN followed similar seasonal and site trends and spiked at the same time as ammonia (Table 3, Fig. 6E-F).

Table 2. Lake-wide means (1 SD) of select general water quality parameters recorded during 2025 monitoring year. Data are shaded for readability. Dates of sampling events: 5/22/2025; 7/23/2025; 10/15/2025. "n" is the number of lake sites composing the seasonal mean at each depth.

Season	Depth	n	Temp. (°C)	DO (mg/L)	SpCond (µS/cm)	TDS (g/L)	Turbidity (FNU)	Secchi Depth (m)
Spring	Surface	5	14.12 (0.54)	8.02 (0.56)	580 (70)	0.377 (0.045)	14.1 (1.9)	0.7 (0.1)
	Middle	5	14.11 (0.53)	7.85 (0.59)	580 (69)	0.377 (0.044)	14.3 (2.0)	
	Bottom	5	13.84 (0.49)	7.79 (0.57)	608 (120)	0.395 (0.078)	22.7 (10.5)	
Summer	Surface	5	25.50 (0.54)	9.70 (1.04)	494 (70)	0.321 (0.045)	11.9 (0.9)	0.5 (0.1)
	Middle	5	25.01 (1.20)	7.85 (2.04)	490 (79)	0.319 (0.051)	12.0 (4.0)	
	Bottom	5	23.34 (3.57)	4.96 (3.18)	525 (179)	0.341 (0.116)	16.4 (11.7)	
Fall	Surface	5	21.33 (0.29)	9.50 (1.19)	511 (58)	0.332 (0.038)	8.0 (2.2)	0.7 (0.1)
	Middle	5	21.26 (0.32)	8.97 (1.70)	511 (59)	0.332 (0.038)	8.7 (1.9)	
	Bottom	5	20.61 (0.93)	5.48 (4.21)	477 (62)	0.310 (0.041)	19.5 (6.5)	

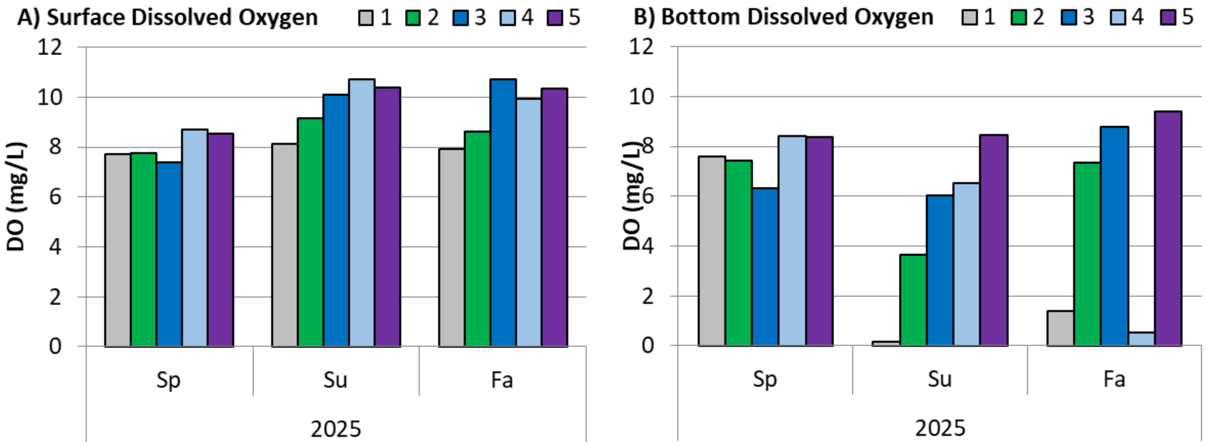


Figure 2. Dissolved Oxygen: A) surface; B) near-bottom concentrations measured at the 5 monitoring stations in Lake Macatawa during 2025.

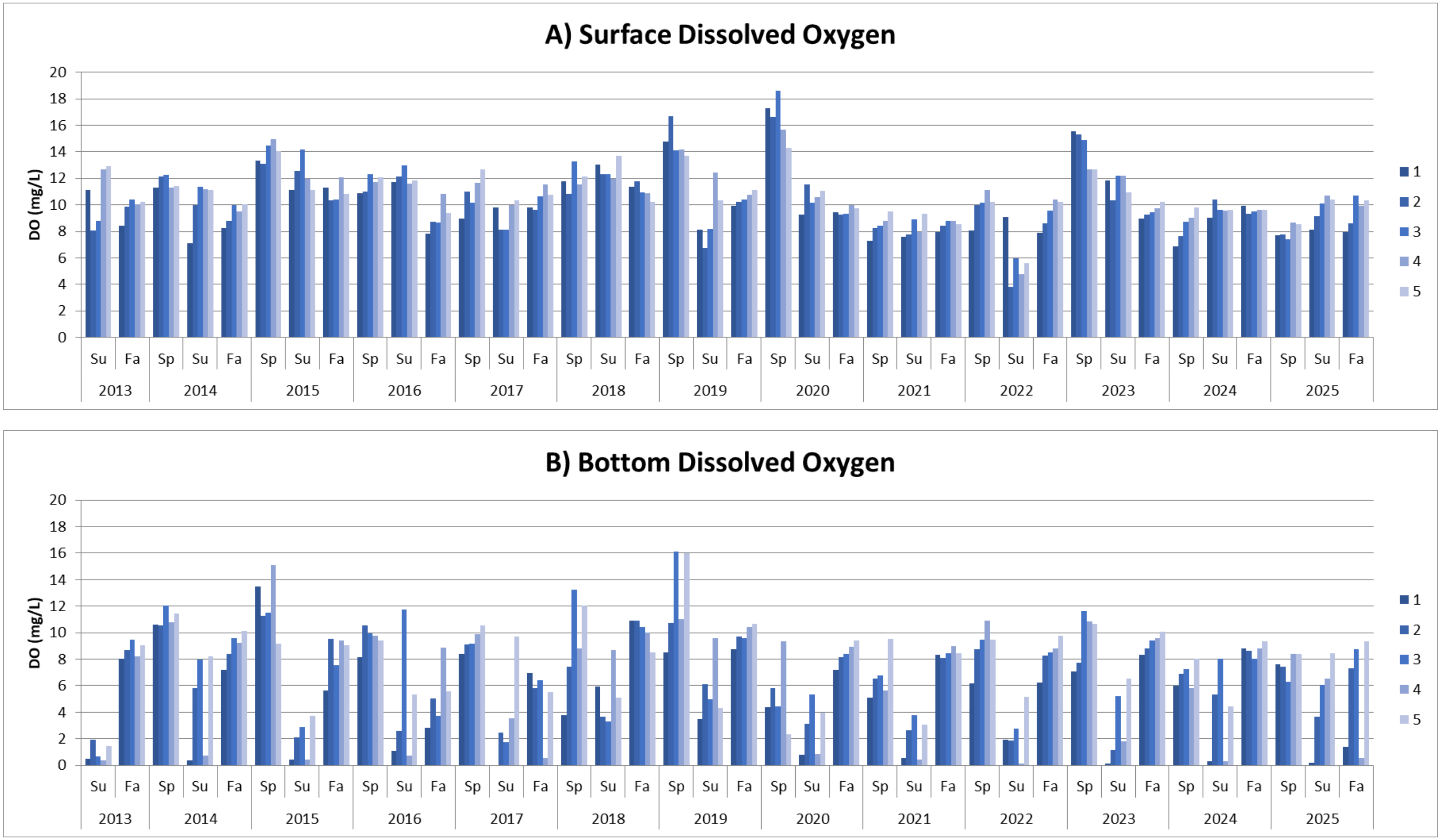


Figure 3. Dissolved Oxygen: A) surface; B) near-bottom concentrations measured at the 5 monitoring stations in Lake Macatawa from 2013 through 2025.

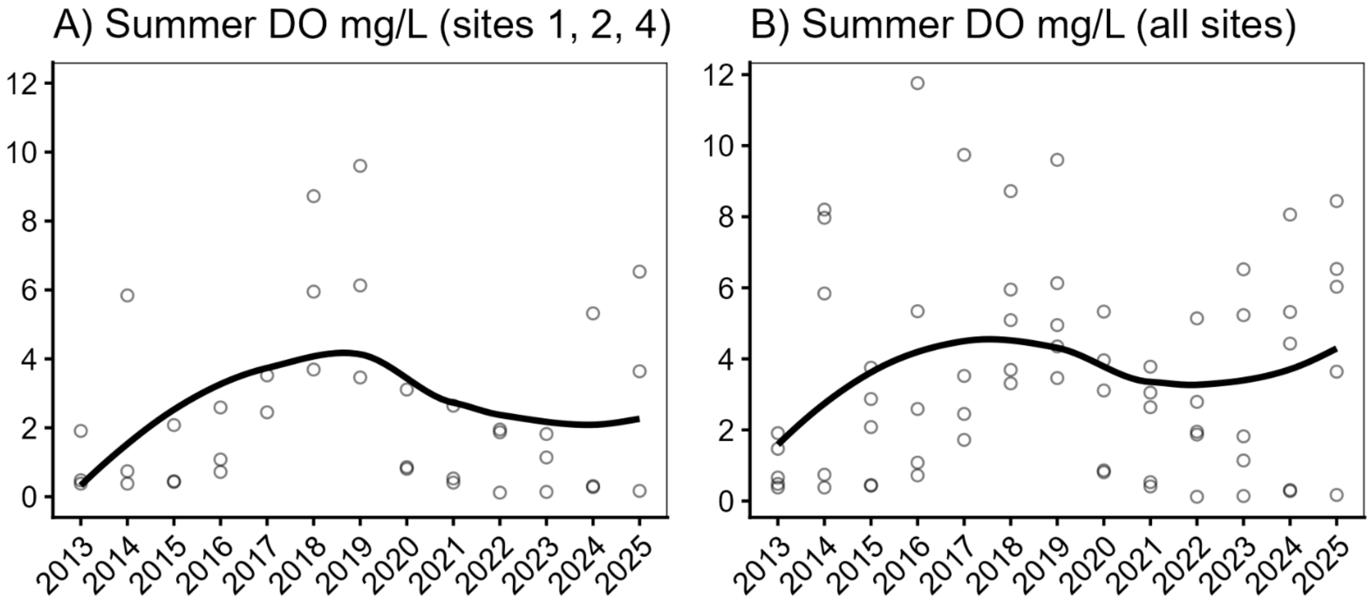


Figure 4. Locally weighted scatterplot smoothing (LOWESS) trend analyses of bottom summer DO site data from Lake Macatawa. A) Sites 1, 2, and 4 represent the main flow of Lake Macatawa via the Macatawa River watershed. B) All 5 sites, including the lake's northern Big Bay and Pine Creek Bay.

Table 3. Lake-wide means (1 SD) of phosphorus (soluble reactive phosphorus [SRP] and total phosphorus [TP]), nitrogen (nitrate [NO_3^-], ammonia [NH_3] and Total Kjeldahl Nitrogen [TKN]), laboratory-extracted chlorophyll *a* (chl *a*), and microcystins (MCs) measured during 2025 monitoring year. Data are shaded for readability. See Table 2 for dates of sampling events. Note different units for the analytes. "n" is the number of lake sites composing the seasonal mean at each depth. BD = below detection; NA = not applicable.

Season	Depth	n	SRP (µg/L)	TP (µg/L)	NO_3^- (mg/L)	NH_3 (mg/L)	TKN (mg/L)	ext. Chl (µg/L)	MCs (µg/L)
Spring	Top	5	38 (17)	103 (29)	1.58 (0.59)	0.59 (0.32)	1.74 (0.49)	5 (2)	BD (NA)
	Bottom	5	38 (20)	118 (49)	2.16 (1.79)	0.68 (0.43)	1.83 (0.48)	5 (1)	BD (NA)
Summer	Top	5	17 (3)	180 (39)	0.11 (0.06)	0.06 (0.07)	1.30 (0.27)	42 (16)	0.30 (0.17)
	Bottom	5	57 (65)	198 (109)	0.13 (0.04)	2.05 (4.36)	2.42 (3.24)	22 (15)	0.15 (0.09)
Fall	Top	5	3 (0)	94 (23)	0.31 (0.19)	0.10 (0.12)	1.53 (0.34)	65 (16)	0.08 (0.07)
	Bottom	5	5 (3)	103 (24)	0.25 (0.15)	0.18 (0.14)	1.32 (0.29)	45 (22)	0.06 (0.07)

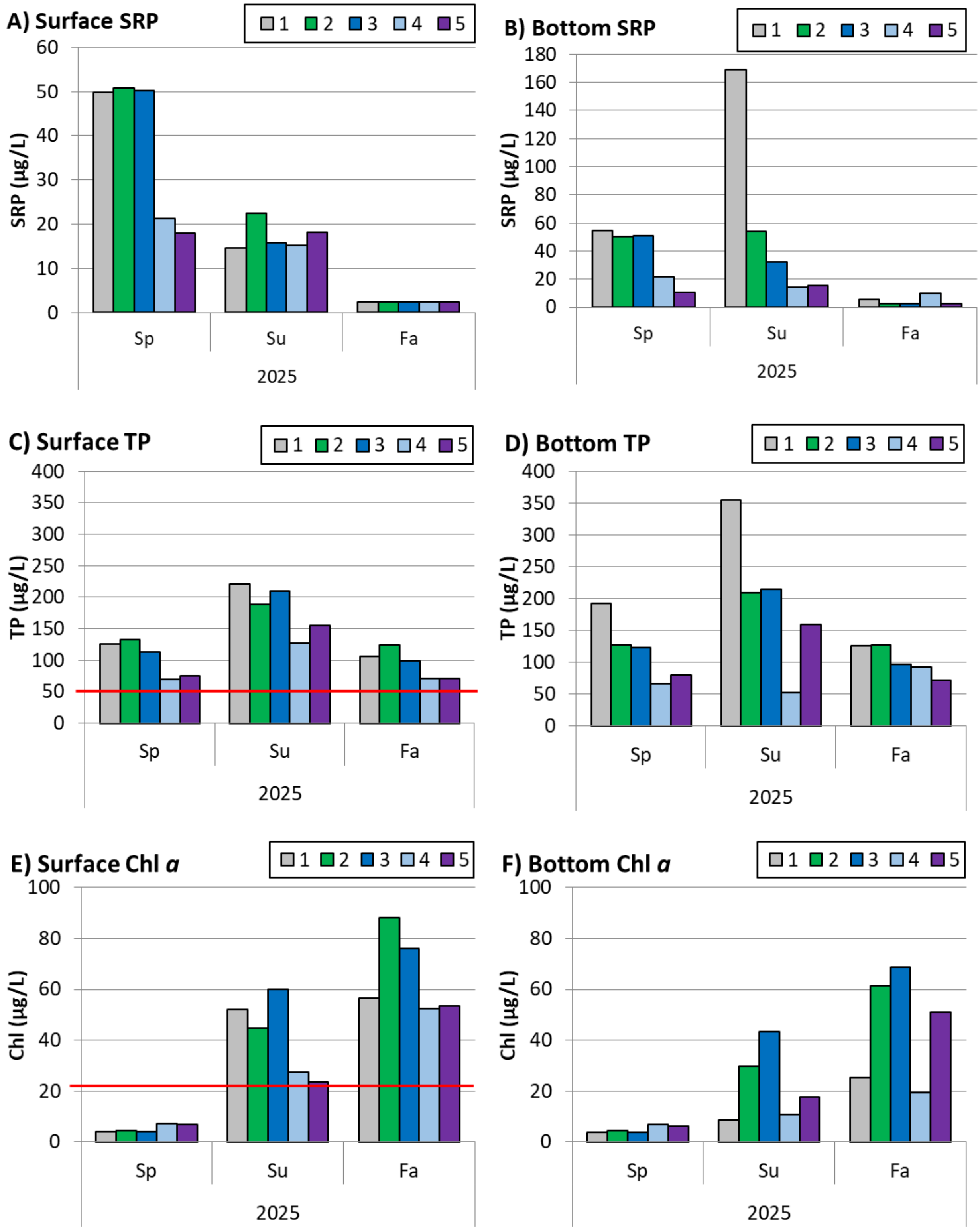


Figure 5. Soluble reactive phosphorus ([SRP]: A, B); total phosphorus ([TP]: C, D); and chlorophyll *a* ([chl *a*]: E, F) concentrations measured at the 5 monitoring stations in Lake Macatawa during 2025. The red horizontal line on surface TP (C) indicates the interim total maximum daily load (TMDL) goal of 50 µg/L (Walterhouse 1999). The red horizontal line on surface chl *a* (E) indicates the hypereutrophic boundary of 22 µg/L used by EGLE for assessing chl *a* in Lake Macatawa (Holden 2014). Note scales change on y-axes.

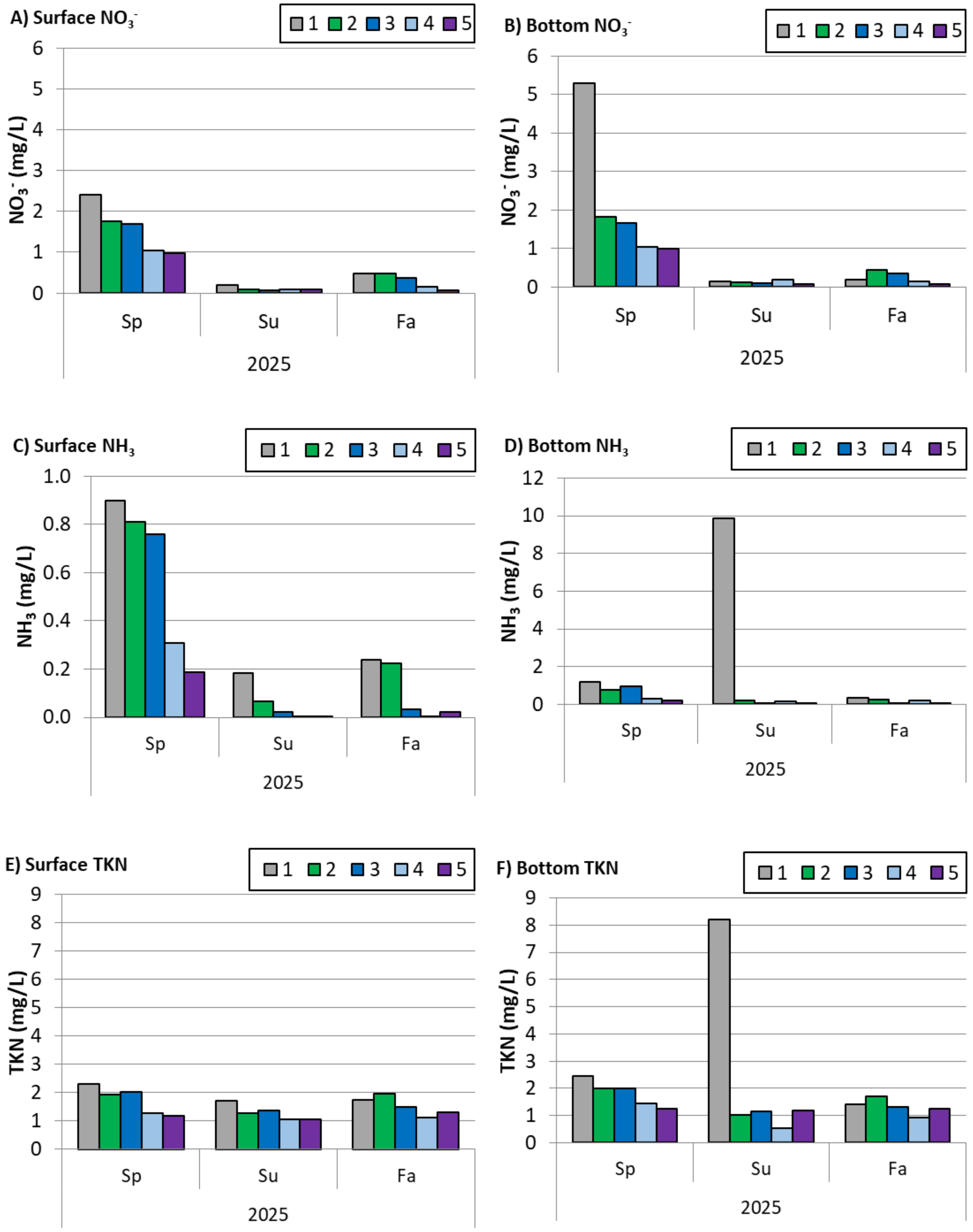


Figure 6. Nitrate ([NO$_3^-$]: A, B); ammonia ([NH$_3$]: C, D); and Total Kjeldahl Nitrogen ([TKN]: E, F) concentrations measured at the 5 monitoring stations in Lake Macatawa during 2025. Note scales change on y-axes.

3.2 Pre- vs. Post-Restoration Comparison

Although we have indicated in prior reports that it will take a considerable period of time before lake water quality responds on a consistent basis to actions taken in the watershed, it also appears that the lake may have reached a plateau in its response to watershed best management practices. The lag time in response is because lakes have a built-in resistance to change (cf. Abell et al. 2020) due to their relatively long hydraulic residence time (pollutants don't leave quickly), the quantity and location of implemented management actions in the watershed (cf. Fales et al. 2016, Steinman et al. 2018), and the potential importance of sediments as a source of nutrients to the lake (Steinman and Spears 2020). Given that watershed-based management changes have been relatively recent and implemented on a relatively modest amount of area in the Macatawa watershed, it was not expected that Lake Macatawa water quality would respond quickly. Nonetheless, the lack of progress, especially in phosphorus concentrations, suggests that the response to improvements has stabilized, and additional measures may be needed to meet the TMDL.

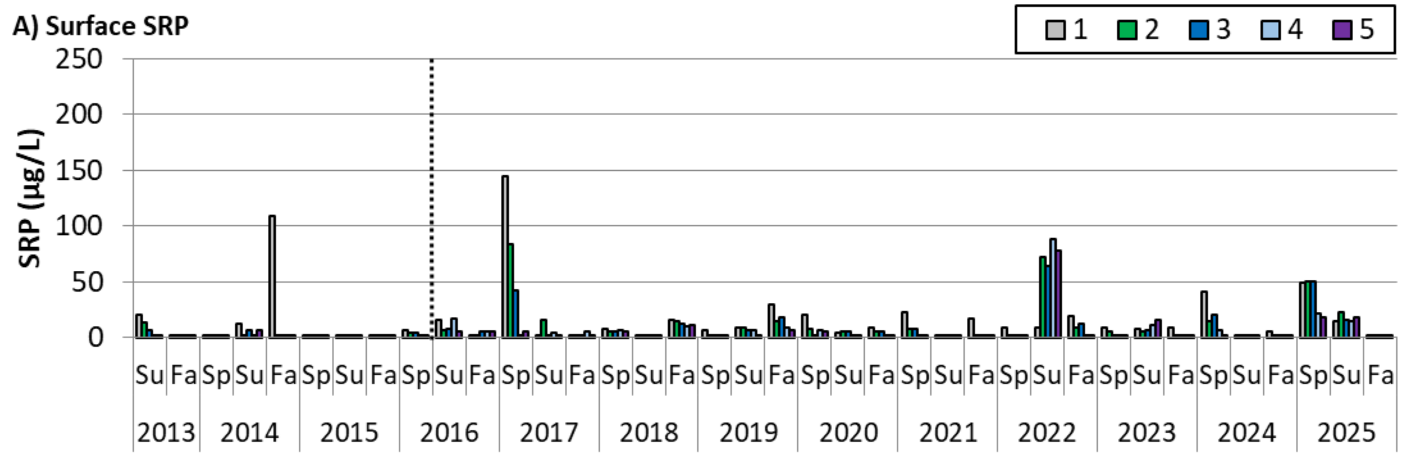
We acknowledge that 3 sampling dates per year can miss important events but with 13 years of monitoring data, we believe the trends we have observed in concentrations are robust. The pre vs. post means in Table 4, complemented by visualization of the trends in Figs. 7-12 help confirm the efforts associated with Project Clarity have reduced fall TP and Chl *a* concentrations, and improved water clarity. This, undoubtedly, has contributed to the positive attitudes of residents to Lake Macatawa conditions. However, the data also clearly show that these parameters have not improved in the spring and summer seasons.

Indeed, explicit comparisons of pre and during restoration (summer 2013-fall 2015) vs. post-restoration (summer 2023-fall 2025) for all seasons reveal that surface and bottom SRP concentrations have significantly increased over time, with Secchi disk depth indicating significantly better water clarity over time (Fig. 13). TP and Chl *a* showed no significant trends.

No pre-restoration data exist for any of the nitrogen forms measured in this study (nitrate, ammonia, TKN), but trends can still be qualitatively evaluated for change over time. Nitrate concentrations remained within range of historical sampling, with the exception of a site 1 spike of 5.3 mg/L (slightly surpassing the previous record high) at near-bottom depth that notably is the first recorded spring nitrate spike observed by this research team (Table 4, Fig. 10A-B). Ammonia and TKN likewise were similar to past years except for the summer site 1 near-bottom spike, a ~2.5x increase in NH_3 and ~0.3x increase in TKN in 2025 compared to previous records (Table 4, Figs. 11-12).

Table 4. Lake-wide grand means (1 SD) of phosphorus concentrations (soluble reactive phosphorus [SRP] and total phosphorus [TP]), laboratory extracted chlorophyll *a* (chl *a*), and Secchi disk depths measured during multi-year project history. Grand mean cells have two rows per cell: data in the top row represent pre-restoration sampling (Summer 2013 – Fall 2015) and data in bottom row represent post-restoration sampling (Spring 2016 – Fall 2025). ND = no data.

Season	Depth	Period	n	SRP (µg/L)	TP (µg/L)	NO_3^- (mg/L)	NH_3 (mg/L)	TKN (mg/L)	ext. Chl (µg/L)	Secchi Depth (m)
Spring	Surface	Pre	2	3 (0)	66 (4)	ND	ND	ND	25 (4)	0.6 (0.1)
		Post	10	15 (18)	96 (46)	1.28 (0.42)	0.37 (0.28)	1.83 (0.29)	45 (29)	0.7 (0.2)
	Bottom	Pre	2	3 (1)	98 (30)	ND	ND	ND	24 (3)	
		Post	10	15 (18)	101 (49)	1.27 (0.53)	0.50 (0.30)	1.74 (0.45)	31 (17)	
Summer	Surface	Pre	3	6 (3)	110 (66)	ND	ND	ND	67 (39)	0.4 (0.1)
		Post	10	14 (18)	103 (51)	0.50 (0.63)	0.29 (0.16)	1.48 (0.33)	66 (29)	0.7 (0.3)
	Bottom	Pre	3	17 (18)	107 (49)	ND	ND	ND	32 (13)	
		Post	10	24 (29)	114 (57)	0.42 (0.46)	0.68 (0.56)	1.57 (0.56)	35 (15)	
Fall	Surface	Pre	3	10 (12)	134 (23)	ND	ND	ND	63 (43)	0.4 (0.1)
		Post	10	7 (4)	82 (18)	0.92 (0.70)	0.38 (0.22)	1.54 (0.34)	54 (22)	0.6 (0.2)
	Bottom	Pre	3	11 (13)	158 (19)	ND	ND	ND	61 (35)	
		Post	10	13 (15)	93 (18)	0.95 (0.73)	0.35 (0.22)	1.44 (0.37)	47 (16)	



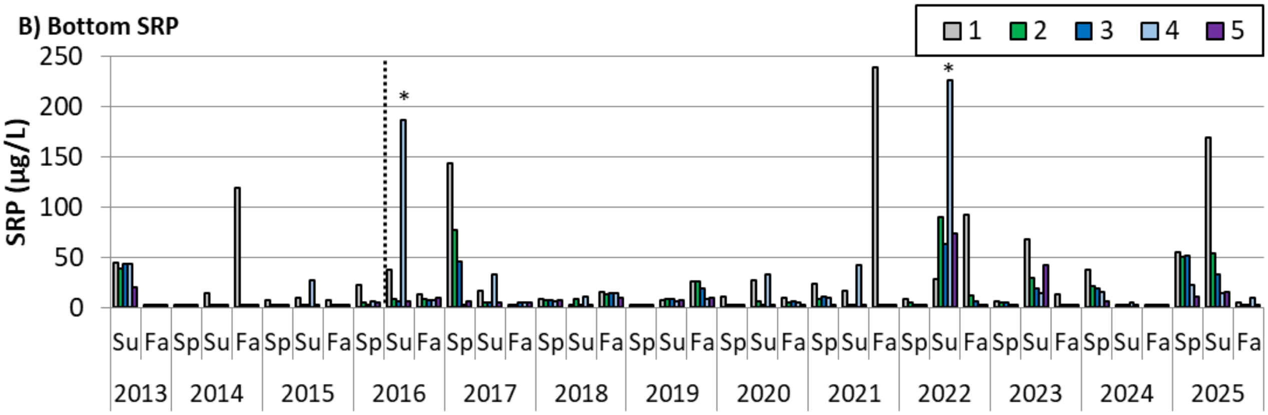


Figure 7. Soluble reactive phosphorus (SRP) levels measured at the 5 monitoring stations in Lake Macatawa from 2013 through 2025. Vertical dotted lines represent approximate restoration construction completion dates for Middle Macatawa and Haworth wetlands. Asterisks in bottom SRP figure indicate possible outliers due to sediment disturbance.

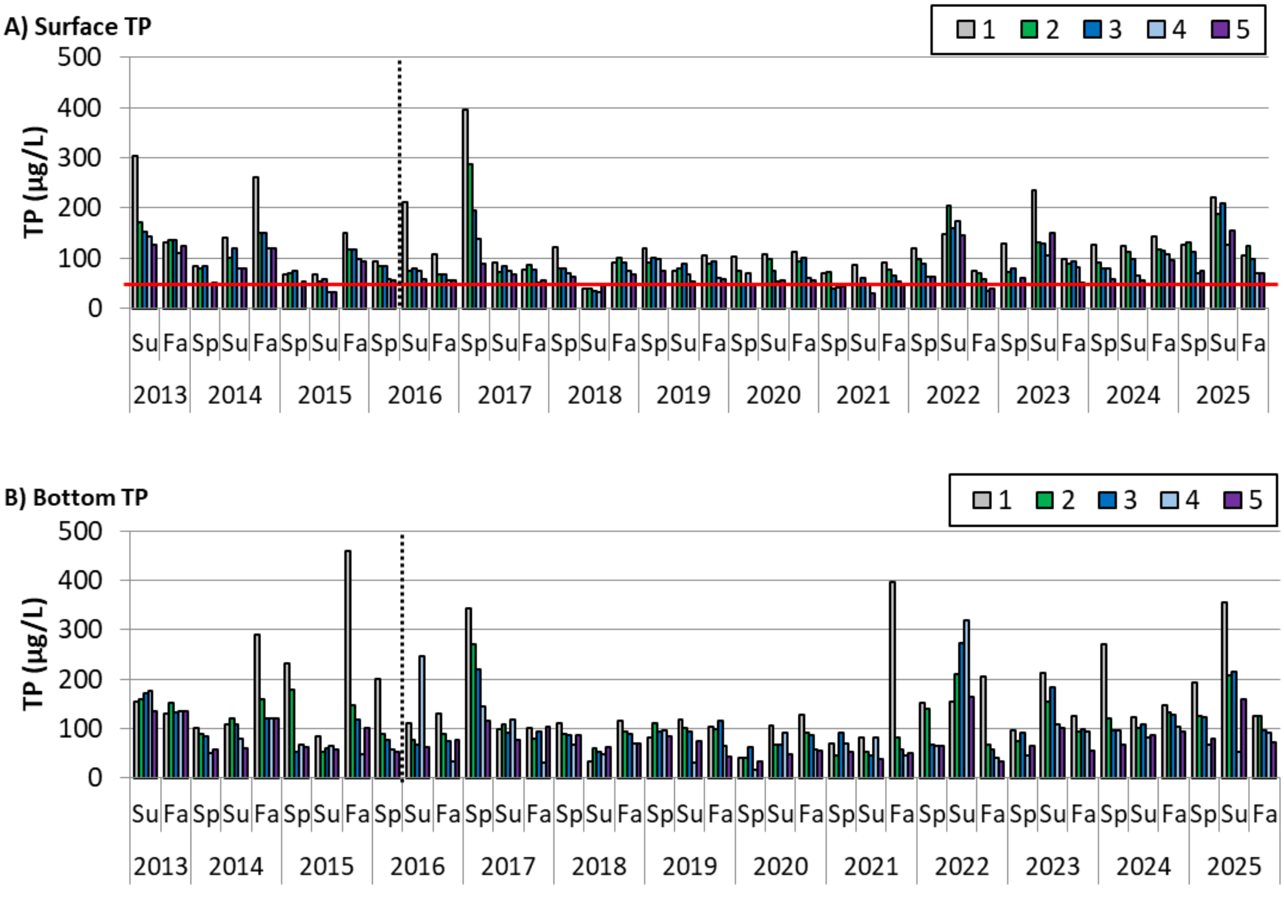


Figure 8. Total phosphorus (TP) levels measured at the 5 monitoring stations in Lake Macatawa from 2013 through 2025. The red horizontal lines on surface TP (A) indicate the interim total daily maximum load (TMDL) goal of 50 µg/L (Walterhouse 1999). Vertical dotted lines represent approximate restoration construction completion dates for Middle Macatawa and Haworth wetlands.

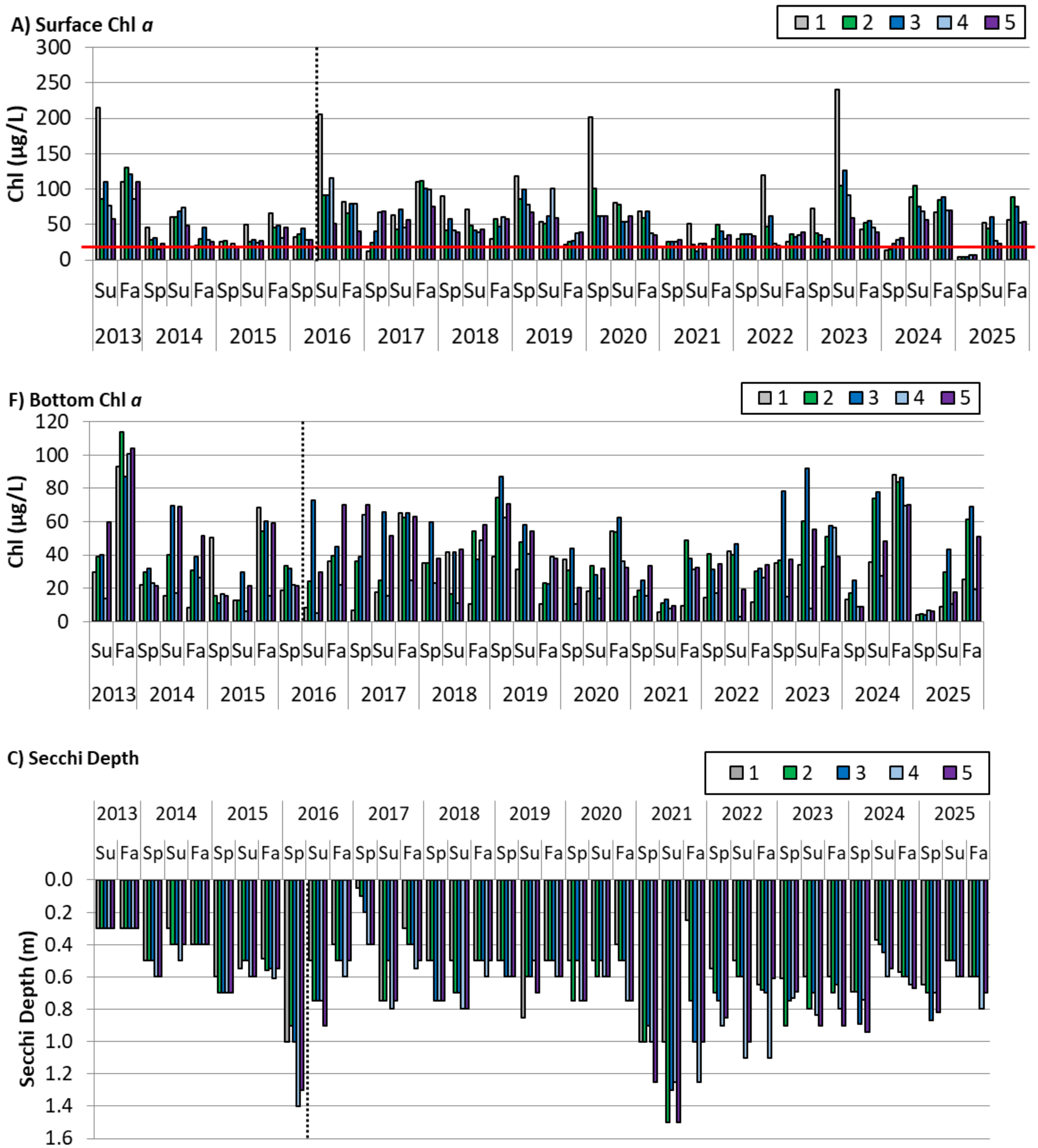


Figure 9. Chlorophyll *a* ([chl *a*]: A, B); and Secchi disk depth: (C) levels measured at the 5 monitoring stations in Lake Macatawa from 2013 through 2025. The red horizontal line on surface chl (A) indicates the hypereutrophic boundary of 22 µg/L used by EGLE to assess chl *a* in Lake Macatawa (Holden 2014). Note scales change on y-axes. Vertical dotted lines represent approximate restoration construction completion dates for Middle Macatawa and Haworth wetlands.

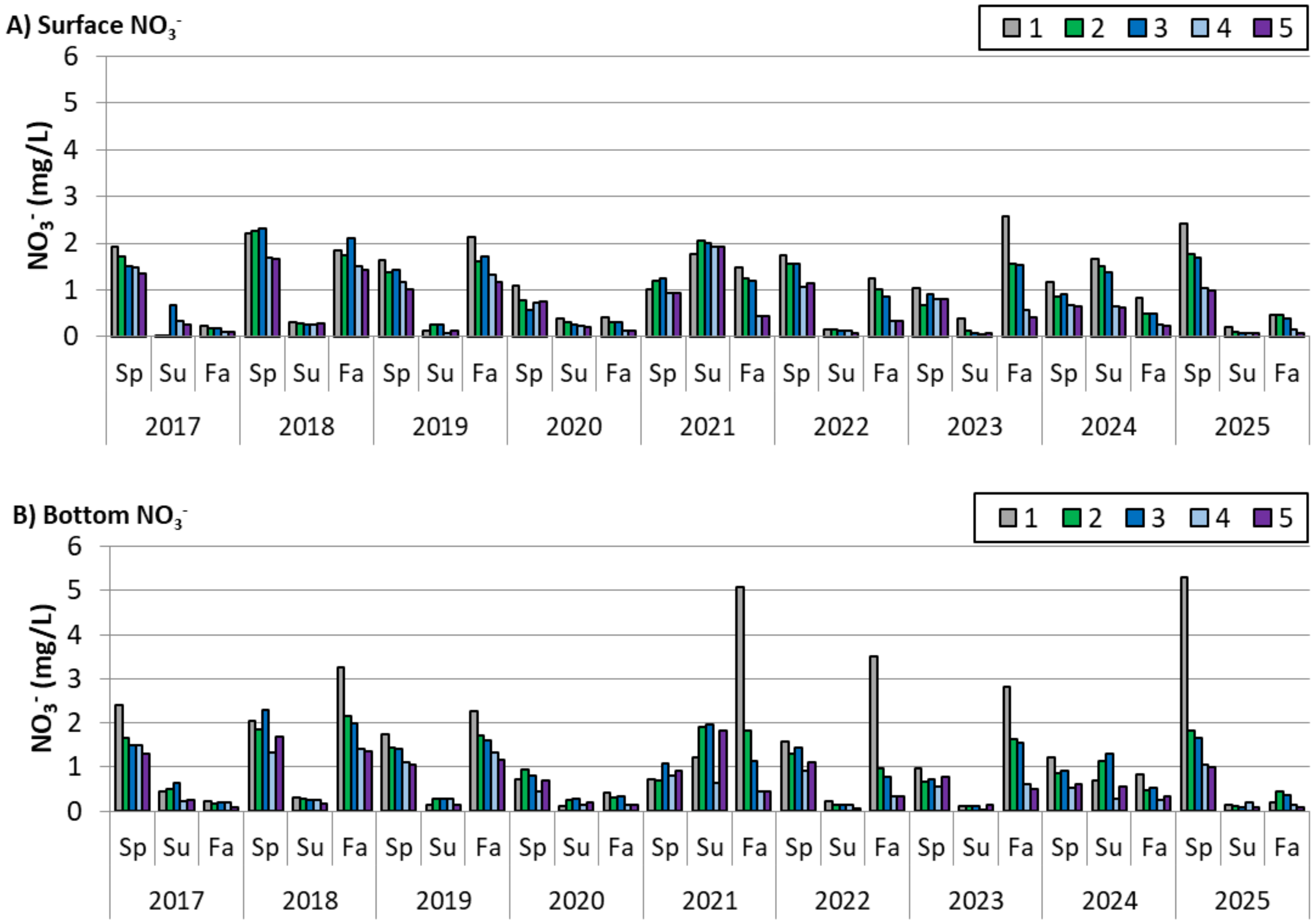
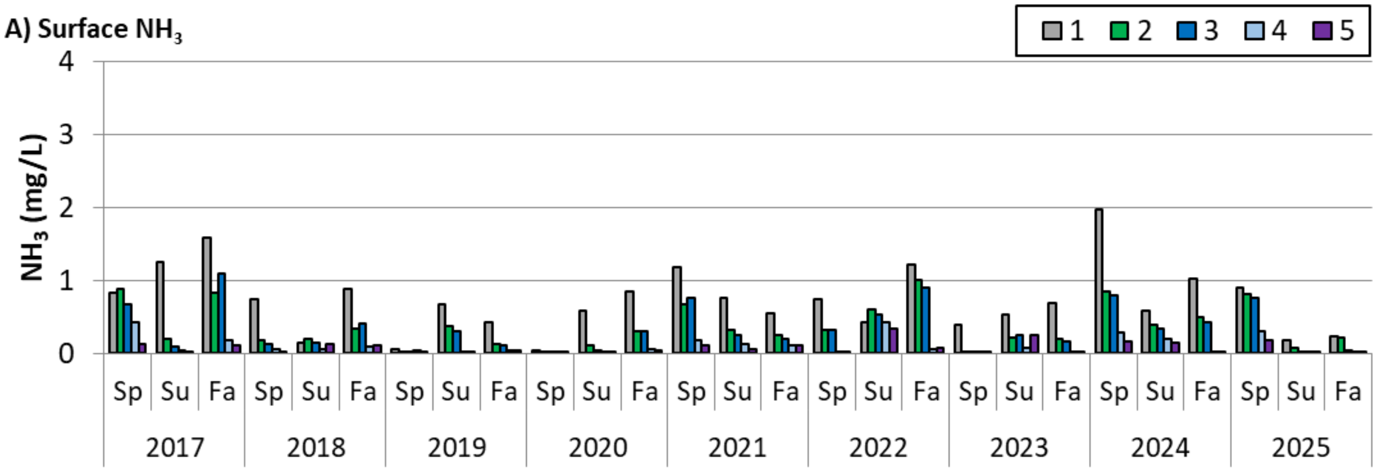


Figure 10. Nitrate (NO_3^-) concentrations measured at the 5 monitoring stations in Lake Macatawa from 2017 through 2025. Note scales change on y-axes.



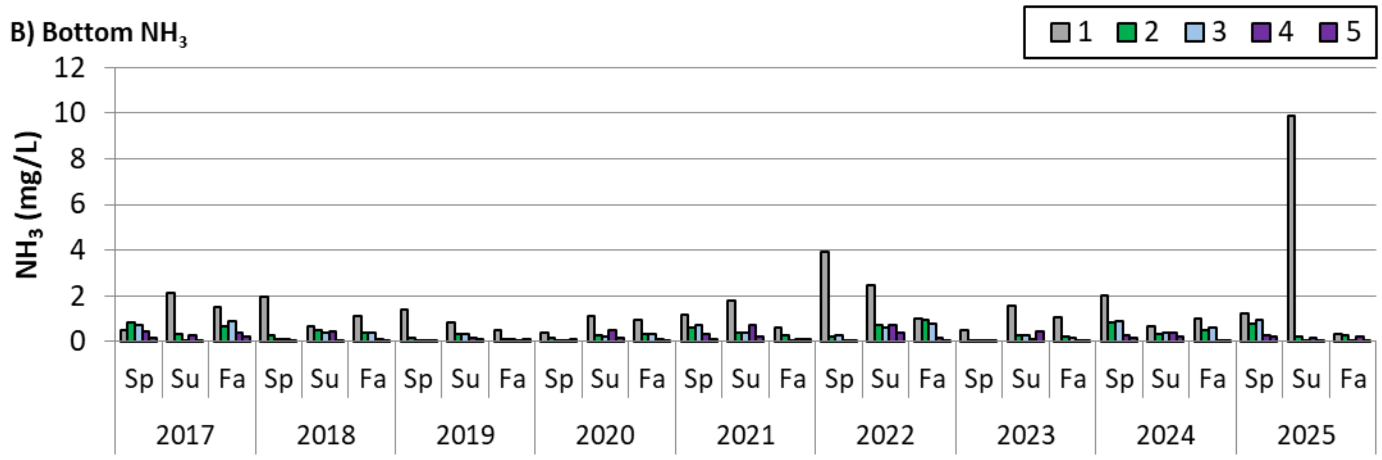


Figure 11. Ammonia (NH_3) concentrations measured at the 5 monitoring stations in Lake Macatawa from 2017 through 2025. Note scales change on y-axes.

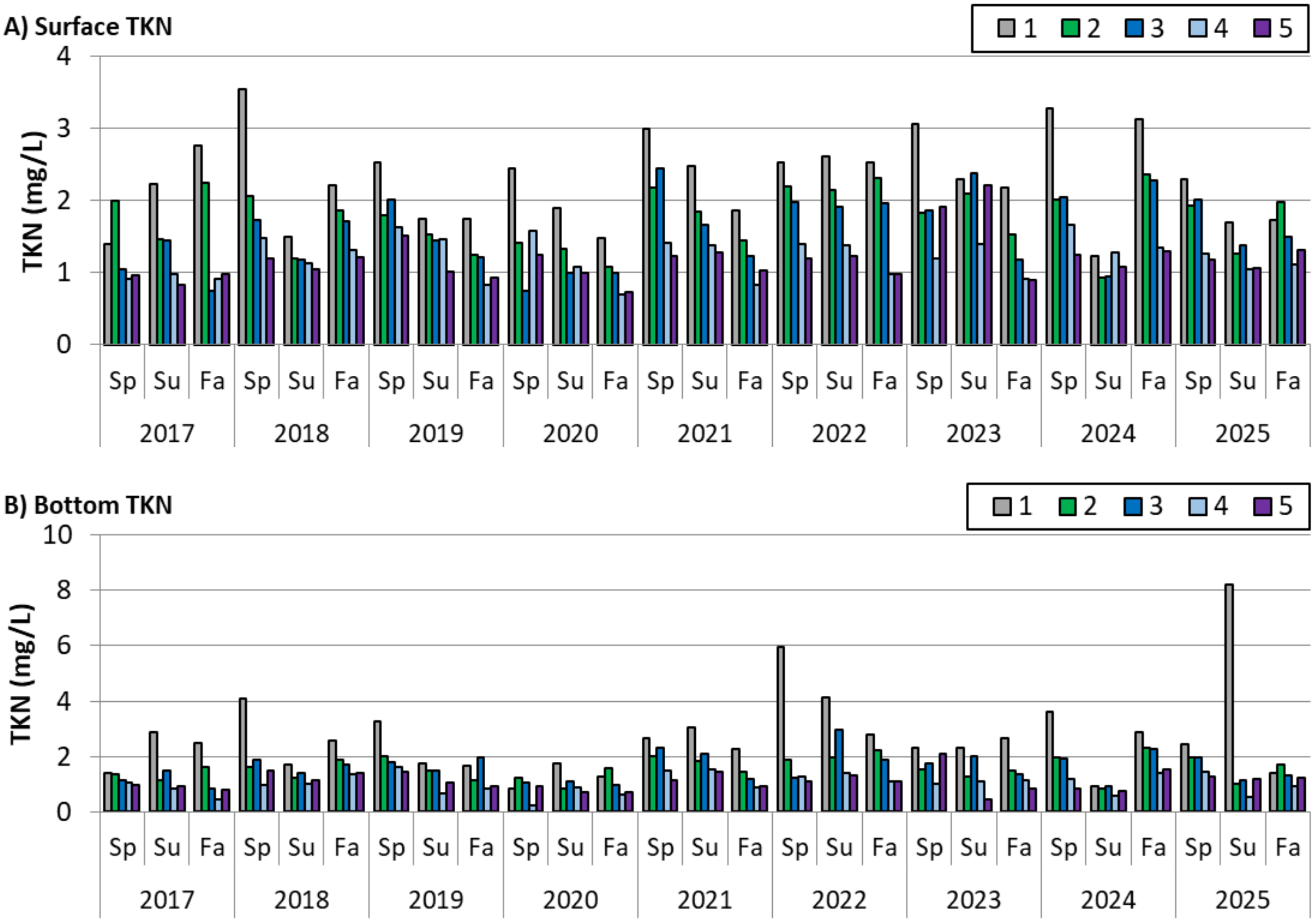


Figure 12. Total Kjeldahl Nitrogen (TKN) concentrations measured at the 5 monitoring stations in Lake Macatawa from 2017 through 2025. Note scales change on y-axes.

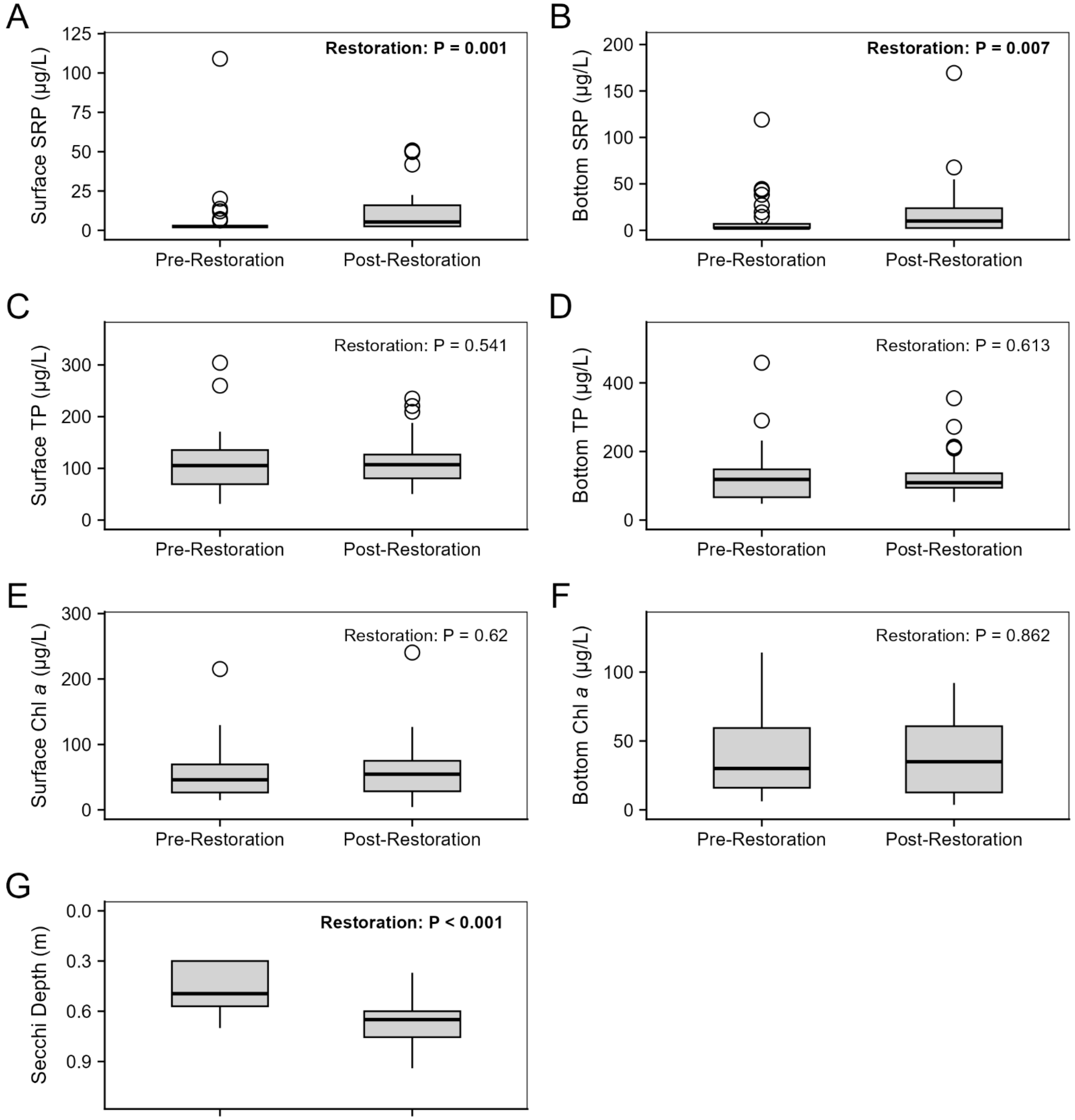


Figure 13. Box plots of soluble reactive phosphorus ([SRP]: A, B); total phosphorus ([TP]: C, D); chlorophyll *a* ([chl *a*]: E, F; and Secchi disk depth: G) levels measured at the 5 monitoring stations in Lake Macatawa during all pre-restoration sampling dates (summer 2013 – fall 2015) and an equal and seasonally corresponding number of post-restoration sampling dates (summer 2023 – fall 2025). Boxes represent the middle 50% of data; the horizontal line crossing the box is the median data value; whiskers represent the upper 25% and lower 25% of data, excluding outliers; points outside of the box and whiskers are considered outliers. Note scales change on y-axes.

4. Summary

As noted in last year's report, the best management practices implemented in the Macatawa watershed have had significant local benefits, from both educational and ecological perspectives. They also have resulted in marginal improvements in Lake Macatawa water quality, with a small and statistically significant improvement in lake water clarity. However, the needle has not moved with respect to phosphorus; indeed, soluble reactive phosphorus, the form that is most bioavailable, has actually increased over time. This is not unique to the Macatawa watershed; as more producers moved to no-till practices in the western basin watershed of Lake Erie, soluble reactive phosphorus concentrations also have increased (Dolaglu et al. 2012).

Restoration efforts in watersheds often take years to manifest as improvements in the water quality of the receiving water body (Sas 1990). Although we sample only 3 times per year, there have now been enough years of data collection to have some confidence in the trends we are observing. Total phosphorus concentrations continue to exceed 100 µg/L and chlorophyll a concentrations that occasionally reach 50 µg/L or more are indicative not only of an impaired water body, but that improved water quality in Lake Macatawa has appeared to reach a plateau.

While nutrient concentrations and chlorophyll *a* remain much higher than desired, there is also good news. Mean water clarity has improved over time and despite the high algal biomass, cyanotoxin concentrations remain below the EPA threshold for recreational water usage. In addition, the installation of a lake observatory this past summer will greatly enhance our understanding of temporal changes in Lake Macatawa. Although the spatial coverage of the observatory is limited, those data combined with our lake-wide sampling, will enable us to detect any major changes in Lake Macatawa.

The appendices include the Lake Macatawa dashboard (Appendix A) and results from the long-term fish monitoring study on Lake Macatawa (Appendix B).

The Lake Macatawa Dashboard (Appendix A) provides a visual option for quickly surveying how critical water quality parameters (total phosphorus, chlorophyll a, and water clarity) are changing over time and responding to restoration efforts in the watershed. Mean conditions show backsliding in total phosphorus, improvement in algal biomass, and similar water clarity to last year. Overall, especially with respect to the lake's TMDL for total phosphorus, Lake Macatawa remains in the impaired state.

As has been the case in the last few years, the long-term fish monitoring (Appendix B) revealed both positive and negative indicators of Lake Macatawa's fishery. Yellow Perch, Bluegill, and Pumpkinseed were common species captured in our surveys, and they are indicators of good water quality, as was the recent appearance of coregonids in the catch, despite their small numbers. Nevertheless, other common fish species in our surveys, such as Gizzard Shad and Spotfin Shiner, are often associated with poor water quality, as was the near absence of Rock Bass in the catch. Overall, the littoral fish assemblage in Lake Macatawa is more reflective of poor ecological condition. If environmental conditions, such as water quality and aquatic macrophyte coverage in Lake Macatawa were to substantially improve, then we predict that the littoral fish assemblage would respond accordingly. A rigorous statistical analysis of the spatiotemporal patterns in the fish assemblage and environmental conditions of Lake Macatawa and Muskegon Lake is necessary to better evaluate the patterns discussed here, but is beyond the scope of this report, and is a goal for the Ruetz Lab over the next two years. More details on fish composition are provided in Appendix B.

We conclude with a list of observations/recommendations:

- With the installation of a monitoring observatory in summer 2025, we hope to access those data next year to complement our long-term monitoring at 5 sites in the lake, and provide a much more robust understanding of lake water quality. Of particular interest will be changes in dissolved oxygen, which influences fish distribution and phosphorus biogeochemistry, and chlorophyll a, which will help resolve short-term changes in algal biomass. The continuous monitoring data will help fill in the data gaps that are inevitable when sampling on only 3 discrete dates per year, but the value of the observatory data must be tempered by its single location.
- Last year, we recommended greater utilization of the SWAT model (Iavorivska et al. 2021) that was developed for the Lake Macatawa watershed to identify agricultural management options. We believe this recommendation is still valid, as any reduction in loadings from the watershed will help lengthen the effectiveness of a phosphorus inactivation treatment in the lake.
- The current monitoring program does not include two important biotic components in the lake: algal taxonomic composition, and aquatic vegetation cover, biomass, and taxonomic composition. We are currently archiving phytoplankton samples in case a future student may be interested in analyzing the samples but this is an ad hoc exercise and not part of the formal monitoring program. Aquatic vegetation provides critical habitat for fish and wildlife, stabilizes lake sediments, and takes up nutrients in the lake. In addition, it is important to know if invasive vegetation is developing in the lake so it can be quickly controlled. If funding is available, we recommend that consideration be given to plant surveys and phytoplankton identification in the future.
- Although the public works program to add alum to the Macatawa River proved to be too expensive to implement, the possibility of adding a chemical to inactivate (bind) phosphorus in the Lake seems a worthwhile undertaking. We believe there has now been sufficient reduction in phosphorus loading to Lake Macatawa to justify such a chemical treatment. The work being done this summer to characterize the sediment phosphorus will identify where the chemical would be most effectively applied, as well as the appropriate concentration. We acknowledge that this activity is not a panacea—it will, in effect, treat the symptom (phosphorus concentration in the lake) and not the disease (phosphorus entering the lake). However, given that the benefits provided by the watershed BMPs appear to have plateaued, a lake chemical application is a reasonable next step.

5. Acknowledgements

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7. Appendices

Appendix A. Lake Macatawa Dashboards

Appendix B. Long-Term Fish Monitoring of Lake Macatawa

Appendix A. Lake Macatawa Dashboards

Lake Macatawa Water Quality Dashboard

2025

Prepared: January 2026

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Kathryn J. Tyrrell
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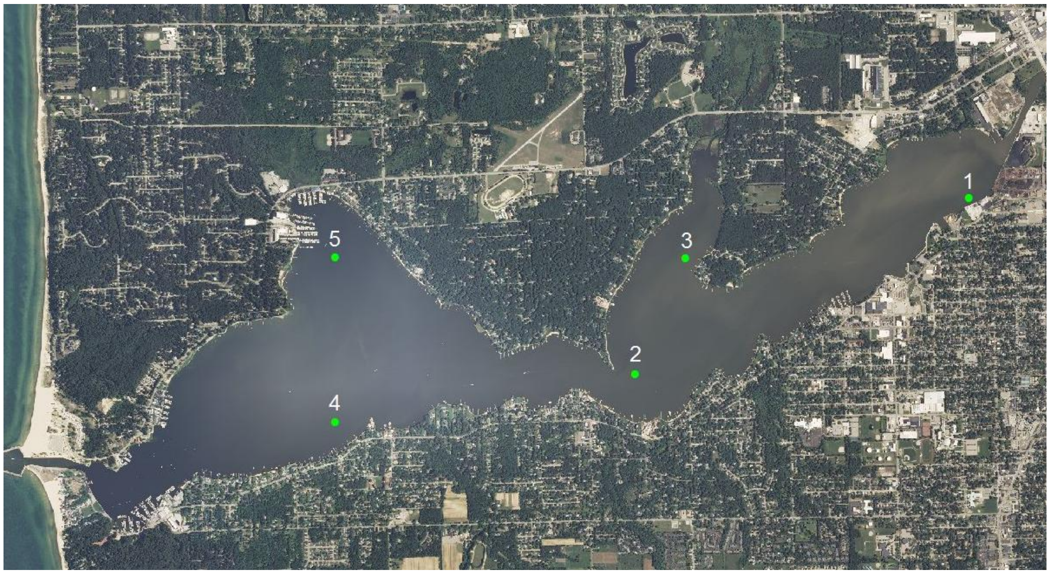
WATER RESOURCES INSTITUTE

Introduction

As part of Project Clarity, Grand Valley State University's Annis Water Resources Institute (AWRI) established a monitoring program on Lake Macatawa in 2013. The goal of the monitoring program is to evaluate and document the progress toward achieving Project Clarity's goal of improved water quality in Lake Macatawa. The monitoring program involves sampling the lake 3 times per year for a suite of biological, physical, and chemical parameters. Although our monitoring occurs on discrete dates, a new monitoring buoy was deployed in summer 2025 and is operated through the Ottawa County Conservation District; their data is not yet publicly available but, in the future, we hope to include the information from the observatory in this dashboard to complement our lakewide data. For the current dashboard, our data may miss events between sampling dates. The value of the dashboard is an assessment of long-term trends, not of short-term events.

Key water quality indicators were selected from the many parameters that are monitored to create a water quality dashboard for Lake Macatawa (see full annual report for all parameters). The goal of the dashboard is to provide a visual representation of the current status and historical trends in Lake Macatawa water quality, by rating each indicator along a scale from desirable (green) to undesirable (red) conditions. Each scale also includes a category that indicates the water quality goal for the lake is being met (yellow). The indicators that were chosen are commonly used to assess lake health: total phosphorus concentration, chlorophyll *a* concentration, and Secchi disk depth (water clarity). Each indicator is described in more detail below.

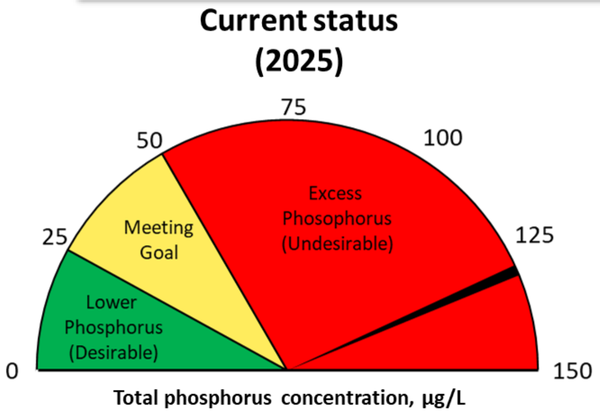
Historical data are included in the dashboard to facilitate comparison of current findings with past status of the selected water quality indicators. Sources for historical data include U.S. EPA (1972; STORET), Michigan Department of Environment, Great Lakes, and Energy (formerly MDEQ; 1982-2012; S. Holden, personal communication), and AWRI (since 2013). All current and historical data shown represent the annual average value of an indicator across Sites 1 (east basin), 2 (central basin), and 4 (west basin; see map below).

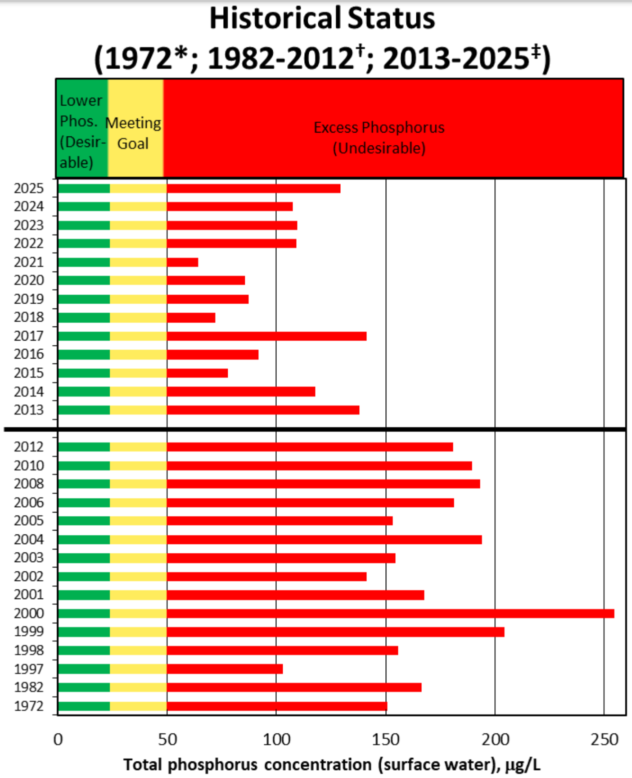


Map of Lake Macatawa showing the 5 sampling locations (green dots) for long-term water quality monitoring. Dashboard indicators were calculated based on data from Sites 1, 2, and 4.

Total Phosphorus

2025 Mean Concentration: 129 µg/L
Target Concentration: 50 µg/L





*U.S. EPA; †EGLE; ‡AWRI

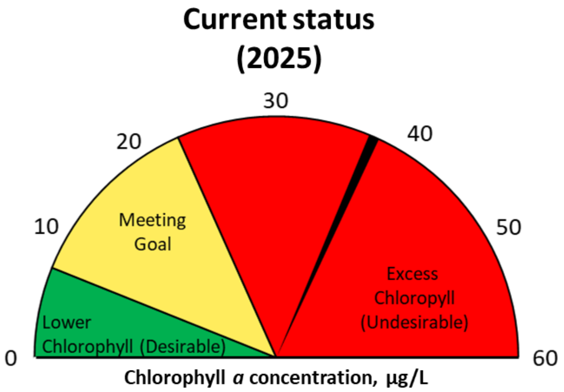
Phosphorus (P) is an essential element for living organisms. In many freshwater systems, P is the element that limits algal growth. However, when it becomes too abundant, it can help stimulate undesirable algal blooms. Phosphorus comes in many forms; we selected Total Phosphorus (TP) as the dashboard indicator because it includes all the forms of P in the lake (i.e., particulate and dissolved).

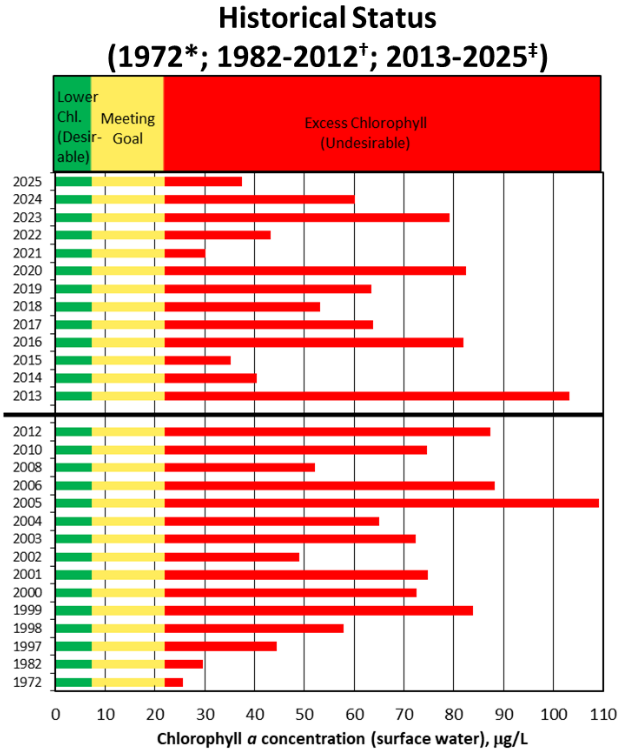
Lake Macatawa has a history of extremely high TP concentrations (i.e., > 100 µg/L), placing it in the past in the "hypereutrophic" trophic state. As a result of this nutrient enrichment, the State of Michigan established an interim target TP concentration of 50 µg/L in Lake Macatawa. Thus, the TP dashboard shows the water quality goal as being met when TP concentrations are < 50 µg/L. While attaining this goal would be a significant improvement in water quality from current conditions, Lake Macatawa would still be in an impaired "eutrophic" state, which we define as TP concentration > 24 µg/L. Therefore, the TP dashboard shows the ultimate desired TP concentration as < 24 µg/L.

The 2025 status for the total phosphorus indicator remains **Undesirable**, indicating that the average TP concentration in 2025 exceeded the water quality goal. TP concentrations had appeared to stabilize between 2022 and 2024 at around 110 µg/L, which is down significantly from pre-Project Clarity but still well above a TP concentration in a healthy lake. However, in 2025, TP increased again to an annual average of ~129 µg/L. This may be due to changing water levels or it may be an indication the watershed best management practices have reached their capacity to provide P reductions. The data indicate that new steps need to be taken to save Lake Macatawa's future ecological health.

Chlorophyll *a*

2025 Mean Concentration: 38 µg/L
Target Concentration: 22 µg/L





*U.S. EPA; †EGLE; ‡AWRI

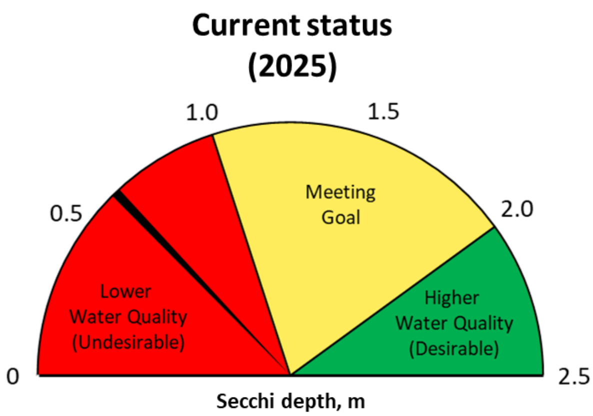
Chlorophyll *a* is the green pigment found in photosynthetic plants and algae. Measuring chlorophyll *a* is a relatively simple way to estimate the amount of algal biomass present in lake water, although it has some limitations. First, chlorophyll *a* does not provide information on whether or not the algae present produce toxins. Second, chlorophyll concentrations can change depending upon environmental conditions, such as light or nutrient level. Finally, chlorophyll *a* concentrations may be low due to very active predation by grazers (zooplankton), so the measurement may give an underestimate of how much algal biomass would otherwise be present.

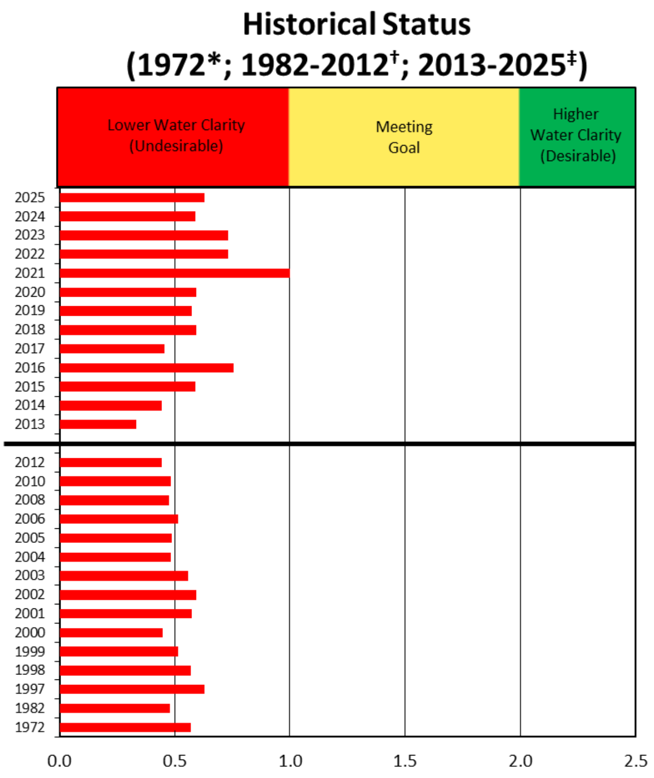
Lake Macatawa has a history of excess algal biomass and high chlorophyll *a* concentrations, typically exceeding the "hypereutrophic" threshold commonly used by EGLE (22 µg/L) in its assessments of the lake. The chlorophyll *a* dashboard shows that the concentration will meet the water quality goal once it is < 22 µg/L. Although meeting the chlorophyll *a* goal would be a significant improvement in water quality, Lake Macatawa would still be categorized as "eutrophic" (i.e., > 7 µg/L chlorophyll *a*). Thus, the chlorophyll *a* dashboard shows that the ultimate desired chlorophyll *a* concentration is < 7 µg/L.

The current status for the chlorophyll *a* indicator is **Undesirable** although one of the lower chlorophyll concentrations observed in the range of Project Clarity monitoring. While the strong decline of ~20 µg/L per year since 2023 is encouraging, it is also deceptive; the 2025 mean concentration was strongly influenced by a low spring mean of 5 µg/L, compared to the much higher summer and fall means of 41-66 µg/L. The higher chlorophyll concentrations occur in the summer and fall when the lake is more heavily used. These relatively high summer/fall chlorophyll concentrations are consistent with the high TP concentrations in summer (but not fall), as well.

Secchi Disk Depth (Water Clarity)

2025 Mean Depth: 0.63 m (~2.1 ft)
Target Depth: 1 m (~3.3 ft)





*U.S. EPA; †EGLE; ‡AWRI

Secchi disk depth is an estimate of water clarity. It is measured using a standard black and white disk, named after the Italian priest Angelo Secchi, who first used an all-white disk for marine waters in 1865. Lake ecologists modified it to black and white in the late 1800s. The Secchi disk is a simple and easy way to measure water clarity, although if waters are cloudy, the disk depth tells you nothing about why the lake is turbid (e.g., is it due to suspended algae or suspended sediment?).

Along with excess phosphorus and chlorophyll *a* concentrations, Secchi depths have historically reflected impaired conditions in Lake Macatawa. Oligotrophic lakes, such as Lake Tahoe, have Secchi disk depths down to 21 m (~70 ft) or deeper. Conversely, hypereutrophic lakes, such as Lake Macatawa, typically have Secchi depths shallower than 1 m (~3 ft). The water clarity goal for Lake Macatawa is modest, with a Secchi depth > 1 m. Because Secchi depths between 1 and 2 m are indicative of a eutrophic state, a desirable Secchi depth is > 2 m.

The current status for the Secchi depth indicator is **Undesirable.** The mean Secchi depth has improved since Project Clarity was implemented but has been relatively stable the past four years, and currently does not meet the water quality goal.

Long-Term Fish Monitoring of Lake Macatawa: Results from 2025

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12 February 2026

An Annual Report
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Introduction

This study was initiated to provide critical information on littoral fish populations in Lake Macatawa and ultimately to evaluate the performance of watershed restoration activities that are part of Project Clarity. In autumn 2014, we initiated long-term monitoring of the littoral fish assemblage of Lake Macatawa to establish baseline ecological conditions and evaluate ecological change over time. Our fish sampling plan for Lake Macatawa is similar to our ongoing, long-term (since 2003) monitoring effort in Muskegon Lake (Ruetz et al. 2007; Bhagat and Ruetz 2011). By using the same monitoring protocols in each water body, Muskegon Lake can serve as a “control” to evaluate temporal changes in Lake Macatawa in an effort to better assess how the lake is responding to watershed restoration activities.

Our primary objective in the twelfth year (2025) of sampling was to continue characterizing the littoral fish assemblage. We made comparisons with work in Muskegon Lake (see Bhagat and Ruetz 2011) as well as with six Lake Michigan drowned river mouths for which we have data (see Janetski and Ruetz 2015). We also assessed patterns over time and how littoral fish assemblages responded to restoration activities in the watershed.

Methods

Study sites.—Lake Macatawa is a drowned river mouth lake in Holland, Michigan that is located on the eastern shore of Lake Michigan in Ottawa County (Mader et al. 2023). Lake Macatawa has an area of 7.20 km^2, mean depth of 3.66 m, and maximum depth of 12.19 m (MDNR 2011). The shoreline has high residential and commercial development, and the watershed consists mainly of agricultural land (MDNR 2011; Mader et al. 2023). Sampling was conducted at four littoral sites in Lake Macatawa that represented a gradient from the mouth of the Macatawa River to the connecting channel with Lake Michigan (Figure 1; Table 1). In 2016, much of the riparian vegetation was removed at site #2 for a construction project (Figure 1), which substantially changed littoral habitat. In 2020, high water levels in the Great Lakes made fish sampling challenging; as a result, fyke nets were not fished at site #3 (but all other sampling was completed). Water levels in Lake Michigan receded in 2021, and we have been able to sample fish at all sites henceforth.

Fish sampling.—At each study site, we sampled fish via fyke netting and boat electrofishing. Using both sampling gears should better characterize the littoral fish assemblage than either gear by itself because small-bodied fishes are better represented in fyke netting and large-bodied fishes are better represented in nighttime boat electrofishing (Ruetz et al. 2007). Fyke nets were set on 10 September 2025 during daylight hours (i.e., between 0750 and 1100) and fished for about 26.1 h (range = 23.8-27.7 h). Except for 2021 when poor weather conditions delayed sampling into October, fyke nets had been previously set in September. Three fyke nets (4-mm mesh) were fished at each site; two fyke nets were set facing each other and parallel to the shoreline, whereas a third fyke net was set perpendicular to the shoreline following the protocol used by Bhagat and Ruetz (2011). A detailed description of the design of the fyke nets is reported in Breen and Ruetz (2006). We conducted nighttime boat electrofishing at each site on 8 September 2025. All previous nighttime electrofishing surveys were conducted during 5-22 September (2014-2025). A 10-min (pedal time) electrofishing transect was conducted approximately parallel to the shoreline at each site with two people at the front of the boat to net fish, although for some transects (particularly sites #2 and #3) we had to navigate around boat docks. The electrofishing boat was equipped with a Smith-Root 5.0 generator-powered pulsator control box (pulsed DC, 220 volts, ~7 amp). For both sampling methods, all fish captured were identified to species, measured (total length), and released in the field; however, some specimens were humanely euthanized to confirm identifications in the laboratory. We followed Bailey et al. (2004) for scientific names of fishes.

We measured water quality variables (i.e., temperature, dissolved oxygen, specific conductivity, turbidity, pH, and chlorophyll *a*) in the middle of the water column using a YSI sonde. We made one measurement at each fyke net (n = 12 per year) and one measurement at the beginning of each electrofishing transect (n = 4 per year). We measured the water depth at the mouth of each fyke net and visually estimated the percent macrophyte cover for the length of the lead between the wings of each fyke net (see Bhagat and Ruetz 2011). We also visually estimated the percent macrophyte cover for the length of each nighttime electrofishing transect. For both fyke netting and boat electrofishing surveys, percentage macrophyte cover was estimated only when water clarity was sufficient to observe the lake bottom.

Results and Discussion

We characterized water quality variables at each site during fish sampling in September 2025 (Tables 2 and 3), although inferences about changes in water quality over time should be based on the companion monitoring efforts by the Steinman Lab (see main body of report). The mean water depth at fyke nets was 79 cm (Table 2), which was less than the long-term mean water depth of 90 cm (range = 79-104 cm; *n* = 12 years) at fyke nets. Mean water temperature during fyke netting (18.9 °C; Table 2) was similar to conditions during nighttime boat electrofishing (19.5 °C; Table 3). The long-term mean water temperature during fyke netting was 22.0 °C (range = 18.3-25.5 °C; *n* = 12 years) and nighttime boat electrofishing was 21.9 °C (range = 19.2-24.2 °C; *n* = 12 years). The mean estimated percent macrophyte cover at sites during fyke netting was: 0% at site #1, 5% at site#2, 75% at site #3, 70% at site #4. For nighttime electrofishing, the estimated percent macrophyte cover was: 0% at site #1, 5% at site #2, and 100% at site #3; we did not record macrophyte cover at sites #4 (which typically was among the highest of the sites). The mean percent macrophyte cover in 2025 was the highest we have recorded during fyke netting surveys (Figure 2). We hypothesize that macrophyte growth in Lake Macatawa will be lower in years when insufficient light penetrates the water column to allow submersed plants to grow; both turbidity from inflowing sediment and abundant phytoplankton growth in the lake water column can reduce light penetration.

As stated in past reports, aquatic macrophytes are important habitat for fish (e.g., Radomski and Goeman 2001), and their return is an important goal for the restoration of the fish assemblage in Lake Macatawa. The presence of macrophyte beds in the vicinity of our fish sampling sites is likely related to turbidity (i.e., lower turbidity is associated with more macrophytes), with overall mean turbidity (30.4 NTU, *n* = 12 nets) in 2025 greater than the long-term mean (19.0 NTU, *n* = 144 nets; Figure 3) at the time of autumn fish sampling. A detailed macrophyte survey, conducted every 3-5 years, would provide useful information for Lake Macatawa's ecological status (see Ogdahl and Steinman 2014; Kleindl and Steinman 2021).

We captured 3,851 fish comprising 25 species in Lake Macatawa during 2025 sampling surveys (Table 4). The total catch in 2025 was above the long-term mean of 1,750 fish (SD = 870, *n* = 12 years), but the number of fish species captured was similar to the long-term mean of 27 species (SD = 2.5, *n* = 12 years; Figure 4). The most common fishes in the combined catch (i.e., fyke netting and boat electrofishing) were Bluegill (38%), Gizzard Shad (20%), Brook Silverside (12%), Spottail Shiner (8%), White Perch (6%), Yellow Perch (4%), and Banded Killifish (4%), which composed 91% of the total catch (Table 4). Four of the 25 species captured during 2025 were non-native to the Great Lakes basin (Bailey et al. 2004)—Goldfish, Common Carp, White Perch, and Round Goby—which composed 7% of the total catch, although most of the non-native fishes were White Perch (Table 4). For comparison, we captured 959 fishes comprising 24 species in Muskegon Lake during autumn 2025 (with similar sampling effort in terms of sites and gear to the sampling reported here for Lake Macatawa). Similar to Lake Macatawa, 3 of the 24 species in Muskegon Lake were non-native to the Great Lakes basin—Common Carp, White Perch, and Round Goby—with non-native species in Muskegon Lake composing a similar proportion of the total catch compared with Lake Macatawa (10% vs. 7%, respectively) in 2025. Rock Bass—associated with excellent biotic integrity in Great Lakes coastal wetlands (Cooper et al. 2018)—composed about 8% of the catch in Muskegon Lake during September 2025, whereas this species composed <0.1% of the total catch in Lake Macatawa (2014-2025) with Rock Bass only captured during 2021 (3 individuals) and 2025 (1 individual).

In fyke netting alone, Bluegill (40%), Gizzard Shad (22%), Brook Silverside (14%), Spottail Shiner (8%), and White Perch (5%), and were the most common fishes in the catch, composing nearly 90% of all fish captured (Table 5). The mean size of the Bluegill (6.1 cm TL, *n* = 1,300; Table 5) suggested most of these individuals were young given that mean sizes for Bluegill in Michigan are 4.6 cm TL for age-0 in October-December and 8.4 cm TL for age-1 in August-September (Schneider et al. 2000). The most common species in the catch at each site were Bluegill and Gizzard Shad at site #1, Gizzard Shad, Bluegill, and White Perch at site

#2, Brook Silverside at site #3, and Bluegill and Spottail Shiner at site #4 (Table 5). Notably, six coregonids (likely Bloater *Coregonus hoyi* or Cisco *Coregonus artedi*) were captured at site #4, marking three consecutive years that this "species" was encountered[2]. The number of Cisco is increasing in eastern Lake Michigan (Claramunt et al. 2019), and the species may be using drowned river mouth lakes seasonally (Tingley et al. 2025). The total number of fish captured in fyke nets also varied among sites, with the most fish captured at sites #1 and #2 (Table 5; Figure 5A). Compared with previous fyke netting surveys, the most common species in the catch varied among years (Figure 6), as did patterns in total catch among sites (Figure 5A). Based on relative abundance (i.e., percentage of a fish species in the total catch for a given year) in 2025, Bluegill was more common and Round Goby and Spotfin Shiner were less common in the catch than in most previous years (Figure 6). Gizzard Shad continues to be a substantial portion of the catch in most years (Figure 6).

In boat electrofishing alone, the most common fishes captured were Bluegill (26%), Banded Killifish (16%), Yellow Perch (15%), White Perch (9%), and Gizzard Shad (8%), which composed nearly 74% of the total catch (Table 6). The most common species in the catch were Bluegill and White Perch at sites #1, Gizzard Shad at site #2, Bluegill and Banded Killifish at site #3, and Bluegill and Yellow Perch at site #4 (Table 6). Total catch also varied among sites in 2025, with the highest catches at sites #3 and #4 (Table 6; Figure 5B). Compared with previous boat electrofishing surveys, the most common species in the catch varied among years (Figure 7). In 2025, Bluegill and Banded Killifish were more common in the catch than in most previous years (Figure 7). For comparison, we captured 123 Banded Killifish in 12 years of electrofishing surveys (2014-2025) with 81% of those individuals captured in 2025.

After 12 years of fish monitoring, there are both positive and negative indicators of Lake Macatawa's ecological condition. Yellow Perch, Bluegill, and Pumpkinseed were common species captured in our surveys, and they are indicators of good water quality (Janetski and Ruetz 2015; Cooper et al. 2018). The recent

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[2] The coregonids captured were small (Table 5), which could be consistent with natural reproduction. However, genetic testing is needed for species identification (Lachance et al. 2021). Previous identifications of Bloater (2 individuals in 2023 and 2 individuals in 2024) should not be considered definitive without genetic identification to exclude Cisco.

appearance of coregonids in the catch also is a good indicator, although the “species” only represent a very small proportion of the catch and their expansion may be indicative of a larger scale pattern in Lake Michigan (e.g., Claramunt et al. 2019). Nevertheless, other common fish species in our surveys, such as Gizzard Shad and Spotfin Shiner, are often associated with poor water quality (Janetski and Ruetz 2015). The near absence of Rock Bass in the catch also likely indicates poor water quality and/or habitat (Janetski and Ruetz 2015; Cooper et al. 2018). In the 12 years of sampling, the Rock Bass was captured in only two years (2021 and 2025) in Lake Macatawa, whereas this species was captured every year in Muskegon Lake (with similar sampling effort for the same time period). Taken in aggregate, the littoral fish assemblage in Lake Macatawa is more reflective of poor ecological condition. If environmental conditions (e.g., water quality) in Lake Macatawa were to substantially improve (e.g., to conditions more similar to Muskegon Lake), then we predict that the littoral fish assemblage would respond accordingly (Janetski and Ruetz 2015; Cooper et al. 2018). A rigorous statistical analysis of the spatiotemporal patterns in the fish assemblage and environmental conditions of Lake Macatawa and Muskegon Lake is necessary to better evaluate the patterns discussed here, but is beyond the scope of this report, and is a goal for the Ruetz Lab over the next two years.

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Table 1. Locations (latitude and longitude in decimal degrees) for each 2025 fish sampling site: coordinates are the means of the three fyke nets and the start and end of each boat electrofishing transect. Approximate site locations are depicted in Figure 1.

			Electrofishing			
	Fyke Netting		Start		End	
Site	Lat (º)	Long (º)	Lat (º)	Long (º)	Lat (º)	Long (º)
1	42.79585	86.12104	42.79567	86.12055	42.79557	86.12307
2	42.79227	86.14471	42.78831	86.14490	42.79045	86.14395
3	42.78606	86.17462	42.78657	86.17545	42.78524	86.17402
4	43.11326	86.19591	42.78061	86.19507	42.77945	86.19646

Table 2. Mean ± 1 standard error (*n* = 3) of water quality variables at fish sampling sites in Lake Macatawa that were measured during fyke netting (daylight hours) on 10 September 2025 with a YSI sonde.

Site	Depth (cm)	Water Temperature (ºC)	Dissolved Oxygen (mg/L)	Dissolved Oxygen (%)	Specific Conductivity (µS/cm)	Turbidity (NTU)	pH	Chlorophyll a (µg/L)
1	80±5	19.67±0.04	7.86±0.12	86.1±1.2	667±8	37.2±5.0	7.51±0.04	38.7±0.4
2	87±7	18.92±0.01	8.71±0.06	93.8±0.7	500±0	38.0±6.8	8.35±0.01	75.1±1.4
3	74±6	18.43±0.07	11.79±0.06	125.7±0.8	378±0	22.9±2.5	9.10±0.01	23.3±1.0
4	74±6	18.51±0.07	9.69±0.11	103.5±1.2	390±0	23.3±5.4	8.69±0.02	24.9±2.7

Table 3. Water quality variables at fish sampling sites in Lake Macatawa that were measured during nighttime boat electrofishing surveys on 8 September 2025 with a YSI sonde.

Site	Water Temperature (ºC)	Dissolved Oxygen (mg/L)	Dissolved Oxygen (%)	Specific Conductivity (µS/cm)	Turbidity (NTU)	pH	Chlorophyll a (µg/L)
1	19.686	10.54	115.4	595.0	12.25	8.32	39.20
2	19.379	10.54	114.2	497.9	10.05	8.68	51.56
3	19.548	14.86	162.4	381.8	4.87	9.29	26.71
4	19.215	13.25	143.7	377.2	5.03	9.03	10.57

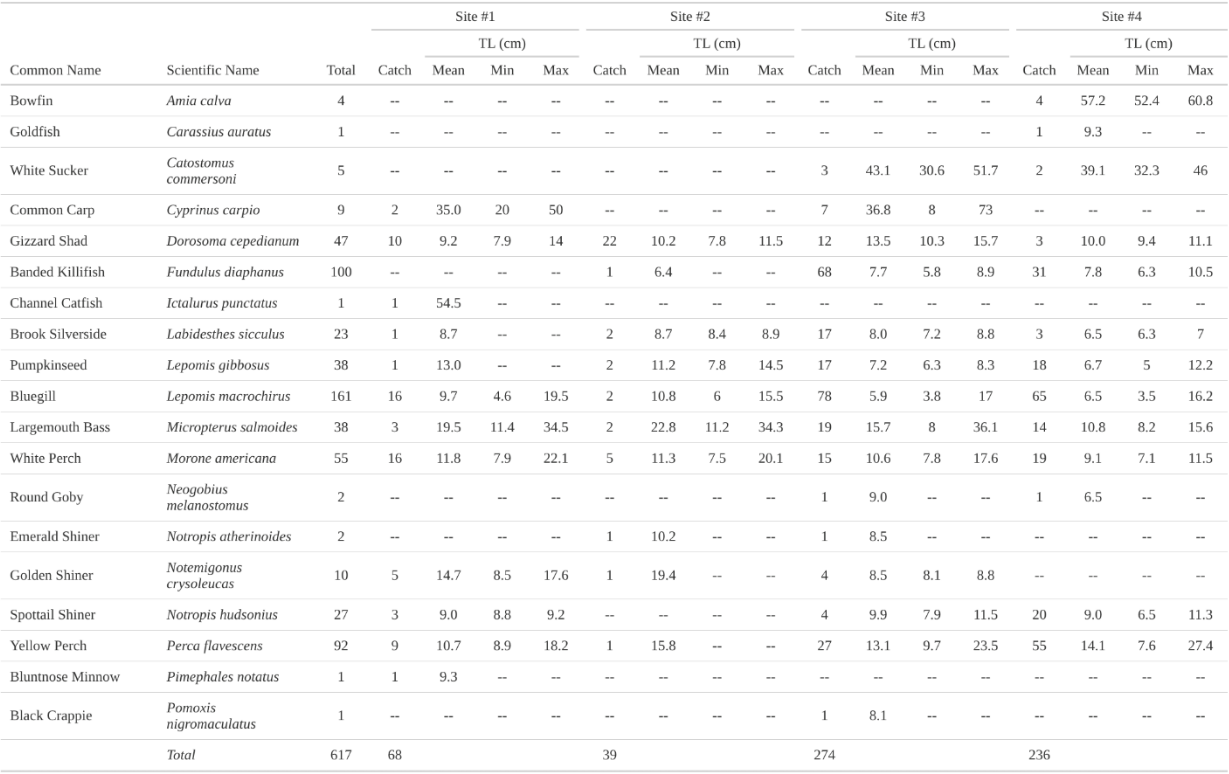
Table 4. Number and total length (TL; mean, minimum, and maximum) of fish captured by fyke netting (*n* = 12 nets) on 11 September at four sites and boat electrofishing (*n* = 4 transects) on 8 September 2025 at four sites in Lake Macatawa. Total is the combined catch for both gear. Scientific names are based on Bailey et al. (2004).

			Fyke Netting				Electrofishing			
				TL (cm)				TL (cm)		
Common Name	Scientific Name	Total	Catch	Mean	Min	Max	Catch	Mean	Min	Max
Rock Bass	*Ambloplites rupestris*	1	1	17.9	--	--	--	--	--	--
Yellow Bullhead	*Ameiurus natalis*	3	3	21.4	20.6	22.5	--	--	--	--
Bowfin	*Amia calva*	8	4	59.3	52.0	62.0	4	57.2	52.4	60.8
Goldfish	*Carassius auratus*	1	--	--	--	--	1	9.3	--	--
Quillback	*Carpiodes cyprinus*	1	1	15.0	--	--	--	--	--	--
White Sucker	*Catostomus commersoni*	6	1	43.4	--	--	5	41.5	30.6	51.7
Bloater/Cisco	*Coregonus sp.*	6	6	6.5	5.4	7.7	--	--	--	--
Spotfin Shiner	*Cyprinella spiloptera*	2	2	9.2	8.3	10.2	--	--	--	--
Common Carp	*Cyprinus carpio*	13	4	37.4	12.6	62.0	9	36.4	8.0	73.0
Gizzard Shad	*Dorosoma cepedianum*	769	722	9.3	4.3	17.5	47	10.8	7.8	15.7
Banded Killifish	*Fundulus diaphanus*	153	53	7.6	4.0	10.1	100	7.8	5.8	10.5
Channel Catfish	*Ictalurus punctatus*	3	2	62.0	50.1	74.0	1	54.5	--	--
Brook Silverside	*Labidesthes sicculus*	463	440	7.6	5.0	10.0	23	7.9	6.3	8.9
Pumpkinseed	*Lepomis gibbosus*	156	118	7.3	4.2	16.6	38	7.3	5.0	14.5
Bluegill	*Lepomis macrochirus*	1461	1300	6.1	2.5	20.5	161	6.6	3.5	19.5
Largemouth Bass	*Micropterus salmoides*	58	20	11.4	8.0	27.2	38	14.6	8.0	36.1
White Perch	*Morone americana*	230	175	10.0	5.0	19.0	55	10.5	7.1	22.1
Round Goby	*Neogobius melanostomus*	8	6	8.7	5.7	10.2	2	7.8	6.5	9.0
Golden Shiner	*Notemigonus crysoleucas*	21	11	12.8	8.7	16.3	10	12.7	8.1	19.4
Emerald Shiner	*Notropis atherinoides*	28	26	8.4	6.3	10.4	2	9.3	8.5	10.2
Spottail Shiner	*Notropis hudsonius*	289	262	8.5	4.9	12.5	27	9.2	6.5	11.5
Mimic Shiner	*Notropis volucellus*	13	13	5.9	4.5	7.4	--	--	--	--
Yellow Perch	*Perca flavescens*	153	61	13.7	5.1	22.6	92	13.5	7.6	27.4
Bluntnose Minnow	*Pimephales notatus*	1	--	--	--	--	1	9.3	--	--
Black Crappie	*Pomoxis nigromaculatus*	4	3	10.4	6.6	17.4	1	8.1	--	--
	Total	3851	3234				617			

Table 5. Number and total length (TL; mean, minimum, and maximum) of fish captured by fyke netting (*n* = 3 nets/site) on 11 September 2025 at four sites in Lake Macatawa. Total is the catch at all fyke-netting sites combined. Scientific names are based on Bailey et al. (2004).

			Site #1				Site #2				Site #3				Site #4			
				TL (cm)				TL (cm)				TL (cm)				TL (cm)		
Common Name	Scientific Name	Total	Catch	Mean	Min	Max	Catch	Mean	Min	Max	Catch	Mean	Min	Max	Catch	Mean	Min	Max
Rock Bass	*Ambloplites rupestris*	1	1	17.9	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Yellow Bullhead	*Ameiurus natalis*	3	3	21.4	20.6	22.5	--	--	--	--	--	--	--	--	--	--	--	--
Bowfin	*Amia calva*	4	--	--	--	--	--	--	--	--	2	61.6	61.5	61.8	2	57.0	52	62
Quillback	*Carpiodes cyprinus*	1	--	--	--	--	1	15.0	--	--	--	--	--	--	--	--	--	--
White Sucker	*Catostomus commersoni*	1	--	--	--	--	--	--	--	--	--	--	--	--	1	43.4	--	--
Bloater/Cisco	*Coregonus sp.*	6	--	--	--	--	--	--	--	--	--	--	--	--	6	6.5	5.4	7.7
Common Carp	*Cyprinus carpio*	4	--	--	--	--	--	--	--	--	4	37.4	12.6	62	--	--	--	--
Spotfin Shiner	*Cyprinella spiloptera*	2	--	--	--	--	2	9.2	8.3	10.2	--	--	--	--	--	--	--	--
Gizzard Shad	*Dorosoma cepedianum*	722	156	9.2	4.3	15.1	558	9.3	5.6	17.5	4	8.7	6.5	11.6	4	9.9	8.7	10.8
Banded Killifish	*Fundulus diaphanus*	53	2	7.8	7.7	8	3	7.5	7.4	7.5	35	7.4	4	8.7	13	8.3	6.4	10.1
Channel Catfish	*Ictalurus punctatus*	2	--	--	--	--	1	74.0	--	--	1	50.1	--	--	--	--	--	--
Brook Silverside	*Labidesthes sicculus*	440	8	7.6	7.1	8	20	8.0	7	10	317	7.6	5	9.1	95	7.5	5.2	8.9
Pumpkinseed	*Lepomis gibbosus*	118	17	6.8	5.2	9	26	7.1	4.2	13.6	19	7.8	5	16.6	56	7.3	5.5	14.7
Bluegill	*Lepomis macrochirus*	1300	822	6.0	2.5	20.5	187	6.5	3.1	20.5	61	6.0	4.5	15.3	230	6.4	4.7	15.3
Largemouth Bass	*Micropterus salmoides*	20	3	10.0	8	12.1	--	--	--	--	12	12.4	9	27.2	5	10.0	8.9	11.5
White Perch	*Morone americana*	175	4	12.3	9.7	19	148	9.9	5	11.8	9	8.8	7.6	10.9	14	10.7	8	18.3
Round Goby	*Neogobius melanostomus*	6	1	10.2	--	--	--	--	--	--	--	--	--	--	5	8.4	5.7	10.1
Emerald Shiner	*Notropis atherinoides*	26	9	8.6	6.6	10	12	8.0	6.3	10.1	5	9.2	7.1	10.4	--	--	--	--
Golden Shiner	*Notemigonus crysoleucas*	11	1	16.3	--	--	9	12.0	8.7	16	--	--	--	--	1	16.0	--	--
Spottail Shiner	*Notropis hudsonius*	262	45	8.0	5.1	12.5	53	8.3	4.9	12.2	22	8.8	7.5	12.1	142	8.8	5.7	11.5
Mimic Shiner	*Notropis volucellus*	13	12	5.8	4.5	7.4	1	7.2	--	--	--	--	--	--	--	--	--	--
Yellow Perch	*Perca flavescens*	61	9	13.4	6.1	20.3	13	12.2	5.1	22.6	15	14.6	9.3	22	24	14.2	5.8	21.7
Black Crappie	*Pomoxis nigromaculatus*	3	1	17.4	--	--	--	--	--	--	--	--	--	--	2	6.9	6.6	7.3
	Total	3234	1094				1034				506				600			

Table 6. Number and total length (TL; mean, minimum, and maximum) of fish captured by nighttime boat electrofishing (n = 1 transect/site) on 8 September 2025 at four sites in Lake Macatawa. Total is the catch at all electrofishing transects combined. Scientific names are based on Bailey et al. (2004).



			Site #1				Site #2				Site #3				Site #4			
				TL (cm)				TL (cm)				TL (cm)				TL (cm)		
Common Name	Scientific Name	Total	Catch	Mean	Min	Max	Catch	Mean	Min	Max	Catch	Mean	Min	Max	Catch	Mean	Min	Max
Bowfin	*Amia calva*	4	--	--	--	--	--	--	--	--	--	--	--	--	4	57.2	52.4	60.8
Goldfish	*Carassius auratus*	1	--	--	--	--	--	--	--	--	--	--	--	--	1	9.3	--	--
White Sucker	*Catostomus commersoni*	5	--	--	--	--	--	--	--	--	3	43.1	30.6	51.7	2	39.1	32.3	46
Common Carp	*Cyprinus carpio*	9	2	35.0	20	50	--	--	--	--	7	36.8	8	73	--	--	--	--
Gizzard Shad	*Dorosoma cepedianum*	47	10	9.2	7.9	14	22	10.2	7.8	11.5	12	13.5	10.3	15.7	3	10.0	9.4	11.1
Banded Killifish	*Fundulus diaphanus*	100	--	--	--	--	1	6.4	--	--	68	7.7	5.8	8.9	31	7.8	6.3	10.5
Channel Catfish	*Ictalurus punctatus*	1	1	54.5	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Brook Silverside	*Labidesthes sicculus*	23	1	8.7	--	--	2	8.7	8.4	8.9	17	8.0	7.2	8.8	3	6.5	6.3	7
Pumpkinseed	*Lepomis gibbosus*	38	1	13.0	--	--	2	11.2	7.8	14.5	17	7.2	6.3	8.3	18	6.7	5	12.2
Bluegill	*Lepomis macrochirus*	161	16	9.7	4.6	19.5	2	10.8	6	15.5	78	5.9	3.8	17	65	6.5	3.5	16.2
Largemouth Bass	*Micropterus salmoides*	38	3	19.5	11.4	34.5	2	22.8	11.2	34.3	19	15.7	8	36.1	14	10.8	8.2	15.6
White Perch	*Morone americana*	55	16	11.8	7.9	22.1	5	11.3	7.5	20.1	15	10.6	7.8	17.6	19	9.1	7.1	11.5
Round Goby	*Neogobius melanostomus*	2	--	--	--	--	--	--	--	--	1	9.0	--	--	1	6.5	--	--
Emerald Shiner	*Notropis atherinoides*	2	--	--	--	--	1	10.2	--	--	1	8.5	--	--	--	--	--	--
Golden Shiner	*Notemigonus crysoleucas*	10	5	14.7	8.5	17.6	1	19.4	--	--	4	8.5	8.1	8.8	--	--	--	--
Spottail Shiner	*Notropis hudsonius*	27	3	9.0	8.8	9.2	--	--	--	--	4	9.9	7.9	11.5	20	9.0	6.5	11.3
Yellow Perch	*Perca flavescens*	92	9	10.7	8.9	18.2	1	15.8	--	--	27	13.1	9.7	23.5	55	14.1	7.6	27.4
Bluntnose Minnow	*Pimephales notatus*	1	1	9.3	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Black Crappie	*Pomoxis nigromaculatus*	1	--	--	--	--	--	--	--	--	1	8.1	--	--	--	--	--	--
	Total	617	68				39				274				236			

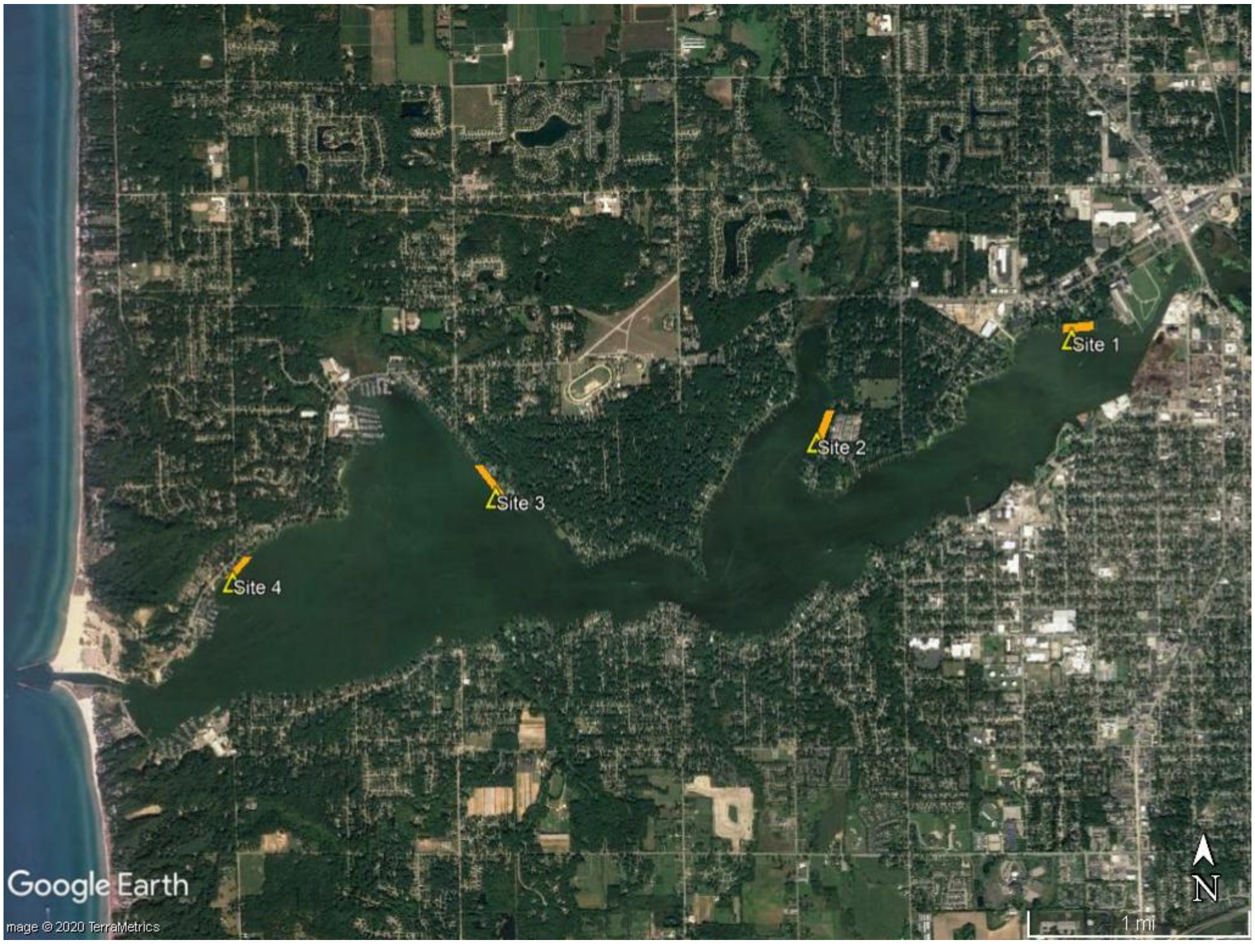


Figure 1. Map of Lake Macatawa (Ottawa County, Michigan) showing fish sampling sites (triangles). The orange transects depict approximately where boat electrofishing was conducted at each site. Site #1 is closest to the Macatawa River and site #4 is closest to Lake Michigan. Note that riparian vegetation was cleared at site #2 in 2016.

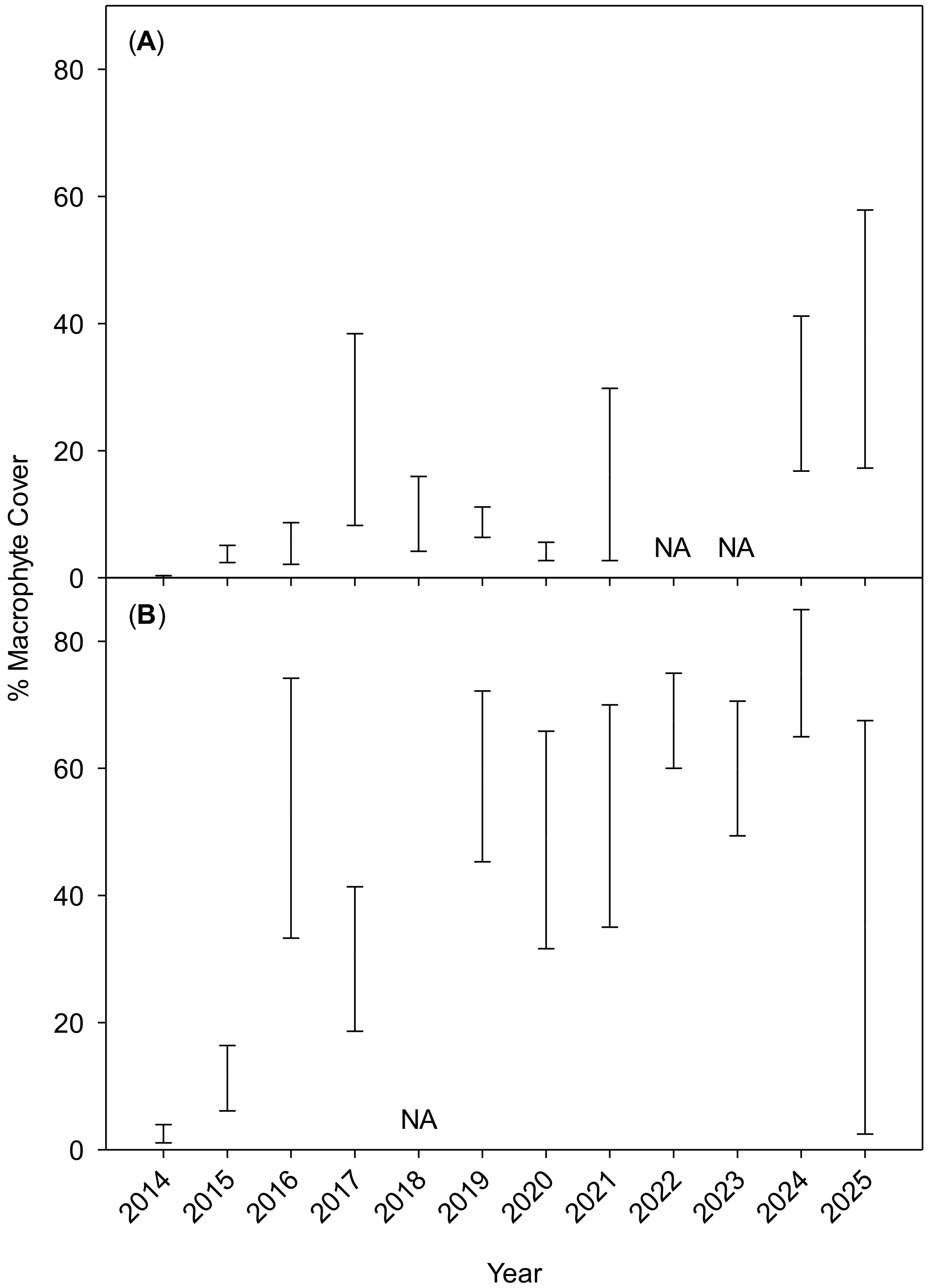


Figure 2. Mean (±1 standard error) percent macrophyte cover visually estimated at (**A**) fyke net locations and (**B**) boat electrofishing transects in Lake Macatawa (*n* = 4 sites/year; however, *n* = 2 sites for the 2021, 2022, and 2024 boat electrofishing surveys because of poor visibility and *n* = 3 sites for the 2025 boat electrofishing survey). The area where macrophyte cover was assessed during fyke netting is much less than for a boat electrofishing transect. NA means data were not available (i.e., water clarity prevented visual estimation).

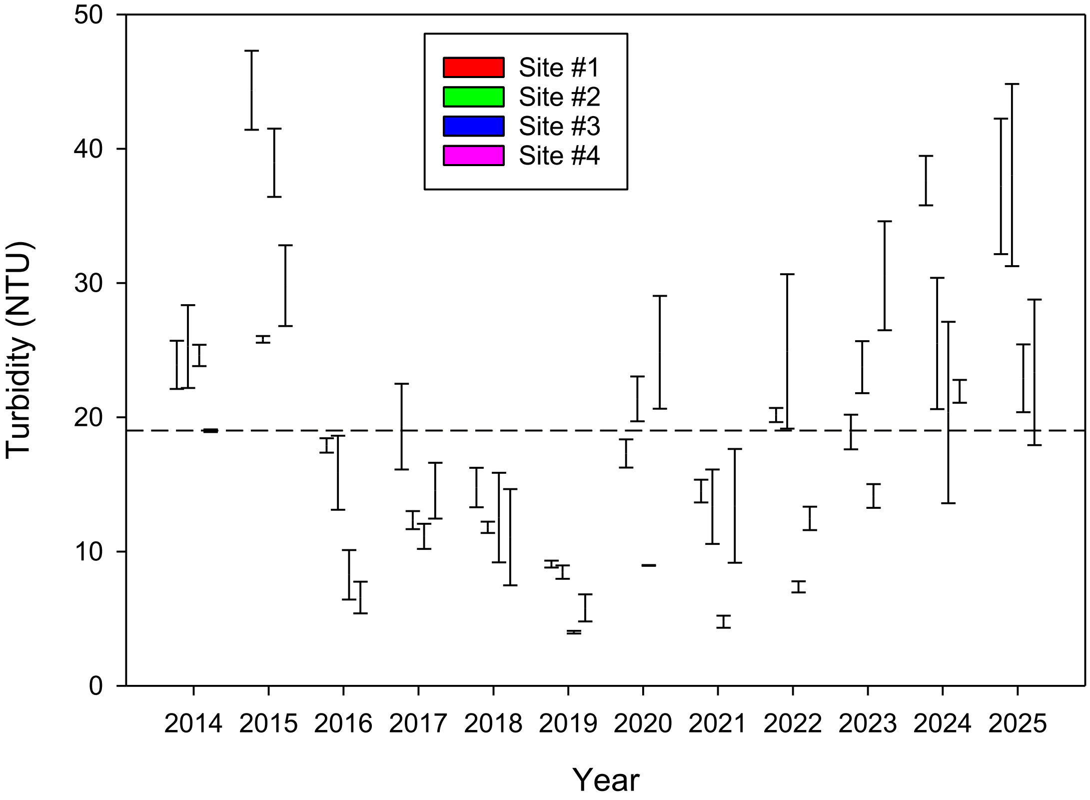


Figure 3. Mean (±1 standard error) turbidity measured during fyke netting in Lake Macatawa (*n* = 3 nets per site). Dashed line is the long-term mean of 19.0 NTU (*n* = 12 years).

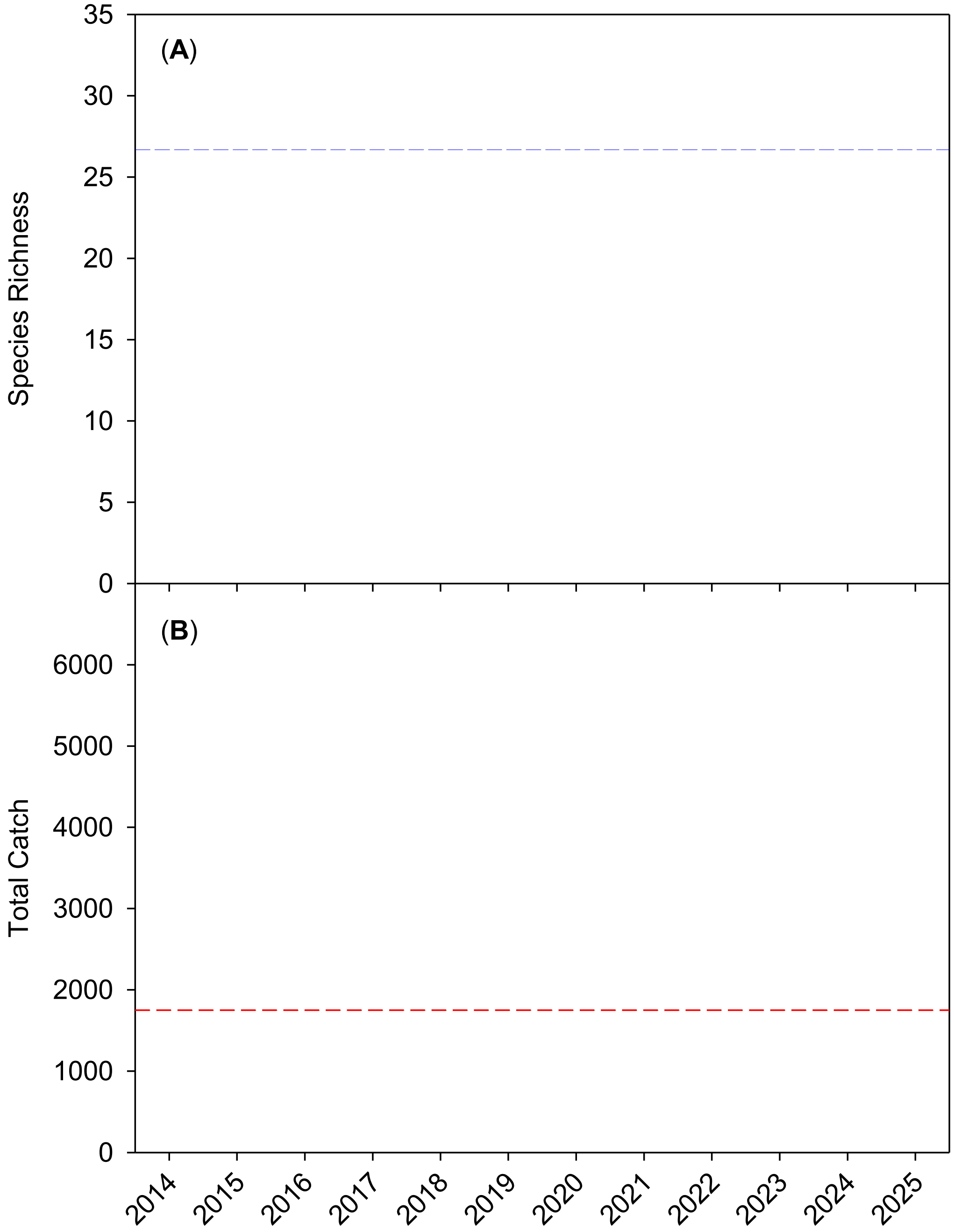


Figure 4. (**A**) Number of fish species captured (dashed blue line is long-term mean; *n* = 12 years) and (**B**) total number of fish captured using both fyke netting and boat electrofishing each year in Lake Macatawa (dashed red line is long-term mean; *n* = 12 years). The long-term mean total catch ($\bar{x}$ = 1,750 individuals/year) excludes 5,288 Brook Silversides captured in 2017 from a single fyke net at site #4 (i.e., a total catch of 1,180 fish in 2017 was used to calculate the long-term mean); fyke netting in 2020 was completed at three sites rather than the typical four sites.

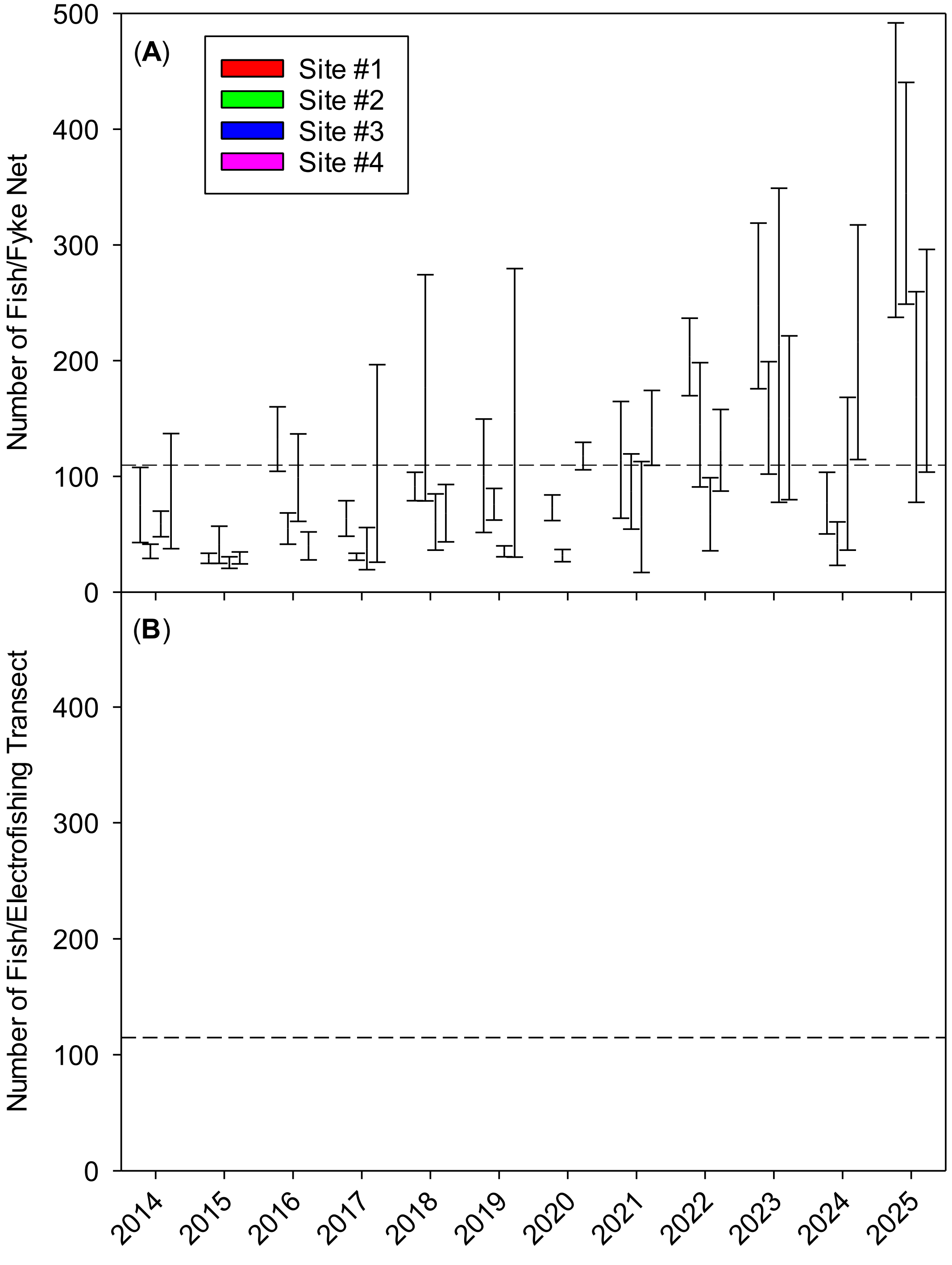


Figure 5. (**A**) Mean number (±1 standard error) of fish captured in fyke nets (*n* = 3 nets/site) and (**B**) number of fish captured during a boat electrofishing transect (*n* = 1 transect/site) in Lake Macatawa. The 5,288 Brook Silversides captured in a single fyke net at site #4 in 2017 were excluded when calculating means (and SE) for fyke netting. Fyke nets were not set at site #3 in 2020 because of high water levels in the lake. The dashed line represents the long-term mean for fyke netting (*n* = 141 nets) and boat electrofishing (*n* = 48 transects).

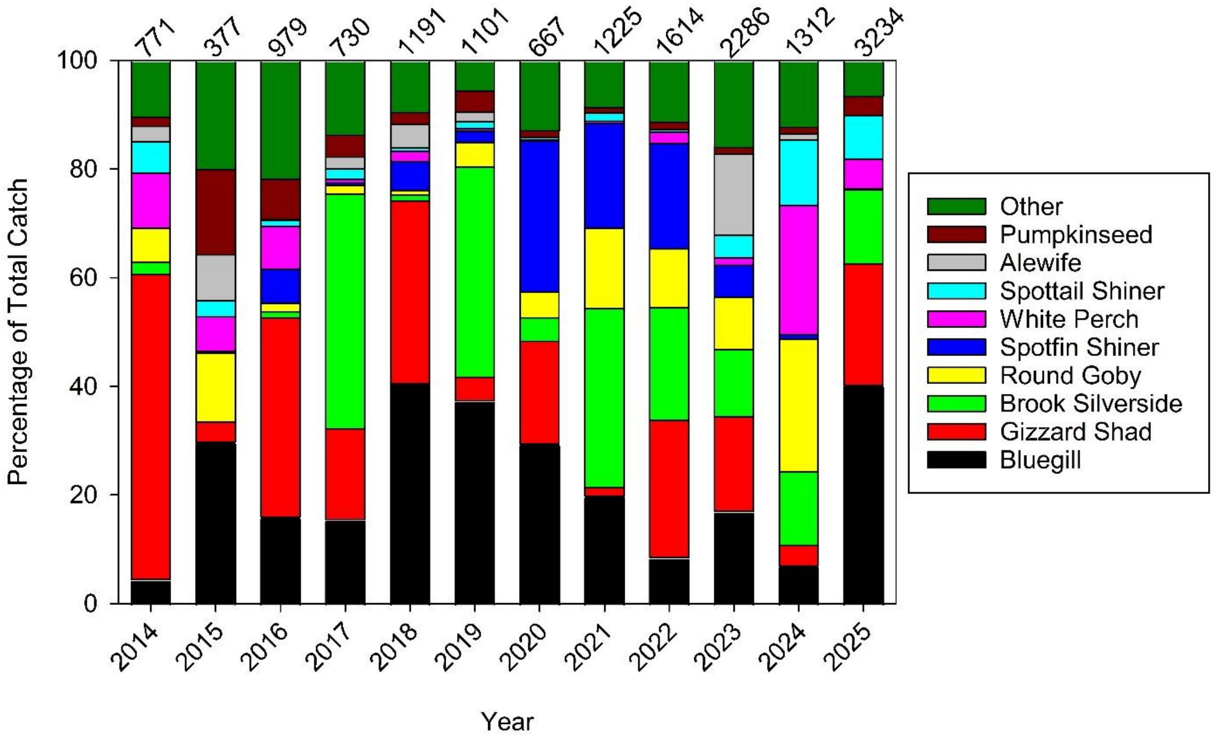


Figure 6. Fish species composition (pooled across sites) in fyke netting surveys for each sampling year. The number of fish captured differed among years, which is reported at the top of each bar. The 5,288 Brook Silversides captured in a single fyke net at site #4 in 2017 were excluded from the percentage of total catch and the number of fish reported at the top of the bar; fyke nets were not set at site #3 in 2020. The fewest fish were captured in 2015 and the most fish in 2017 (when all Brook Silversides are included).

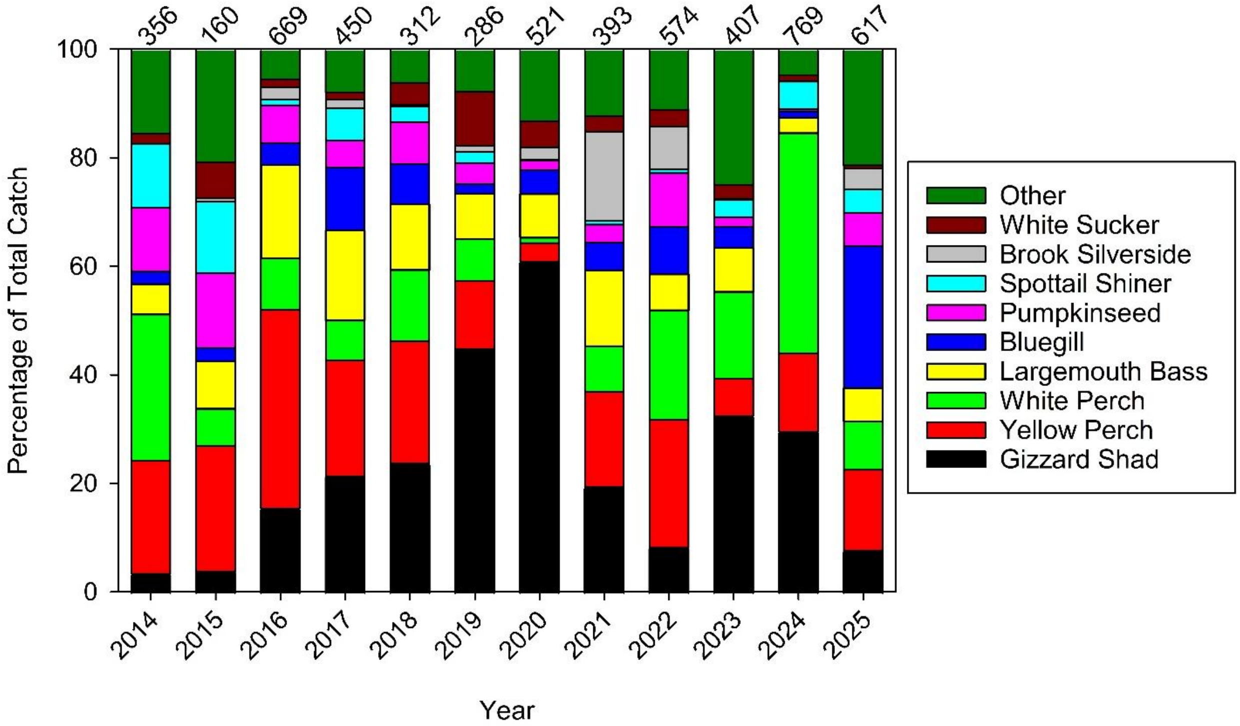


Figure 7. Fish species composition (pooled across sites) in nighttime boat electrofishing surveys for each sampling year. The number of fish captured differed among years, which is reported at the top of each bar. The fewest fish were captured in 2015, and the most were captured in 2024.