Little Black Lake Water Quality Study Update

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Alan D. Steinman*, Michael C. Hassett, Kathryn J. Tyrrell

Annis Water Resources Institute, Grand Valley State University
740 West Shoreline Drive, Muskegon, MI 49441

*Contact Information
Email: steinmaa@gvsu.edu
Voice: 616-331-3749

Introduction

Little Black Lake is a 95-ha lake located in Norton Shores, Michigan (43°07'20"N, 86°14'47"W) directly east of P.J. Hoffmaster State Park (Figure 1). It is a shallow lake located in a rapidly urbanizing region. In 2007, the Robert B. Annis Water Resources Institute (AWRI) of Grand Valley State University was contracted by the City of Norton Shores to conduct a general assessment of water quality conditions in Little Black Lake and its connecting waterways. Our findings were that the lake had generally good water quality, the fishery was in good shape, and that the macrophyte community was relatively devoid of invasive species. We also cautioned that despite the healthy conditions at the time, there were some indications the lake is starting to experience ecological pressures. As a consequence, we recommended that the City and lakefront homeowners become active stewards of the lake and its watershed to maintain the lake's condition.

In 2022, representatives from the City of Norton Shores and Spring Lake Township contacted AWRI again to explore the possibility of a re-study of Little Black Lake based on concerns from local residents regarding the growth of invasive plants and the loss of mollusks in the lake. The municipalities were interested in a targeted study, focusing on water quality of the lake and its tributaries, lake macrophytes, and lake sediments. AWRI sampled these parameters in the summer of 2023. This report describes our findings.

Methods

Field and laboratory activities were designed to be consistent with AWRI's previous work in Little Black Lake (Steinman et al. 2011). Five tributaries of Little Black Lake were sampled, including four inflows (Hickory, Wood, Yonkers, and Greek) and one outflow (Figure 1). Sampling was done on two separate dates to capture both baseflow and stormflow conditions. Baseflow was sampled on August 11, 2023. Stormflow was defined as 0.25 inches of precipitation preceded by 72 hours of dry weather and was sampled on August 18, 2023.

Physical and chemical water quality parameters including temperature, dissolved oxygen, pH, specific conductance, and total dissolved solids were measured using YSI EXO2 sonde (YSI, Inc., Yellow Springs, OH). Surface water grab samples were collected in 250-mL bottles, kept on ice, and returned to the laboratory for measurement of chloride (Cl^-), sulfate (SO_4^-), nitrate (NO_3), ammonia (NH_3), total Kjeldahl nitrogen (TKN), soluble reactive phosphorus (SRP), and total phosphorus (TP). Upon returning to the lab, subsamples for the Cl^-, SO_4^-, NO_3^-, and SRP analyses were filtered through 0.45-µm membrane filters into scintillation vials, and samples for NH_3 and TKN analysis were acidified with concentrated sulfuric acid. SRP, TP, NH_3, and TKN samples were refrigerated at 4°C, while Cl^-, SO_4^-, and NO_3^- samples were frozen until analysis. TP, SRP, NH_3, and TKN samples were analyzed on a Seal AQ2 discrete autoanalyzer (USEPA 1993). Cl^-, SO_4^-, and NO_3^- samples were analyzed by ion chromatography on a Dionex DX500 (APHA 1999). Additional surface water grab samples were collected in 1-L amber bottles and stored on ice for chlorophyll *a* (chl *a*) extraction. Chl *a* samples were filtered through GF/F filters and frozen until analysis on a Shimadzu UV-1601 spectrophotometer (APHA 1992).

Water and sediment in Little Black Lake were sampled on July 21, 2023. Sediment cores and sonde measurements were taken from eight sites; these included four sites previously sampled in 2007 (South, Center, Windflower, and Yonkers) and four new sites (Far South, Southwest, North, and Southeast; Fig. 1). Sediment cores were collected using a modified piston corer (Oldenborg and Steinman 2019) and taken back to the laboratory, where each core was split into 0-5 cm and 5-10 cm depths. Sediment core segments were separately homogenized and subsampled for analyses of sediment TP, as well as 10 sediment toxins (mercury, arsenic, barium, cadmium, chromium, copper, lead, selenium, silver, and zinc). Metals were compared to sediment guidelines identified in MacDonald et al. (2000), using both the toxic effect threshold (TET) and the consensus-based probably effect concentration (PEC), above which adverse effects are expected to occur more often than not. Additionally, at the three sites for which water chemistry data from 2007 were available (South, Center, and Yonkers), water samples were collected for Cl^-, SO_4^-, NO_3^-, NH_3, SRP, and TP analyses as described above.

An aquatic macrophyte survey was conducted in Little Black Lake on August 22-23, 2023. Every site visited during the AWRI's previous aquatic macrophyte survey (Steinman et al. 2011) was revisited in 2023. To briefly summarize earlier site selection methods, the lake was overlain with a grid network with grid cells measuring 100 m × 100 m. Sample points were located at each of the line intercepts on the grid, resulting in a total of 108 sample points. Along the shoreline, where macrophyte vegetation was dense, every sample point was visited. In the middle of the lake, where macrophyte growth was less dense, every other point was sampled, resulting in a total of 74 locations visited in 2007. In 2023, all sampled locations were re-visited and 69 of them were determined to still be viable aquatic macrophyte monitoring sites (i.e., sites being physically accessible by the field crew and able to be monitored). Depth and percent coverage were recorded for each site, and macrophyte species were noted as either present or absent and summarized in a modified ranking system. Each of three field technicians independently conducted a visual estimate via kayak of the sites' macrophyte cover and then compared results and to reach a mutual consensus. Cover was classified into broad categories of 1: 1%-25%; 2: 26%-50%; 3: 51%-75%; and 4: 76%-100%. A sampling device made of two metal garden rake heads tied together on the end of a rope was used to assess macrophyte coverage from sites too deep to visually assess, as well as for collecting macrophytes for species identification that were too deep to either see or collect by hand.

Data analysis focused on summary statistics for 2023 data and a comparison between the 2007 and 2023 findings for any parameters sampled in both monitoring periods. Any values below detection were calculated as ½ the method detection limit. R Statistical Software (v4.3.0; R Core Team 2023) was used to perform two-tailed paired t-tests across all sampling locations that occurred in both studies. Differences in mean values for a given measurement were considered statistically significant for p-values < 0.05.

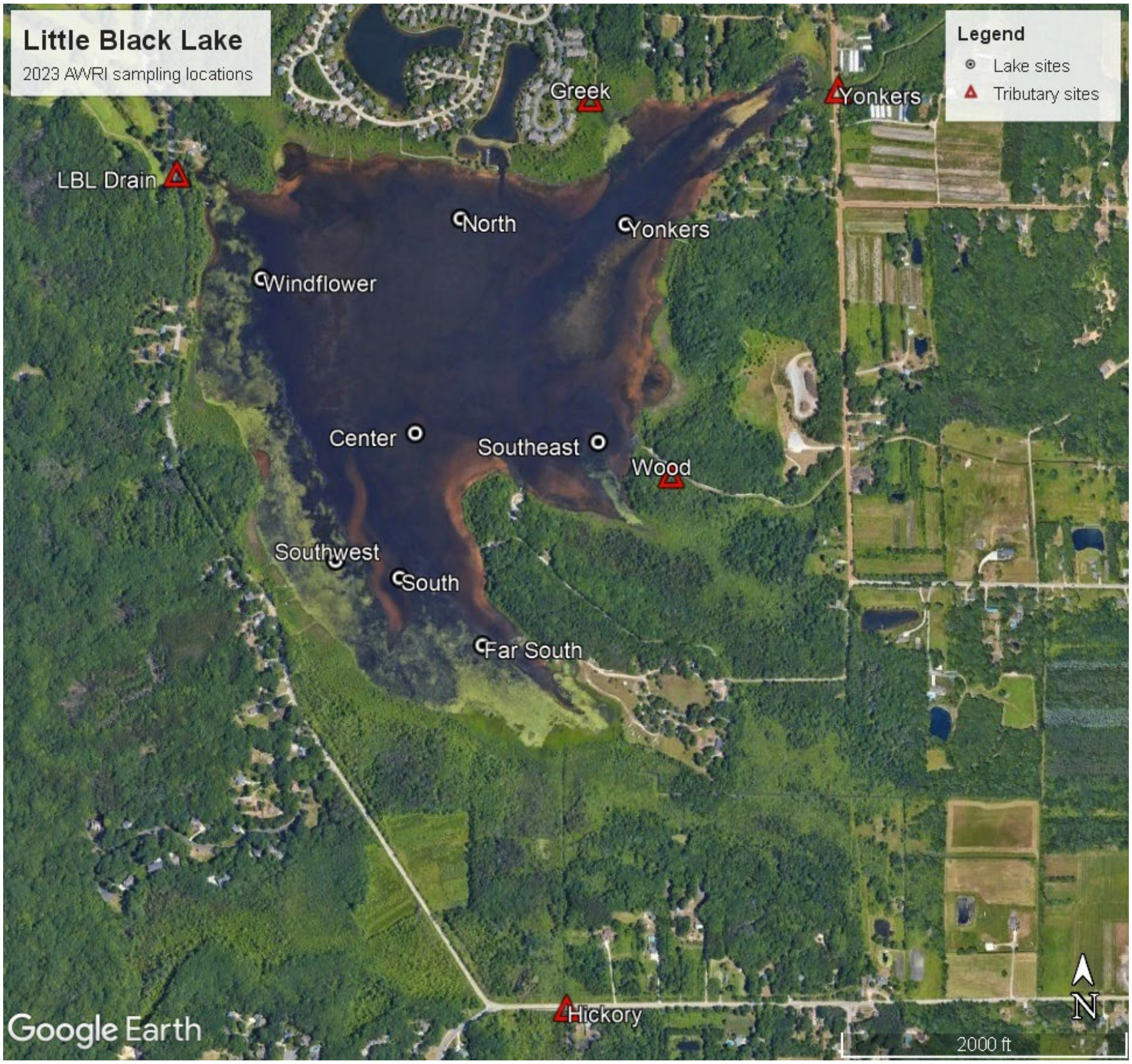

Figure 1. Map of Little Black Lake (white circle) and tributary (red triangle) water quality and sediment sampling sites. LBL Drain is the outflow tributary; all others are inflows.

Results

Tributary Water Quality (note: more detailed descriptions of these water quality parameters can be found in Steinman et al. (2011); figures showing comparisons between 2007 and 2023 are included in the Appendix).

Dissolved Oxygen (DO) concentrations < 5 mg/L can be indicative of impaired water quality. DO measurements at all five tributaries were above this threshold under both base- and stormflow conditions (Tables 1, 2; Fig. A1). DO concentrations during baseflow were 1.5 to 2 mg/L lower in 2023 compared to 2007 at 3 of the 4 inflows; this may be due to the greater amount of organic matter (decaying macrophytes) observed in 2023 compared to 2007. The outflow was 1.5 mg/L higher in 2023 than in 2007 (Table 1). During stormflow, DO concentrations were lower at all inflows except Hickory sites in 2023 compared to 2007 (Table 2). In addition, 2023 stormflow DO concentrations were lower at all sites except Hickory compared to baseflow DO concentrations. This is likely due to greater oxygen demand (both biological and chemical) during storm events as more organic material enters and leaves these systems.

pH is an indicator of the hydrogen ion content in water. pH values for the Little Black Lake tributaries ranged from 7.47 to 8.46 at baseflow and from 7.62 to 7.87 during stormflow (Tables 1, 2). In general, pH values in 2023 were very similar to those in 2007, with no obvious differences in trend.

Specific Conductance (or conductivity) reflects the amount of ionized salts in solution. In west Michigan water bodies, specific conductance generally ranges from 100 (precipitation and surface water-driven) to 600 µS/cm (more groundwater-dominated systems), with values > 600 suggesting human-induced stress to aquatic systems. Specific conductance was ~2-4× greater in the Yonkers tributary during 2023 baseflow than any other inflow, which is similar to what was observed in 2007 (Table 1). Stormflow sampling revealed a similarly high value in Yonkers drain, although that was not the case in 2007 (Table 2). Both Yonkers and the outflow had the highest specific conductance values, exceeding the 600 µS/cm threshold. In general, the 2023 baseflow and stormflow specific conductance values were similar, indicating runoff into the tributaries did not carry many ions during this summer sampling; it is likely that these values are elevated in the winter (along with chloride and sodium), when de-icing salt is being applied to Pontaluna Road, Black Lake Road, and Hickory Street. The 2007 and 2023 specific conductance values were generally similar (Fig. A2).

Total Dissolved Solids (TDS) refers to the portion of solids in water that can pass through a 2-µm filter. TDS is an indicator of aesthetic characteristics of drinking water and reveals the presence of a broad array of chemical contaminants. Waters with high TDS levels are generally of inferior quality. Michigan water quality standards limit TDS to 500 mg/L as a monthly average, or 750 mg/L at any time (EGLE 2006). TDS results mirrored those of specific conductance with Yonkers having the highest values (exceeding 500 mg/L) among inflows in 2023 for both baseflow and stormflow (Tables 1, 2). Outflow TDS again was elevated but not to the degree of Yonkers.

Chloride (Cl^-) is often used as an indicator of human disturbance to freshwaters; industrial sources, road salting, and municipal wastewater operations all contribute chloride to waters. The State of Michigan defines the final acute value of chloride as 640 mg/L (daily maximum limit) and the final chronic value as 150 mg/L (monthly average limit; EGLE 2023a). All inflows contained chloride concentrations at or below 30 mg/L for both baseflow and stormflow conditions, with the exception of Yonkers, which measured 189 mg/L at baseflow and 172 mg/L during stormflow (Tables 3, 4). As was the case for both specific conductance and TDS, chloride results are similar to those in 2007 with the exception that in 2007, the Yonkers tributary exceeded the final chronic value for chloride only at baseflow and not at stormflow (154 and 35 mg/L, respectively).

Sulfate (SO_4^-) The State of Michigan final acute value for sulfate is 1200 mg/L; the final chronic value is 370 mg/L (EGLE 2023b). Sulfate concentrations in the Little Black Lake tributaries were low, ranging from 8 to 34 mg/L during baseflow and between 7 and 20 mg/L during stormflow (Tables 3, 4). These baseflow and stormflow measurements generally indicate a drop (although likely not of ecological significance given the small absolute difference) from the concentrations measured in 2007.

Nitrate (NO_3^-) is often found in fertilizers. Excess levels of nitrate can cause hypoxia (low levels of dissolved oxygen) and can become toxic to warm-blooded animals at higher concentrations (10 mg/L) under certain conditions. The natural level of nitrate in surface water is typically low (< 1 mg/L); however, in the effluent of wastewater treatment plants, it can range up to 30 mg/L. Baseflow and nitrate concentrations were higher in 2023 than in 2007 for all tributaries but absolute concentrations remained low (< 0.4 mg/L; Tables 3, 4). Stormflow nitrate concentrations were half higher and half lower in 2023 vs 2007. The elevated stormflow concentrations measured in Hickory and Greek in 2007 were not present in 2023 (Tables 3, 4).

Ammonia (NH_3) levels at 0.1 mg/L usually indicate polluted surface waters, whereas concentrations > 0.2 mg/L can be toxic for some aquatic animals (Cech 2003). Ammonia levels were near or below the detection limit in all cases except for Hickory at baseflow, which measured 0.25 mg/L (Table 3). Concentrations in all tributaries were below the detection limit under stormflow conditions, suggesting concentrations in the tributaries were diluted by stormwater runoff. Other than the 2023 Hickory baseflow concentration, ammonia concentrations were lower in 2023 than in 2007 (Tables 3, 4).

Total Kjeldahl Nitrogen (TKN) measures the combined nitrogen contained in both organic matter and ammonia/ammonium ions. TKN was not previously measured in 2007, but other AWRI studies have found summer surface water TKN concentrations averaged 1.05 mg/L in nearby Spring Lake (Steinman et al. 2018) and averaged 0.47 mg/L in Green Lake in Allegan County, MI (Steinman and Hassett 2022). TKN values in Little Black Lake tributaries ranged from 0.56 to 1.22 mg/L (Table **3**, 4). Interestingly, TKN concentrations were not related to ammonia, suggesting a large fraction of TKN is dissolved organic nitrogen (DON). It is likely that elevated TKN in the outflow is DON leaching from the macrophytes but the source(s) of DON in the inflowing tributaries to Little Black Lake is not known.

Soluble Reactive Phosphorus (SRP) is a measurement of the bioavailable phosphorus in water. Although a high concentration is indicative of enrichment, a low concentration may be because the SRP is being actively taken up by the plants and algae in the water body. Therefore, caution must be used when evaluating the significance of SRP levels. SRP values were at or below 0.01 mg/L in all tributaries at baseflow, which is generally consistent with good water quality and similar to concentrations measured in 2007 (Table 3). During stormflow, 2023 inflow values ranged from 0.008 to 0.054 mg/L, increasing to some degree at all inflows compared to 2007 (Table 4; Fig. A3). SRP concentrations at the outflow during both baseflow and stormflow remained below the detection limit (Table 3, 4) likely due to assimilation by the macrophyte and algal communities.

Total Phosphorus (TP) is a measurement of all the various forms of phosphorus (inorganic, organic, dissolved, and particulate) in the water. TP concentrations indicative of non-impaired waters in west Michigan should be between 0.02 and 0.03 mg/L (USEPA 2000). In 2023, TP concentrations in the inflows ranged from 0.017 to 0.024 mg/L and were slightly greater than in 2007 at each site (Table 3); in contrast, the outflow concentration declined slightly from 2007 to 2023 at baseflow (Table 3). TP concentration in stormflow in 2023 varied by an order of magnitude from 0.009 to 0.095 mg/L (Table 4). There was no consistent trend in stormflow TP over time among sites; some sites increased from 2007 to 2023 (Wood, Hickory) while one declined (Yonkers), and others were similar (Yonkers, outflow) (Table 4; Fig. A4). This suggests that the inflows behave individually and there is no system-wide coherence, at least with respect to TP.

Table 1. Water quality parameters measured in 4 inflows and 1 outflow (LBL) of Little Black Lake during base flow conditions (July 19, 2007 and August 11, 2023).

Site	Year	Temp (°C)	DO (mg/L)	DO (%)	pH	Sp Cond (µS/cm)	TDS (mg/L)
Hickory	2007	19.74	7.34	80.4	7.49	358	233
	2023	18.92	5.94	63.9	7.47	280	182
Wood	2007	23.41	6.44	75.7	7.66	550	358
	2023	19.44	5.54	60.3	7.69	530	345
Yonkers	2007	18.68	9.51	102.1	7.86	872	567
	2023	17.99	7.72	81.8	7.82	981	637
Greek	2007	19.88	7.07	77.7	7.38	387	251
	2023	18.14	7.60	80.6	7.85	420	273
Outflow	2007	26.19	6.38	79.0	7.85	629	409
	2023	22.94	7.79	90.9	8.46	638	415

Table 2. Water quality parameters measured in 4 inflows and 1 outflow (LBL) of Little Black Lake during storm flow conditions (August 20, 2007 and August 18, 2023).

Site	Year	Temp (°C)	DO (mg/L)	DO (%)	pH	Sp Cond (µS/cm)	TDS (mg/L)
Hickory	2007	15.82	6.47	65.4	7.02	244	159
	2023	17.81	7.32	77.1	7.64	233	151
Wood	2007	16.90	6.64	68.7	7.64	419	272
	2023	19.25	5.36	58.2	7.62	404	262
Yonkers	2007	16.44	8.32	85.1	7.54	221	144
	2023	18.21	6.74	71.7	7.79	881	573
Greek	2007	16.04	7.34	74.5	7.18	292	190
	2023	17.97	7.09	74.9	7.75	339	220
Outflow	2007	18.05	8.34	88.3	8.16	574	373
	2023	21.80	7.08	80.8	7.87	628	408

Table 3. Water chemistry parameters measured in 4 inflows and 1 outflow (LBL) of Little Black Lake during base flow conditions (July 19, 2007 and August 11, 2023).

Site	Year	Cl^- (mg/L)	SO_4^- (mg/L)	NO_3^- (mg/L)	NH_3 (mg/L)	TKN (mg/L)	SRP (mg/L)	TP (mg/L)
Hickory	2007	29	7	0.02	0.04	ND	<0.005	0.017
	2023	3	8	0.12	0.25	0.56	0.01	0.024
Wood	2007	34	40	<0.01	0.03	ND	<0.005	0.015
	2023	29	34	0.07	<0.01	0.70	0.008	0.024
Yonkers	2007	154	33	0.27	0.04	ND	0.007	0.015
	2023	189	22	0.33	<0.01	0.65	0.005	0.017
Greek	2007	37	15	0.10	0.09	ND	<0.005	0.017
	2023	22	10	0.24	0.03	0.61	0.006	0.021
Outflow	2007	125	20	<0.01	0.03	ND	<0.005	<0.010
	2023	137	11	0.02	<0.01	0.84	<0.005	<0.007

Table 4. Water chemistry parameters measured in 4 inflows and 1 outflow (LBL) of Little Black Lake during storm flow conditions (August 20, 2007 and August 18, 2023).

Site	Year	Cl^- (mg/L)	SO_4^- (mg/L)	NO_3^- (mg/L)	NH_3 (mg/L)	TKN (mg/L)	SRP (mg/L)	TP (mg/L)
Hickory	2007	21	31	1.00	0.13	ND	0.007	0.026
	2023	8	7	0.11	<0.01	0.81	0.014	0.040
Wood	2007	30	49	0.12	0.04	ND	<0.005	<0.010
	2023	30	17	0.05	<0.01	0.95	0.054	0.095
Yonkers	2007	35	7	0.20	0.10	ND	0.006	0.061
	2023	172	20	0.35	<0.01	0.94	0.008	0.015
Greek	2007	30	20	0.70	0.08	ND	0.010	0.032
	2023	24	8	0.26	<0.01	0.69	0.012	0.031
Outflow	2007	95	14	<0.01	0.03	ND	<0.005	0.012
	2023	138	11	0.02	<0.01	1.22	<0.005	0.009

Lake Water Quality

Bottom Depth across the eight sample sites in Little Black Lake ranged from 0.71 m at the Southeast site to 2.13 m at the Yonkers site (Table 5). In general, water levels were similar between 2007 and 2023; the difference seen at the Center site is likely due more from a change in our sampling location than changes in actual water volumes.

Secchi Disk Depth is an indicator of water clarity, with deeper (larger) values indicating clearer water. Visibility extended all the way to the lake bottom for all sites except the deepest, Yonkers, which had a measured Secchi depth of 1.7 m (Table 5). In Muskegon Lake, the restoration target for Secchi disk depth is 2 m; Little Black Lake is too shallow to determine if the Secchi depths would reach that point throughout the lake.

Dissolved Oxygen (DO) for all sites was > 6 mg/L, with percent saturation ranging from 75-115%. For the sites that were previously studied in 2007, measured DO concentrations showed a statistically significant ($p < 0.05$) average increase of 0.55 mg/L (Table 5), likely reflecting photosynthetic activity of the more established 2023 macrophyte community. When all 8 sites sampled in 2023 were considered, there was little difference with the 2007 DO data (Figure A5).

pH values within the lake were generally alkaline, ranging from 7.89 to 9.55 (Table 5). Compared to 2007, pH values increased in 2023; this is consistent with greater photosynthesis from the macrophytes, as seen in the DO values. As plants photosynthesize, they take up CO_2 from the water column (and release oxygen); uptake of the CO_2 releases hydroxyl (OH^-) ions, resulting in a more alkaline condition. The pH will fluctuate throughout the day, peaking in mid to late afternoon when photosynthetic activity is greatest. Hence, the high pH values that we measured, while greater than the high range for optimal water conditions (9.0), are likely to come down as photosynthesis recedes and respiration dominates in the evening hours.

Specific Conductance values in 2023 ranged from 596 to 675 µS/cm, suggesting possible anthropogenic impacts to the lake; these values are similar to those we observed in 2007 (Table 5). Specific conductance changed very little when all 8 sites sampled in 2023 were considered (Figure A6).

Total Dissolved Solids (TDS) measurements were similar among sites, all ~ 400 to 440 mg/L, and showed a consistent trend with specific conductance. Values were generally similar to those measured in 2007 (Table 5).

Chloride (Cl^-) measurements in 2023 ranged from 121 to 141 mg/L at the 3 sampling sites, falling below the threshold for the state of MI standard. All values were higher than in 2007, but not to the point of ecological concern (Table 6).

Sulfate (SO_4^-) concentrations in 2023 ranged from 12-14 mg/L. These measurements show a statistically significant ($p < 0.05$) average decrease of 5 mg/L from the concentrations measured in 2007 (Table 6).

Nitrate (NO_3^-) and Ammonia (NH_3) concentrations were consistently low across the 3 sites in 2023, with all nitrate concentrations measured to be < 0.05 mg/L and all ammonia levels below the detection limit. Both measurements showed a small but statistically significant ($p < 0.05$) change from 2007, with nitrate concentrations increasing by an average of 0.02 mg/L and ammonia decreasing by an average of 0.02 mg/L (Table 6). It is highly unlikely that these changes have any ecological significance given the low absolute concentrations.

Soluble Reactive Phosphorus (SRP) and Total Phosphorus (TP) measurements across the South, Center, and Yonkers sites were all near or below the detection limit, with no significant difference from 2007 (Table 6; Figs. A7 and A8).

Chlorophyll *a*, a proxy for algal abundance, was low and not significantly different between 2007 and 2023 (Table 6, Fig. A9).

Table 5. Lake depth and water quality parameters measured at 3 sites within Little Black Lake on August 1, 2007 and July 21, 2023.

Site	Year	Bottom (m)	Secchi (m)	Temp (°C)	DO (mg/L)	DO (%)	pH	Sp Cond (µS/cm)	TDS (mg/L)
South	2007	0.63	bottom	26.88	6.76	84.8	8.26	655	425
	2023	0.81	bottom	23.66	7.31	86.5	8.58	609	396
Center	2007	1.45	bottom	26.99	8.00	100.5	8.60	643	418
	2023	0.77	bottom	24.17	8.52	101.7	9.31	619	403
Windflower	2007	1.00	bottom	27.19	7.25	91.4	8.23	638	415
	2023	1.00	bottom	25.39	7.69	93.8	9.05	602	391
Yonkers	2007	2.20	bottom	27.31	8.72	110.2	8.65	669	435
	2023	2.13	1.7	25.54	9.41	115.1	9.35	675	439
Far South	2023	0.96	bottom	22.73	7.16	83.2	8.82	630	410
Southwest	2023	0.80	bottom	23.84	6.43	76.3	7.89	596	388
North	2023	1.29	bottom	24.76	8.67	104.6	9.55	647	420
Southeast	2023	0.71	bottom	24.84	7.96	96.2	9.05	645	419

Table 6. Water chemistry parameters measured at 3 sites within Little Black Lake on August 1 2007 and July 21, 2023.

Site	Year	Cl^- (mg/L)	SO_4^- (mg/L)	NO_3^- (mg/L)	NH_3 (mg/L)	SRP (mg/L)	TP (mg/L)	Chl *a* (µg/L)
South	2007	113	17	<0.01	0.03	0.006	<0.010	1.18
	2023	121	12	0.02	<0.01	<0.005	<0.007	0.76
Center	2007	105	18	<0.01	0.03	<0.005	0.013	2.12
	2023	131	13	0.03	<0.01	<0.005	0.009	2.43
Yonkers	2007	105	19	<0.01	0.02	<0.005	0.010	1.87
	2023	141	14	0.03	<0.01	<0.005	<0.007	1.53

Lake Sediment Chemistry

Characteristics of Little Black Lake sediments remain spatially variable in 2023 (Table 7). Notably, the Center site had a higher percentage of solid matter in surface and bottom core samples in 2023 (73-80%) compared to 2007 (11-12%; Table 7; Fig. A10). Likewise, sediment TP at the Center site decreased 99% from 2007, with concentrations in 2023 ranging 22-32 mg/kg (Table 7). After a review of logged site coordinates, this difference at the Center site was attributed to sampling at a site farther south in 2023 than we sampled in 2007 (Figure 1; cf. Figure 1 in Steinman et al. 2011). This is a further reflection of how much the sediment varies, even within a few hundred meters, in Little Black Lake.

Among the newly sampled sites in 2023, the muckiest sediment and highest sediment TP concentrations were found at the Southwest site (3.1% solids and 1126 mg TP/kg; Table 7), which covers the western and southern shorelines of Little Black Lake (Figure 1). However, as seen in 2007, the Yonkers site continues to have high sediment TP (1364 mg TP/kg; Table 7).

There is a clear inverse relationship between %solids and TP concentration. This reflects that TP is related to the amount of organic matter in the sediment; the higher the solids in the sediment, the less organic matter is present. Hence, a site such as Southeast with high %solids has a very low TP concentration; in contrast, the surface sediment at Southwest has a low %solids content but a high TP concentration (Table 7).

Comparing the sediment TP concentrations between 2007 and 2023 should be done with caution (cf. Fig. A11), especially with a small sample size given the high spatial variability within Little Black Lake. Any changes are as likely due to sampling different sites as changes in lake ecology over the 16-yr sampling period. We believe it is more instructive to compare the 2007 and 2023 TP sediment data with sediment TP from other nearby waterbodies that have been sampled by GVSU-AWRI (Fig. 2). Ideally, sediment TP content (top 10 cm) should be below ~600 mg/kg; most sites in Little Black Lake in 2023 were less than that threshold, and had similar concentrations to post-restoration conditions at former celery fields returned to wetland conditions in the region (Figure 2).

Table 7. Sediment core % solids and dry sediment TP concentrations in 2007 and 2023 at surface (0-5 cm) and bottom (5-10 cm) depths. Results from 2007 are highlighted in gray for readability. ND = "no data" for the bottom Southwest sample. Changes seen at lake's Center site may be due to shifting of monitoring location farther south in 2023 than in 2007.

Site	Year	Depth	% Solids	% Solids % Change 2007-2023	Sed. TP, dry (mg/kg)	Sed. TP % Change 2007-2023
South	2007	Surface	60.8%		196	
		Bottom	77.2%		46	
	2023	Surface	55.4%	-8.9%	87	-55%
		Bottom	79.3%	2.7%	17	-62%
Center	2007	Surface	11.0%		3195	
		Bottom	11.8%		2404	
	2023	Surface	73.1%	566.4%	32	-99%
		Bottom	80.7%	581.5%	22	-99%
Yonkers	2007	Surface	23.1%		823	
		Bottom	23.8%		884	
	2023	Surface	6.8%	-70.7%	1364	66%
		Bottom	9.1%	-61.8%	995	13%
Windflower	2023	Surface	9.4%		592	
		Bottom	13.8%		401	
Far South	2023	Surface	40.2%		166	
		Bottom	73.4%		22	
Southwest	2023	Surface	3.1%		1126	
		Bottom	ND		ND	
North	2023	Surface	46.6%		171	
		Bottom	52.3%		203	
Southeast	2023	Surface	74.4%		29	
		Bottom	56.0%		30	

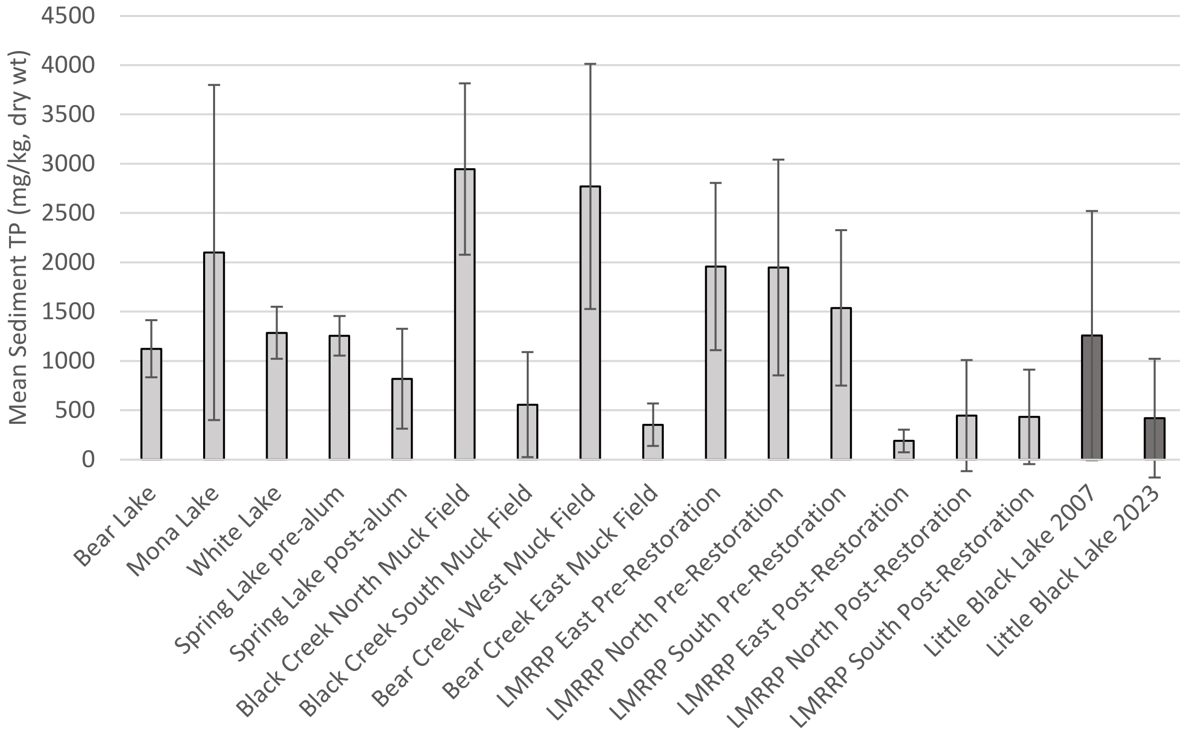

Figure 2. Comparison of mean (±SD) sediment TP measured in Little Black Lake in 2007 and 2023 compared to other west Michigan waterbodies*.
*Sources: Little Black Lake: Steinman et al. 2011; Mona Lake: Steinman et al. 2009; White Lake: Steinman et al. 2008; Spring Lake pre-alum: Steinman et al. 2004; Spring Lake post-alum: Steinman and Ogdahl 2008; Bear Lake: unpublished data; Black Creek muck fields: Steinman and Ogdahl 2011; Bear Creek: Steinman and Ogdahl 2013; LMRRP pre-restoration: Steinman et al. 2017; LMRRP post-restoration: unpublished data.

Michigan 10 Metals are a group of metals of special concern in Michigan as sediment pollutants and include arsenic, barium, cadmium, chromium, copper, lead, selenium, and zinc. Only two sites had sediment metal concentrations that exceeded probable effect concentrations (PECs): Southwest and Yonkers (Table 8). At Southwest, arsenic exceeded the toxic effect threshold (TET) but not the consensus-based PEC, whereas at Yonkers, sediment cadmium, lead, and zinc exceeded the PEC (Table 8), and have the potential for aquatic toxicity.

While we cannot track the origin(s) of these metals, likely sources include runoff from roadways and parking lots, which wash into the tributaries and eventually to the lake, where the metals are transported as sediments move due to wind/wave action. Circulation currents in the lake may then carry sediments along the northern shoreline (Windflower site), with some circulation heading to the outlet and some heading south along the western shoreline (Southwest site). This would account for the high number of exceedances at these three sites. In addition, lead arsenate was a common pesticide and may have been applied to the muck fields along Yonkers Drain. These concentrations suggest it is unlikely for a health hazard to be associated with the recreational use of Black Lake. However, there may be aquatic toxicity issues in the sediment with respect to metals. Ecotoxicological tests would need to be conducted to determine if these metal concentrations are impacting the biological communities in Little Black Lake.

Table 8: Michigan 10 metals measurements from sediment cores collected at 8 sites within Little Black Lake on July 21, 2023. Bold text values exceed the sediment quality guidelines for metals based on toxic effect thresholds (TET) and consensus-based probable effect concentrations (PEC) (MacDonald et al. 2000).

Site	Mercury (mg/kg dry)	Arsenic (mg/kg dry)	Barium (mg/kg dry)	Cadmium (mg/kg dry)	Chromium (mg/kg dry)	Copper (mg/kg dry)	Lead (mg/kg dry)	Selenium (mg/kg dry)	Silver (mg/kg dry)	Zinc (mg/kg dry)
South										
0-5 cm	<0.050	<2.0	21	<0.20	3.5	1.6	11	0.85	<0.49	22
5-10 cm	<0.050	<2.0	<9.5	<0.20	<2.0	<1.0	51	<0.57	<0.47	5.7
Center										
0-5 cm	<0.050	<2.0	<8.2	<0.20	<2.0	<1.0	<10	<0.49	<0.41	7.6
5-10 cm	<0.050	<2.0	<9.5	<0.20	<2.0	<1.0	<10	<0.57	<0.47	5.9
Windflower										
0-5 cm	<0.050	21	240	2.1	45	24	93	9.9	<1.0	260
5-10 cm	<0.050	9.9	78	0.65	23	7.3	14	5.1	<0.72	91
Yonkers										
0-5 cm	<0.050	31	320	2.9	57	40	**140**	14	<1.2	430
5-10 cm	<0.050	29	250	**3.7**	48	28	**220**	10	<0.97	**540**
Far South										
0-5 cm	<0.050	3.1	18	0.35	3.1	1.5	<10	0.61	<0.45	30
5-10 cm	<0.050	<2.0	<9.0	<0.20	<2.0	<1.0	<10	<0.54	<0.45	9.3
Southwest										
0-5 cm	<0.055	**27**	310	2.2	49	28	97	10	<4.2	300
North										
0-5 cm	<0.050	2.4	53	0.37	4.1	2.4	<10	1.1	<0.48	34
5-10 cm	<0.050	<2.0	48	0.29	5.1	1.2	<10	2.1	<0.48	18
Southeast										
0-5 cm	<0.050	<2.0	<9.2	<0.20	<2.0	<1.0	<10	<0.55	<0.46	5.7
5-10 cm	<0.050	<2.0	16	<0.20	2.1	<1.0	<10	0.55	<0.42	5.8
Toxic Effect Threshold	1	17	ND*	3	100	86	170	ND	ND	540
Consensus-Based PEC	1.06	33.0	ND	4.98	111	149	128	ND	ND	459

*No Data

Aquatic Macrophytes

A total of 69 sites within the lake were sampled for aquatic macrophytes (i.e., aquatic plants and macroscopic algae). Macrophyte coverage was high throughout the lake, with a majority of sites having > 75% covered by plants (Figure 3). There was an area along the middle portion of the eastern shoreline that tended to have low coverage, along with shallow depths (Figures 3, 4).

In total, 38 species were observed throughout the lake, the most common of which were *Myriophyllum spicatum* (Eurasian watermilfoil), *Potamogeton amplifolius* and *Potamogeton zosteriformis* (large-leaved and flat-stemmed pondweed, respectively; Table 9). Macrophyte community composition varied with depth (Figure 4). At the shallowest sites (< 0.5 m; n = 13), the most commonly observed species were *Myriophyllum spicatum* and *Nymphaea odorata* (white water lily). At sites with depths 0.5-1.0 m (n = 30), the most commonly observed species were *Brasenia* sp. (water shield) and *Nymphaea odorata*. For depths of 1.0-1.5 m (n = 16), the most commonly observed species were *Potamogeton zosteriformis*, which was found at all sites in this category, and *Potamogeton amplifolius*. At the deepest sites (> 1.5 m, n = 10), the most prevalent species was *Myriophyllum spicatum*, which was observed at every site of this depth.

Major changes in species composition from 2007 to 2023 include the presence of *M. spicatum* and *Potomogeton crispus* (curly leaf pondweed), which were not observed in 2007. Both of these taxa are aquatic invasive species, that are considered restricted by the State of Michigan. Both species can outcompete native aquatic plant species and reduce diversity (but see below; https://www.michigan.gov/invasives/id-report/plants/aquatic). In addition, dense growth can hinder fish movement, as well as recreational activity. Little Black Lake also has experienced a significant decrease in the abundance of *Chara* sp., which decreased to 20.3% of sites compared to 44.6% of sites in 2007. *Chara* is often considered a beneficial species as it helps stabilize sediment and can provide habitat, although some species have been shown to be allelopathic (release chemicals harmful to other plants; Berger and Schagerl 2003).

Macrophyte communities can be quantitatively compared between the 2007 and 2023 sampling events using a floristic quality assessment (FQA), which assesses the ecological integrity of a waterbody according to the species composition of plants found there. This calculation is based upon the number of different kinds of species present, as well as a rating of each species called the coefficient of conservatism (C). Coefficients are assigned by the Michigan DNR on a scale of 0 (low) to 10 (high) and represent the probability that a species will occur within an undisturbed landscape, such that a species with a C-value of 0 can be found in highly degraded areas while a species with a C-value of 10 is usually found in high quality areas (Herman et al. 2001). C-values for the species observed in Little Black Lake span the full range of 0-10, with two observed species having a C-value of 10: *Utricularia purpurea* (purple bladderwort) and *Potamogeton robbinsii* (Robbins' pondweed). Results from the comparison are mixed. A positive difference is that the number of unique species observed increased from 29 in 2007 to 38 in 2023. However, due to the overall lower C values of the taxa observed in 2023, the weighted floristic quality index decreased in 2023 from 2007 (Table 10). Of greater concern is the abundance of Eurasian watermilfoil and curly pondweed, two invasive plants known for causing ecological and recreational problems in Michigan lakes.

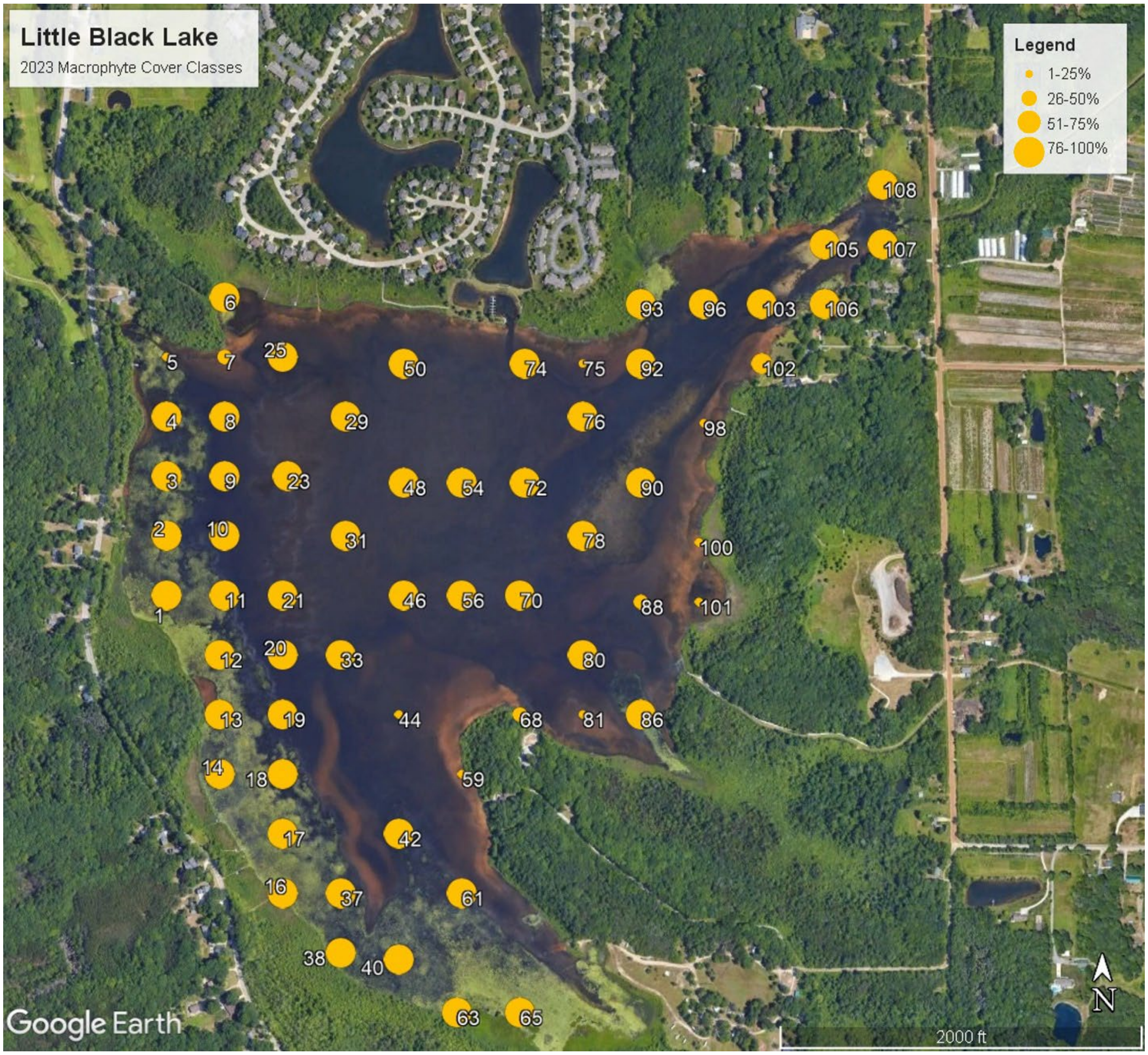

Figure 3. Macrophyte cover at each Little Black Lake sampling site. The larger the circle, the greater the coverage (see legend). Labels on each point refer to site number.

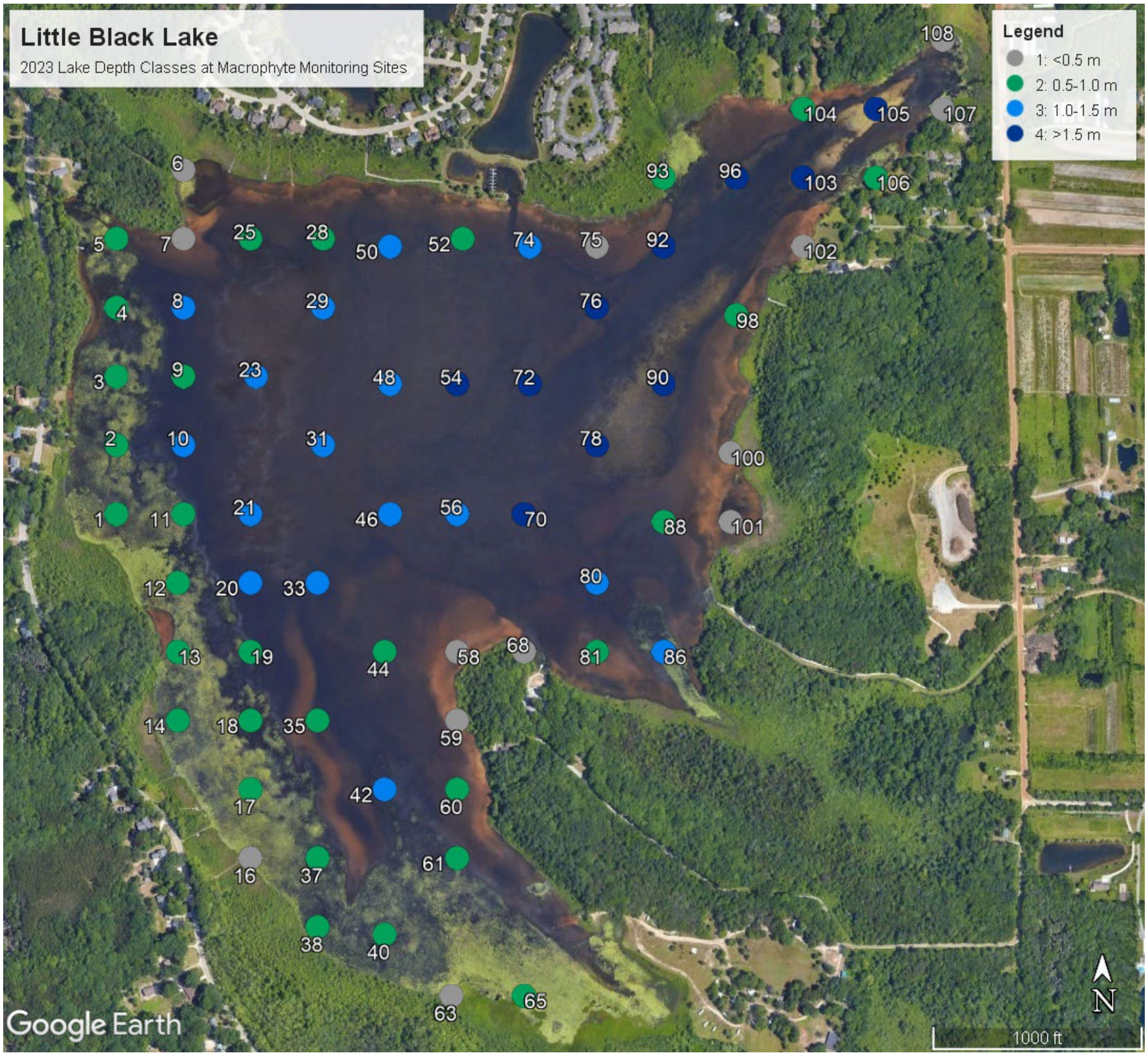

Figure 4. Water depth at the macrophyte sampling sites in Little Black Lake. Depths are color-coded (see legend). Labels on each point refer to site number.

Table 9**:** Aquatic macrophyte species list, number of sites present and corresponding percentage, and the coefficient of conservatism (C) (Herman et al. 2001) in Little Black Lake in 2023.

Species	**#**	**%**	**C**
Myriophyllum spicatum	41	59.4	*
Potamogeton amplifolius	34	49.3	6
Potamogeton zosteriformis	28	40.6	5
Brasenia sp.	27	39.1	6
Nymphaea odorata	25	36.2	6
Potamogeton crispus	24	34.8	*
Vallisneria americana	24	34.8	7
Ceratophyllum demersum	21	30.4	1
Myriophyllum sibiricum	19	27.5	7
Elodea canadensis	18	26.1	1
Chara sp.	14	20.3	--
Nuphar lutea	14	20.3	7
Najas flexilis	14	20.3	5
Potamogeton natans	13	18.8	5
Utricularia purpurea	13	18.8	10
Scirpus americanus	11	15.9	5
Pontederia cordata	11	15.9	8
Myriophyllum heterophyllum	10	14.5	6
Potamogeton pusillus	10	14.5	4
Potamogeton gramineus	7	10.1	5
Schoenoplectus pungens	7	10.1	5
Peltandra virginica	6	8.7	6
Unknown Submerged 1	4	5.8	--
Lythrum salicaria	4	5.8	*
Eleocharis sp.*	3	4.3	4
Unknown Emergent 1	3	4.3	--
Typha latifolia	2	2.9	1
Cephalanthus occidentalis	2	2.9	7
Potamogeton robbinsii	2	2.9	10
Heteranthera dubia	1	1.4	6
Unknown Emergent 2	1	1.4	--
*Eriocaulon aquaticum**	1	1.4	9
Lemna minor	1	1.4	5
Najas sp.	1	1.4	--
Sparganium americanum	1	1.4	6
Schoenoplectus sp.	1	1.4	--
Polygonum sp.	1	1.4	--
Phragmites sp.	1	1.4	0

*Some taxonomic uncertainty on species-level identifications of these taxa.

Table 10**:** Floristic Quality Assessment (FQA) metrics for Little Black Lake in 2007 and 2023.

Metric	**2007**	**2023**
Total number of species (*n*)	29	38
Mean C ($\bar{C}$)	5.6	5.0
Weighted mean C (*wC*)	6.0	4.5
Floristic quality index = $\bar{C}\sqrt{(n)}$	30.4	30.6
Weighted floristic quality index = wC$\sqrt{(n)}$	32.2	27.8

Summary and Conclusions

The results from our monitoring study of Little Black Lake reveal both positive and negative elements. In general, water quality has remained good as most parameters were within the range of healthy ecological conditions. In the tributaries, dissolved oxygen concentrations remained above 5 mg/L, a reasonable threshold for a healthy recreational fishery, during both our baseflow and stormflow sampling. In addition, tributary phosphorus and nitrogen concentrations remained relatively low; total phosphorus and nitrate-nitrogen concentrations were elevated slightly from 2007 but still at desirable levels. In Little Black Lake, water quality in the water column was very good overall with low nutrient and chlorophyll *a* concentrations. The only parameter of some concern is specific conductance, which slightly exceeded 600 µS/cm in both Yonkers Drain and the outflow in 2023, as well as most of the 2023 lake sampling sites. The sediment phosphorus concentrations are low relative to other nearby water bodies, and currently give no indication of concern.

The major areas of concern in Little Black Lake are the sediment metals and macrophyte community structure. Of especial concern are the high levels of cadmium, lead, and zinc in Yonkers Drain and of arsenic at the Southwest site. The municipalities may want to notify EGLE of these exceedances; although these levels are likely not of concern to human health, they could be affecting the biota in Little Black Lake. Metals were not sampled in 2007 so it is not possible to determine if this is an ongoing issue or a legacy issue from the past. At most sites, metal concentrations were elevated in the 0-5 cm sediment core fraction compared to the deeper 5-10 cm sediment core layer. This suggests that metals are still entering the lake (the top layer is newer sediment), although in Yonkers Drain, the high metal concentrations were in the deeper layer. Caution is necessary when using sediment depth as a proxy for age, as it is possible that strong currents, wind/wave action, and invertebrate movements (bioturbation) can mix the sediments, so deeper sediments may actually be a mix of newer and older sediment.

The major concern with the macrophytes is the introduction of two problem invasive species since 2007: curly-leaf pondweed and Eurasian watermilfoil. Both of these taxa are listed as restricted by the State of Michigan, and can impact the movement of watercraft as well as impact habitat for fish and wildlife.

Our recommendations based on these results are as follows:

1) There is no need to address nutrient concentrations but we recommend to continue monitoring water quality on a 5-year cycle to make sure conditions remain stable;

2) Notify EGLE regarding sediment toxicity levels (stroused@michigan.gov) and consider contracting with a consulting firm or university to conduct ecotoxicological laboratory tests to determine if sediments are toxic to biota;

3) Contract with a local applicator (recommendation: Professional Lake Management) to control the Eurasian watermilfoil and curly pond weed, starting in 2024;

4) Develop a 9-element watershed management plan for Little Black Lake to better understand, document, and manage nonpoint source pollution in this system.

While certain aspects of Little Black Lake and its tributaries have shown encouraging resilience to environmental stressors, the most recent data also show some signs of impairment. We recommend these issues be addressed sooner rather than later. While there is an upfront cost, it is ultimately more economical in the long run to address these issues in their early stages.

Acknowledgements

We gratefully acknowledge the City of Norton Shores (Mark Meyers) and Spring Lake Township (Lucas Hill) for funding this study. Dr. Rick Rediske kindly provided ecotoxicological advice, Brian Scull conducted chemistry analyses, Dr. Mark Luttenton assisted on macrophyte identification, and Scott Rood graciously provided us lake access.

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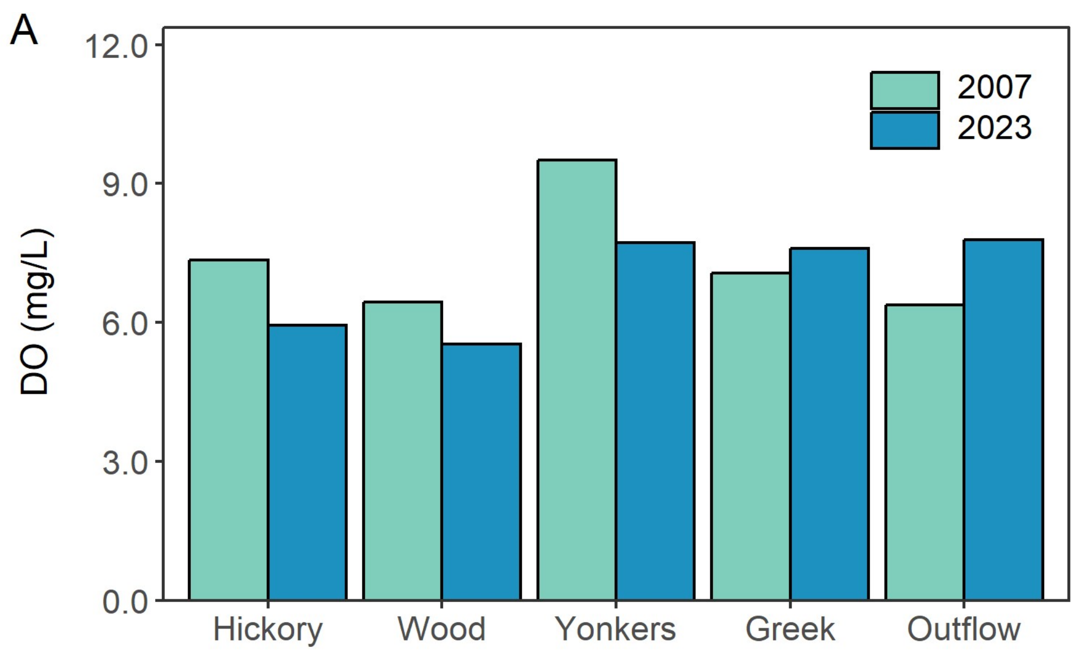
Appendices

Fig. A1. Mean dissolved oxygen concentrations in tributaries from 2023 vs. 2007 under A) baseflow and B) stormflow conditions.



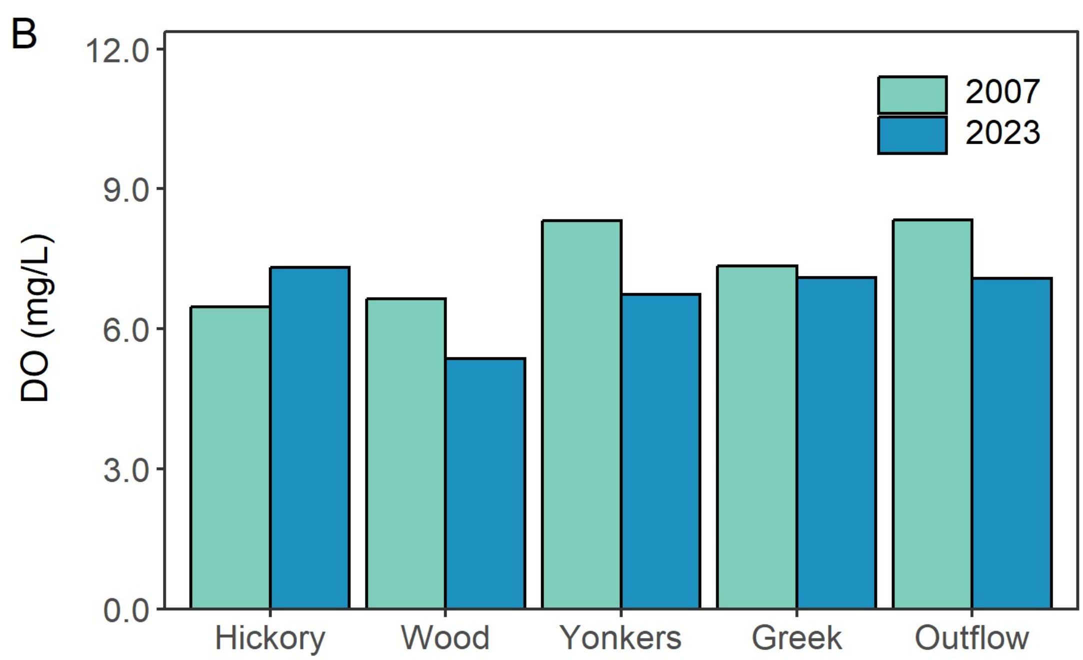


Fig. A2. Mean specific conductivity concentrations in tributaries from 2023 vs. 2007 under A) baseflow and B) stormflow conditions.

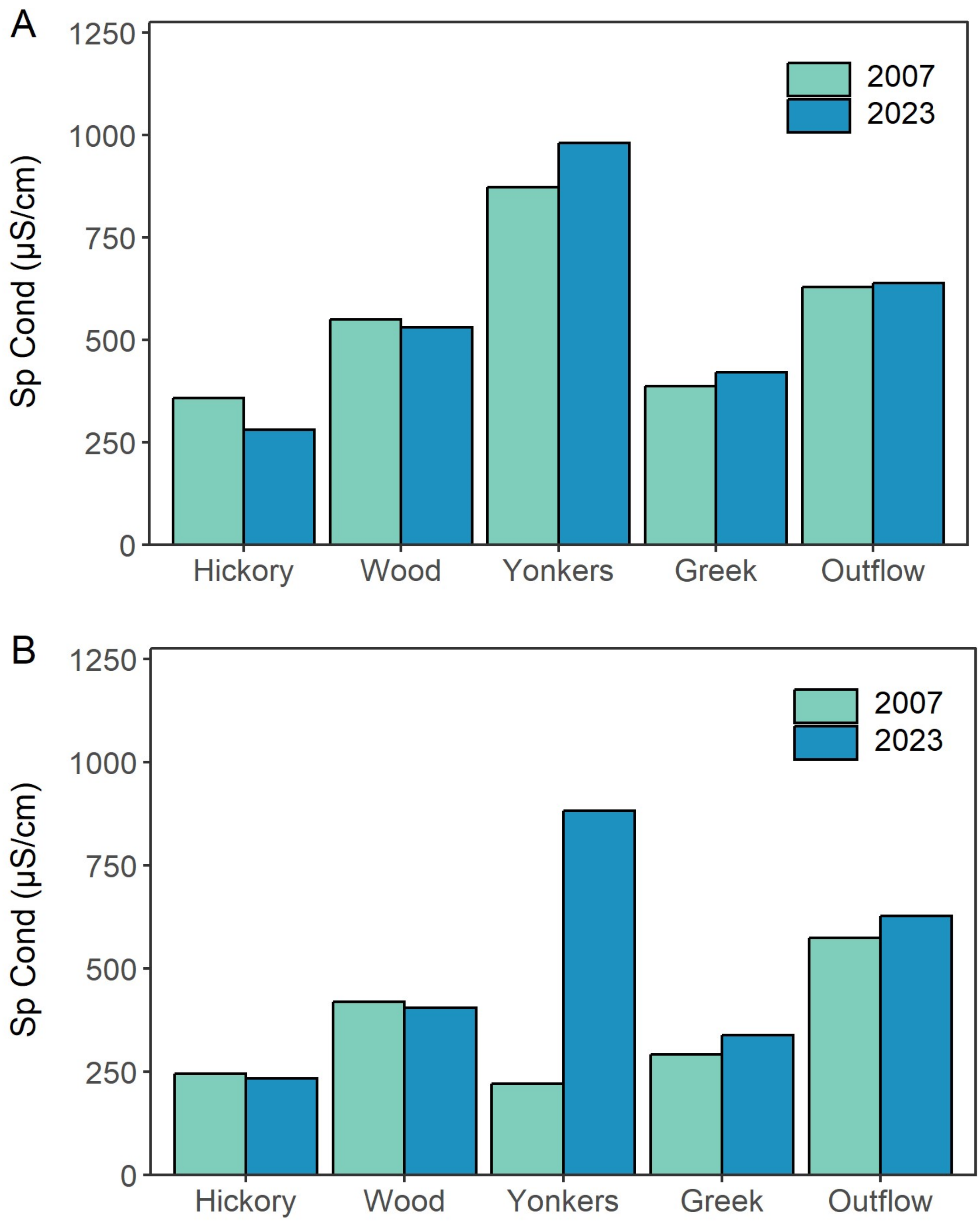
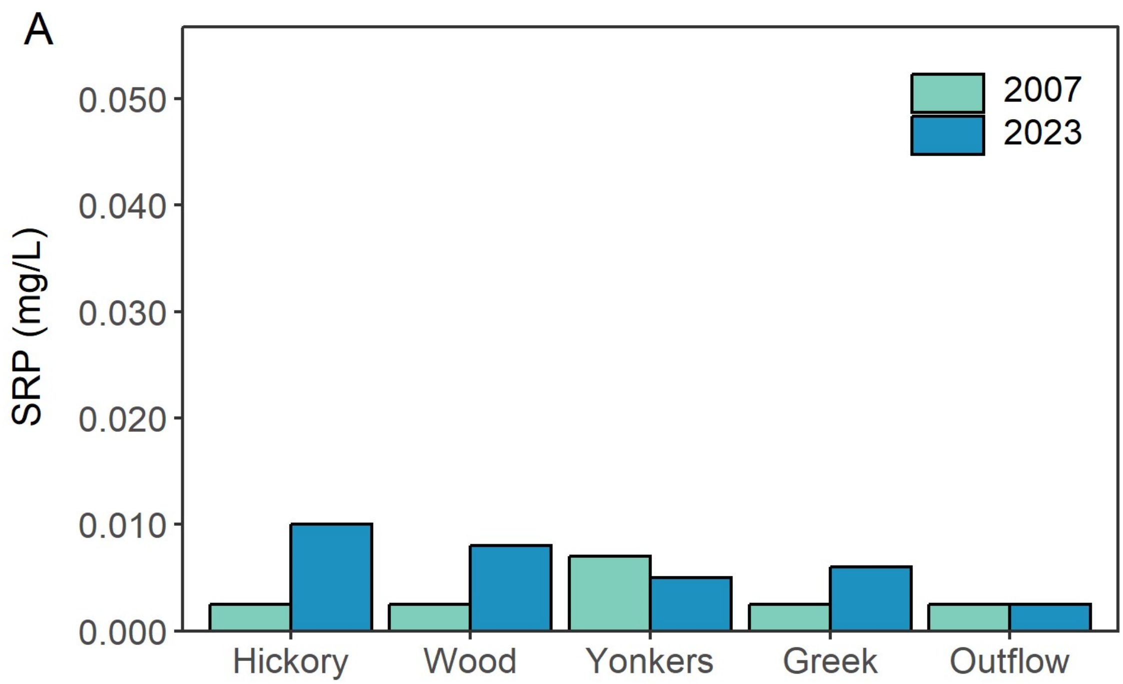


Fig. A3. Mean soluble reactive phosphorus (SRP) concentrations in tributaries from 2023 vs. 2007 under A) baseflow and B) stormflow conditions.



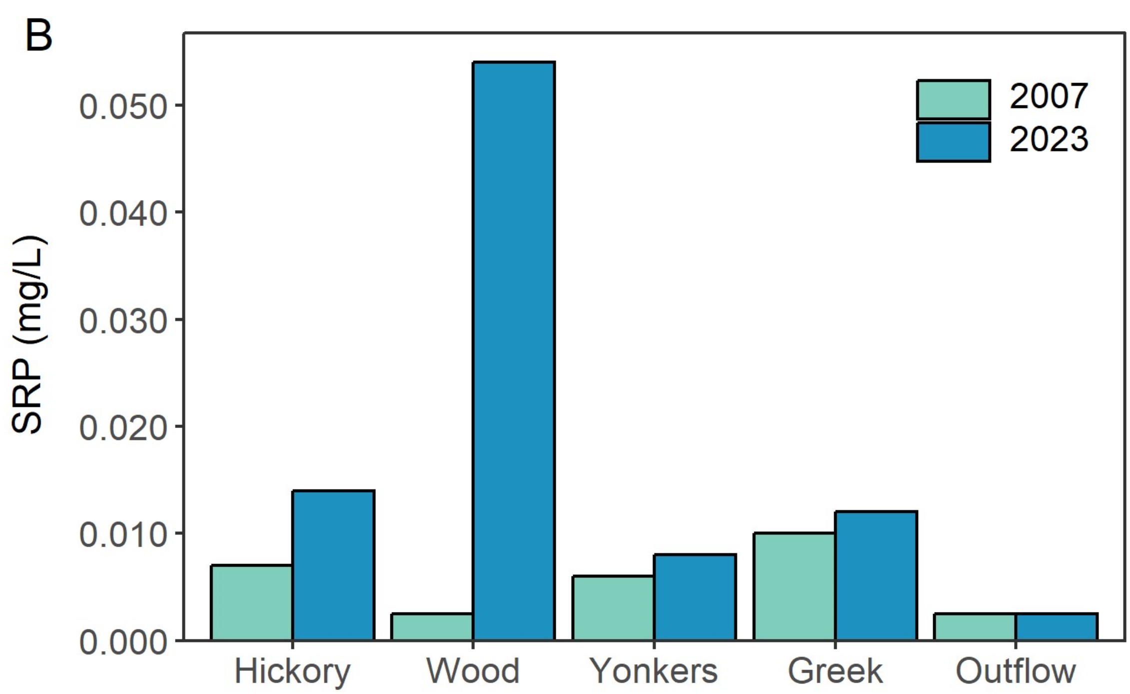


Fig. A4. Mean total (TP) concentrations in tributaries from 2023 vs. 2007 under A) baseflow and B) stormflow conditions.

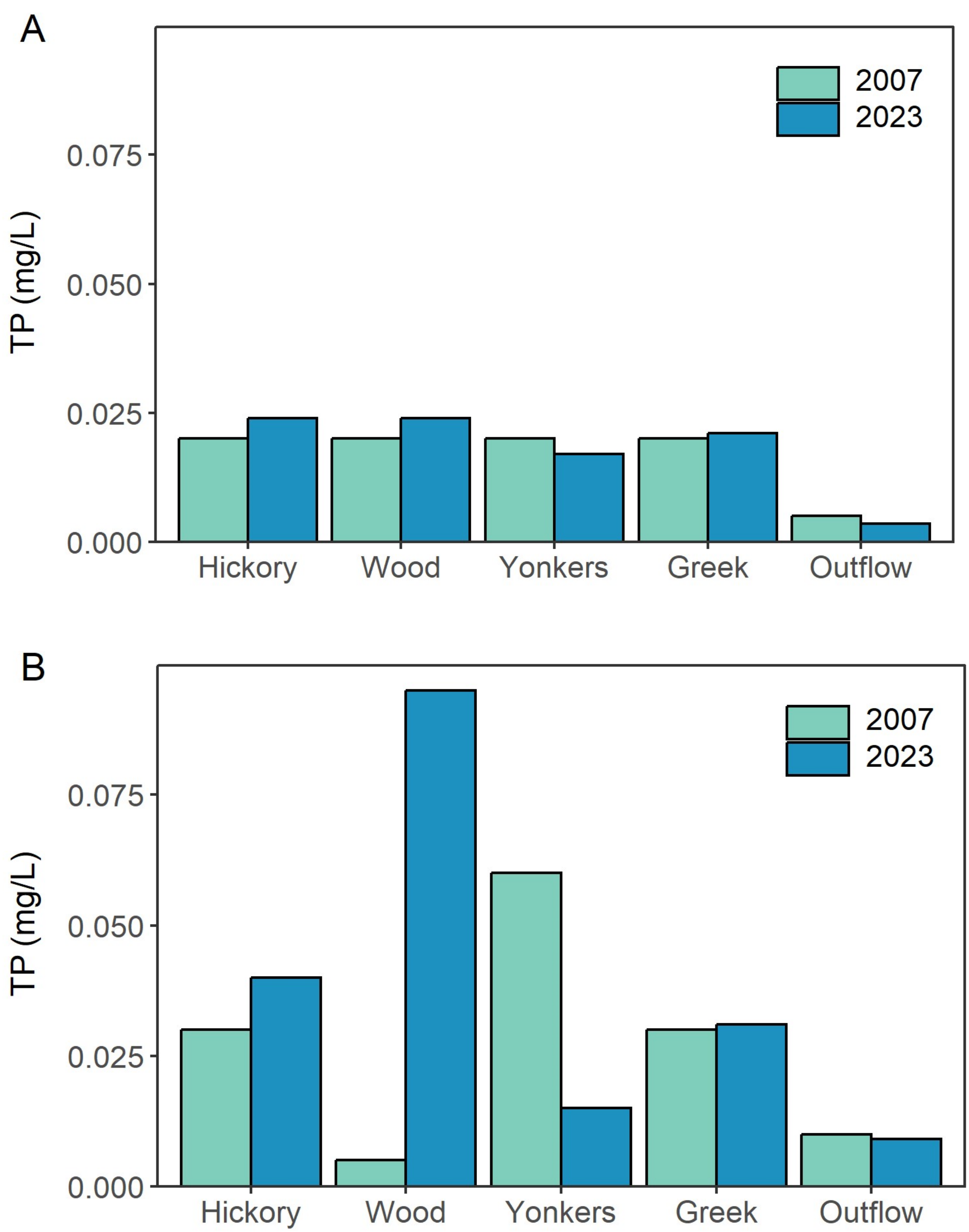


Fig. A5. Mean DO concentrations in Little Black Lake from 2007 and 2023. Data shown from 2023 include the same 4 sites as sampled in 2007 (light blue), as well as all 8 sites sampled in 2023 (dark blue). Error bars = 1 standard deviation.

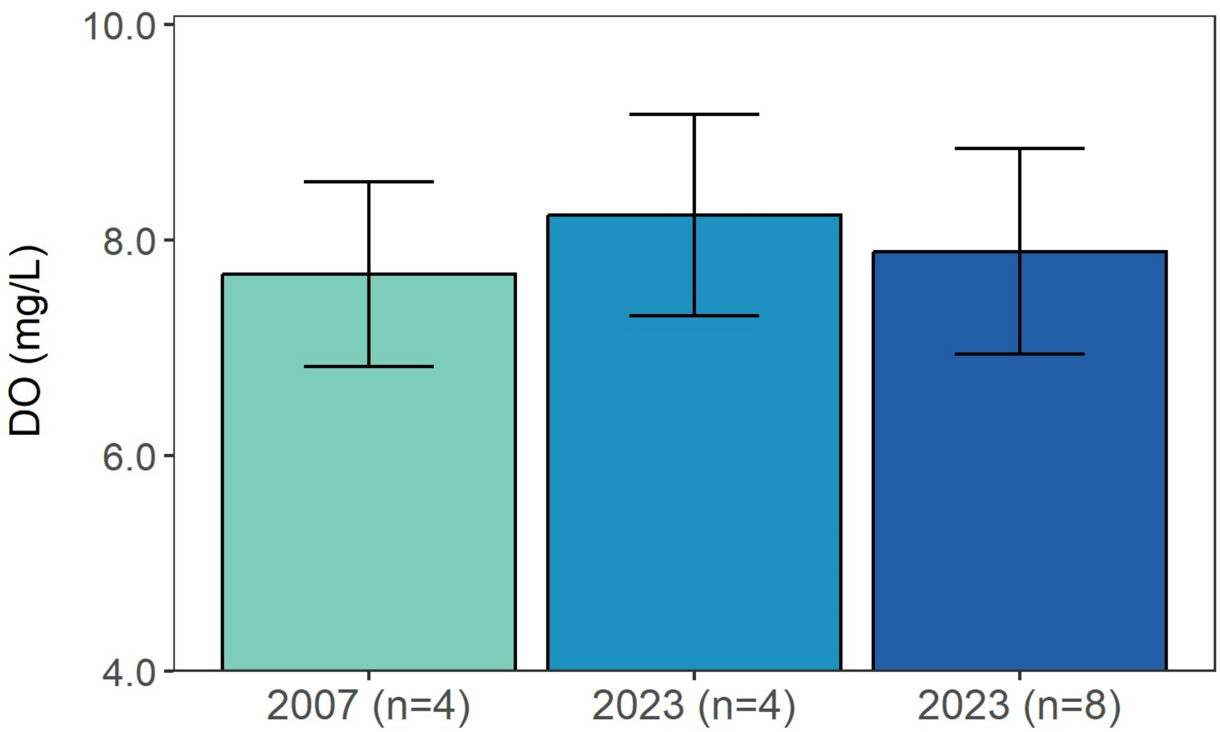


Fig. A6. Mean Specific Conductivity concentrations in Little Black Lake from 2007 and 2023. Data shown from 2023 include the same 4 sites as sampled in 2007 (light blue), as well as all 8 sites sampled in 2023 (dark blue). Error bars = 1 standard deviation.

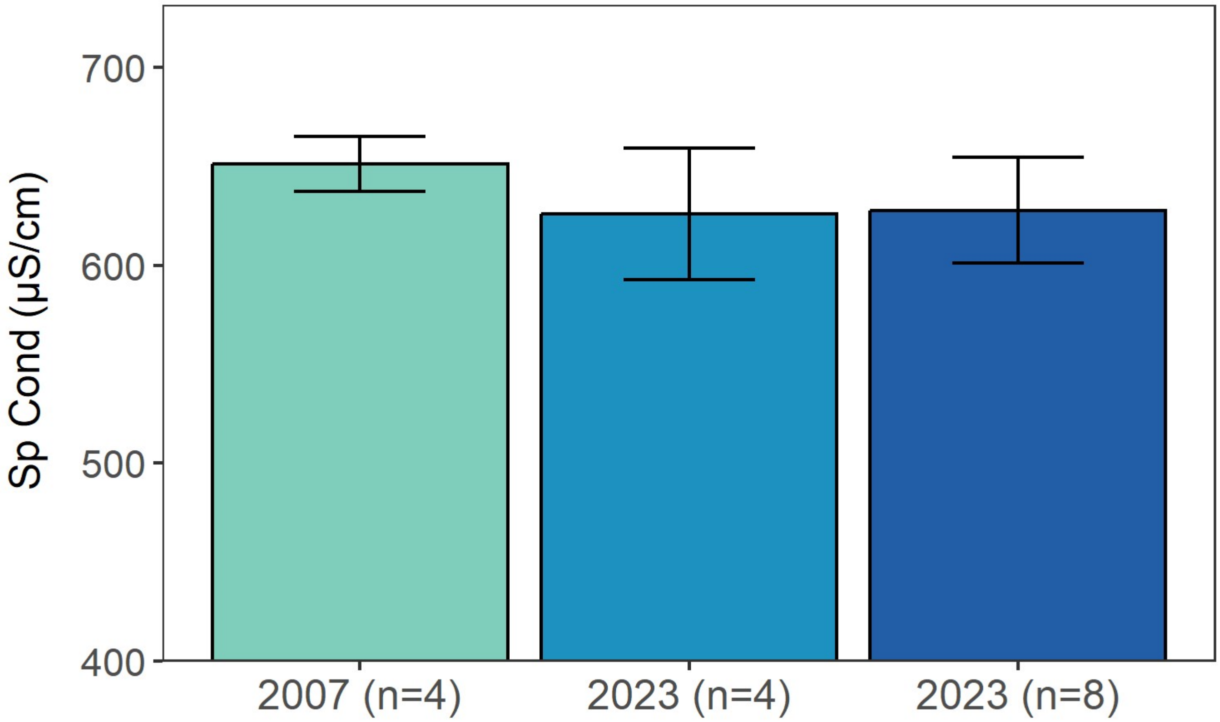


Fig. A7. Mean soluble reactive phosphorus (SRP) concentrations from the same 3 lake sites in 2007 and 2023. Error bars = 1 standard deviation.

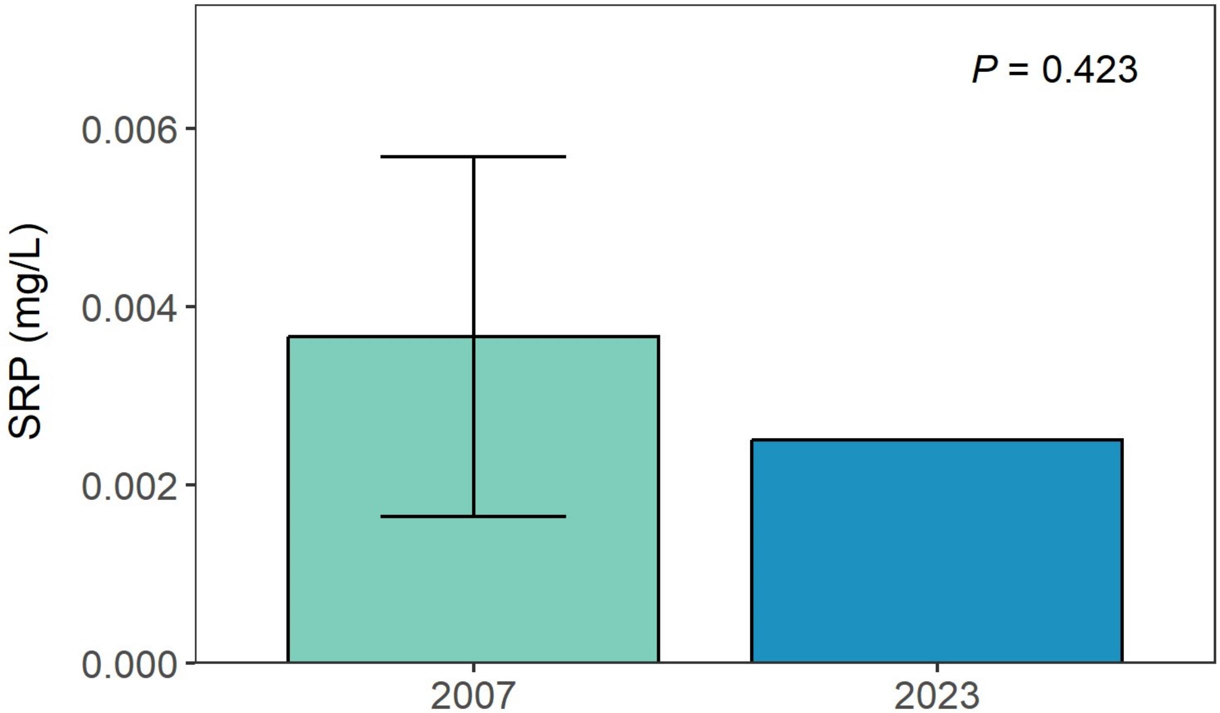


Fig. A8. Mean total phosphorus (TP) concentrations from the same 3 lake sites in 2007 and 2023. Error bars = 1 standard deviation.

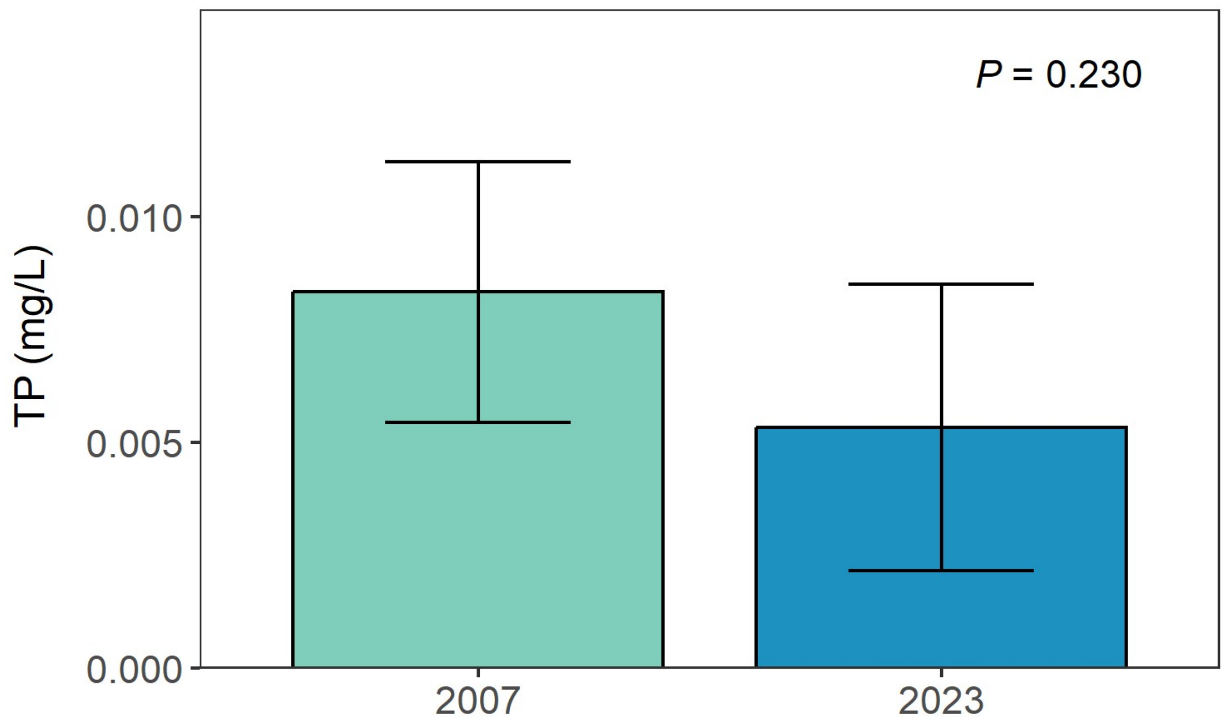


Fig. A9. Mean chlorophyll *a* concentrations from the same 3 lake sites in 2007 and 2023. Error bars = 1 standard deviation.

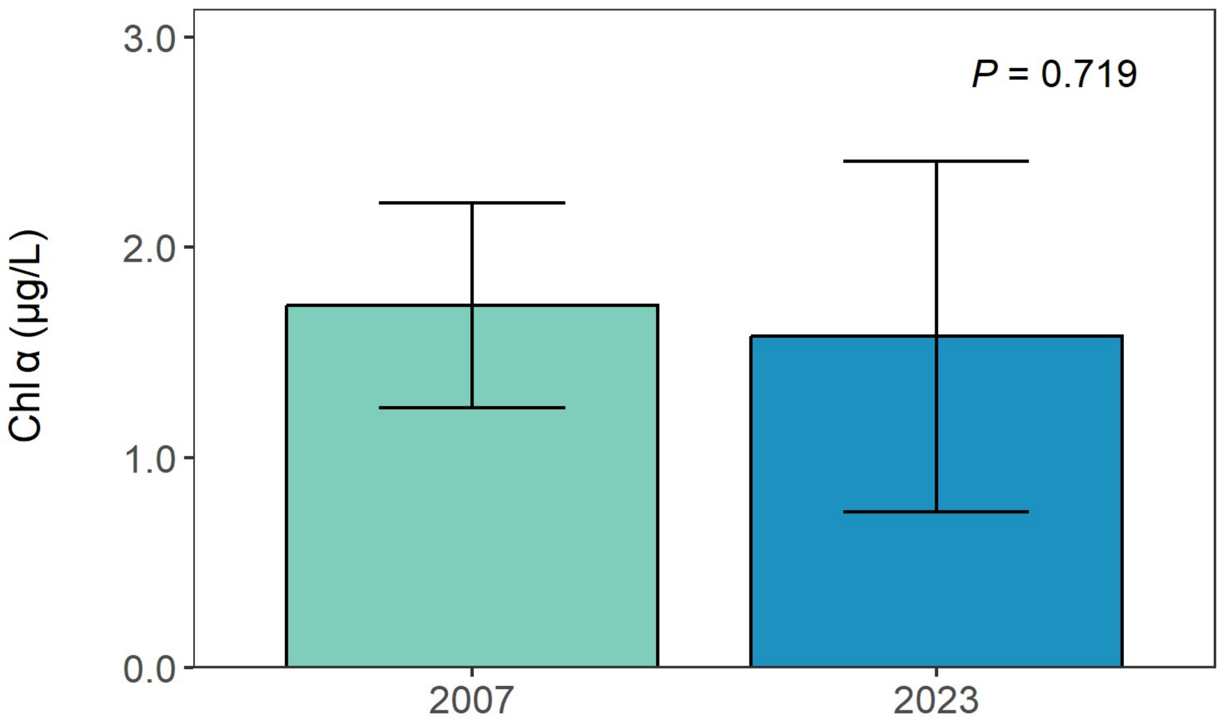


Fig. A10. Mean % solids in top (0-5 cm) and bottom (5-10) layers of sediment from 2007 and 2023. Sediment data shown in 2023 include the same 3 sites as sampled in 2007, as well as all 8 sites sampled in 2023. Error bars = 1 standard deviation.

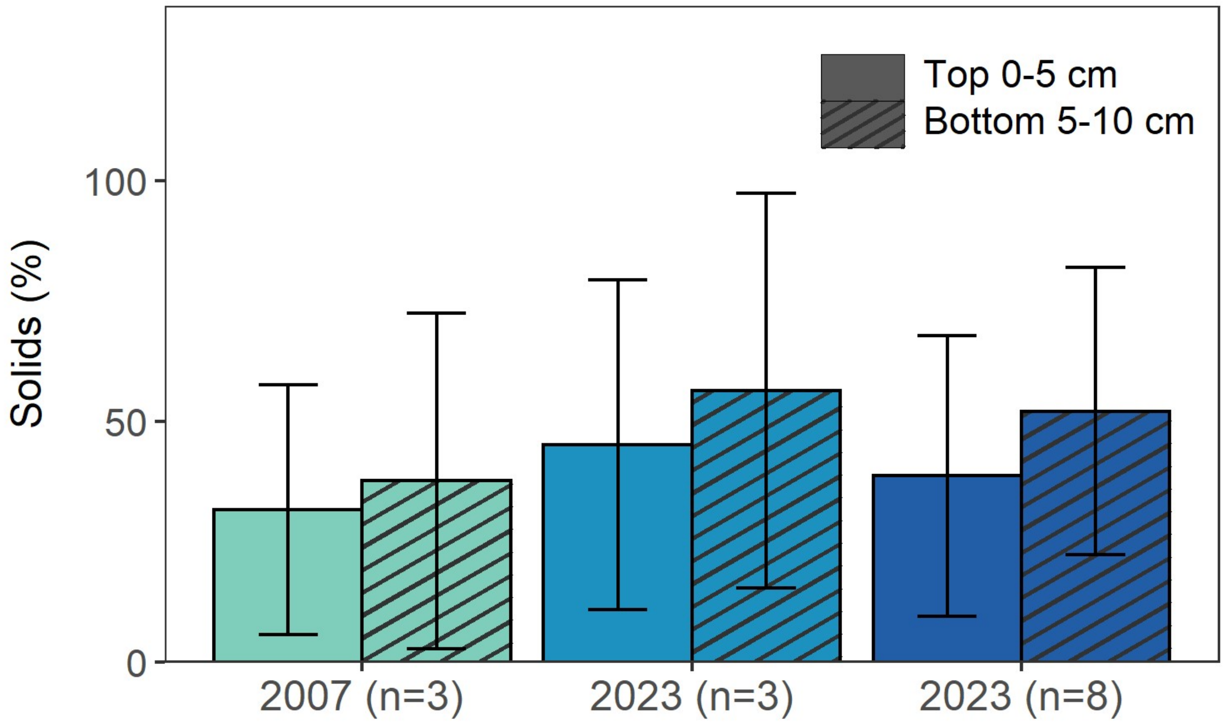


Fig. A11. Mean TP (total phosphorus) concentrations in top (0-5 cm) and bottom (5-10) layers of sediment from 2007 and 2023. Sediment data shown in 2023 include the same 3 sites as sampled in 2007, as well as all 8 sites sampled in 2023. Error bars = 1 standard deviation.