PROJECT CLARITY
2014 Annual Monitoring 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 includes wetland restoration, in-stream remediation, Best Management Practices (BMPs), and community education is being implemented by a diverse and dedicated team in a public-private partnership. Once watershed remediation is complete, the project is expected to have many economic, social, and ecological benefits – while achieving the ultimate goal of improved water quality in Lake Macatawa.

Lake Macatawa is at the terminus of a highly degraded ecosystem and has exhibited the symptoms of a 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 make it one of the most hypereutrophic 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 hypereutrophic 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 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). In recent years, monthly average TP concentrations were greater than 125 µg/L, and at times exceeded 200 µg/L (Holden 2014). Thus, meeting the TMDL target represents a major challenge for the Macatawa watershed. The TMDL estimated that it would require a 72% reduction in phosphorus loads from the watershed (Walterhouse 1999). Through remediation projects and BMPs focused on key areas in the watershed, Project Clarity is focused on reducing P loads and working to meet the TMDL target for Lake Macatawa.

The Annis Water Resources Institute (AWRI) at Grand Valley State University, in cooperation with the Outdoor Discovery Center Macatawa Greenway (hereafter, ODC) and Hope College, is working on a long-term monitoring initiative in the Lake Macatawa watershed. The study will provide critical information on the performance of restoration projects that are part of Project Clarity, as well as the water quality status of Lake Macatawa. The goal of the monitoring effort is to measure pre- and post-restoration conditions in the watershed, including Lake Macatawa. This report documents AWRI's monitoring activities in 2013 and 2014, which represent pre-restoration conditions. Although it will take a number of years before the benefits of restoration actions in the watershed are expressed in the lake, these initial results will establish the baseline conditions against which we can assess future changes (cf. Steinman et al. 2008;

Bhagat and Ruetz 2011).

2. Methods

2.1 Overall site description

The Macatawa watershed (464 km^2/114,000 acres) is located in Ottawa and Allegan Counties and includes Lake Macatawa, the Macatawa River, and many tributaries. It is dominated by agricultural (46%) and urban (33%) land uses, which have accounted for 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.

AWRI's monitoring initiative is focused on 1) two key wetland restoration areas in the Macatawa watershed (Figures 1, 2) and 2) Lake Macatawa (Figure 3). Details on these two efforts are provided below.

2.2 Wetland Restoration: Middle Macatawa & Haworth Properties

2.2.1 Monitoring & Data Collection

Wetland restoration activities are planned for two properties that were acquired as part of Project Clarity. Restored wetlands on the Middle Macatawa and Haworth properties are being designed to slow the flow of water in the Macatawa River and its tributaries, particularly during high flow events, thus trapping and retaining suspended sediments and nutrients.

Both properties have sampling sites located upstream and downstream of the restoration area. The Middle Macatawa study area (Figure 1) has two upstream sites (Macatawa River and Peter's Creek, which flows into the Macatawa River) and two downstream sites (Macatawa River at the USGS gauging station [Macatawa Down USGS] and at Adams Street Landing [Macatawa Down Adams]). The Haworth study area (Figure 2) consists of sampling locations upstream and downstream of the restoration area, on the North Branch of the Macatawa River.

Water quality and hydrologic monitoring began on these properties in April 2014. Sampling occurred monthly during base flow conditions and during 4 storm events (~≥ 0.5 inches of rain proceeded by 72 hours of dry weather; Table 1). During each monitoring event, general water quality parameters (dissolved oxygen [DO], temperature, pH, specific conductance, total dissolved solids [TDS], redox potential [ORP], and turbidity) were measured using a YSI 6600 sonde. Grab samples were collected for analysis of phosphorus (soluble reactive phosphorus [SRP], total phosphorus [TP]) and nitrogen (ammonia [NH_3], nitrate [NO_3], and total Kjeldahl nitrogen [TKN]) species. All water quality measurements and sample collection took place in the thalweg of the channel at permanently-established transects. Duplicate water quality samples and sonde measurements were taken every other month during base flow conditions and during every storm event. All samples were placed in a cooler on ice until received by the AWRI lab, usually within 4 hours, where they were stored and processed appropriately.

Water for SRP and NO_3 analysis was syringe-filtered through 0.45-µm membrane filters into scintillation vials and frozen until analysis. NH_3 and TKN were acidified with sulfuric acid and kept at 20°C until analysis. SRP, TP, NH_3, NO_3, and TKN were analyzed on a SEAL AQ2 discrete automated analyzer (U.S. EPA 1993). Any values below detection were calculated as ½ the detection limit.

Stream hydrographs are in the process of being developed for each monitoring location. Water level loggers and staff gauges were installed at permanently-established transects at each of the 6 monitoring locations. Manual water velocity (using a Marsh McBirney Flow-mate 2000) and stage measurements were taken at each transect during each baseflow sampling event and over a range of high flow conditions to develop stage-pressure, stage-discharge, and pressure-discharge relationships. We anticipate having sufficient high flow measurements by summer of 2015 to develop the discharge models. Once calibrated, these models will be applied to the high-frequency pressure data recorded by the water level loggers to develop a stream hydrograph at each location (Chu and Steinman 2009).

Suspended sediment load associated with high flow events was quantified using PVC sediment collection tubes, which were designed and used by Hope College in previous studies in the Macatawa watershed. Sediment collection tubes were installed near each of the monitoring locations. Sediment samples were collected from the tubes after each high flow event, defined when the USGS gauge station on the Macatawa River reaches 300 cfs, and processed by ODC and/or Hope College staff. The suspended sediment load results will be reported separately by the ODC.

Turbidity sensors (YSI 600OMS V2) were deployed at the upstream and downstream locations on the main branch of the Macatawa River in November 2014. The sensors log turbidity measurements every hour. These sensors will complement the sediment load data obtained from the passive PVC sediment sampler tubes, capturing smaller storm events and base flow events. The turbidity sensors were removed during winter and will be replaced before the snow melt in spring 2015. Because only 4 weeks of data were recorded in 2014, turbidity data will be included in the 2015 annual report.

2.2.2 Data Analysis

Because wetland restoration has not yet begun at the study sites, we cannot compare pre vs. post-restoration differences. Rather, our analysis focuses on characterizing water quality at the two properties, and identifying 1) upstream-downstream differences and 2) baseflow-storm flow differences in nutrients and turbidity. Identification of any patterns prior to restoration will aid in distinguishing restoration effects from inherent variability in the future.

Upstream-downstream differences between site pairs (e.g., Macatawa Up vs. Macatawa Down [USGS]) were statistically tested using either a two-tailed paired t-test (normally-distributed data) or Wilcoxon signed rank test (non-normally distributed data); baseflow and storm flow conditions were evaluated separately for each site pair. Baseflow-storm flow differences at each sampling location were statistically compared using either a two-tailed t-test (normally-distributed data with equal variance) or Mann-Whitney rank sum test (non-normally distributed data and/or unequal variance). Normality was tested using the Shapiro-Wilk test and equal variance was tested using the Brown-Forsythe test. Statistical significance was indicated by p-values < 0.05. All statistical tests were performed using SigmaPlot 13.0.

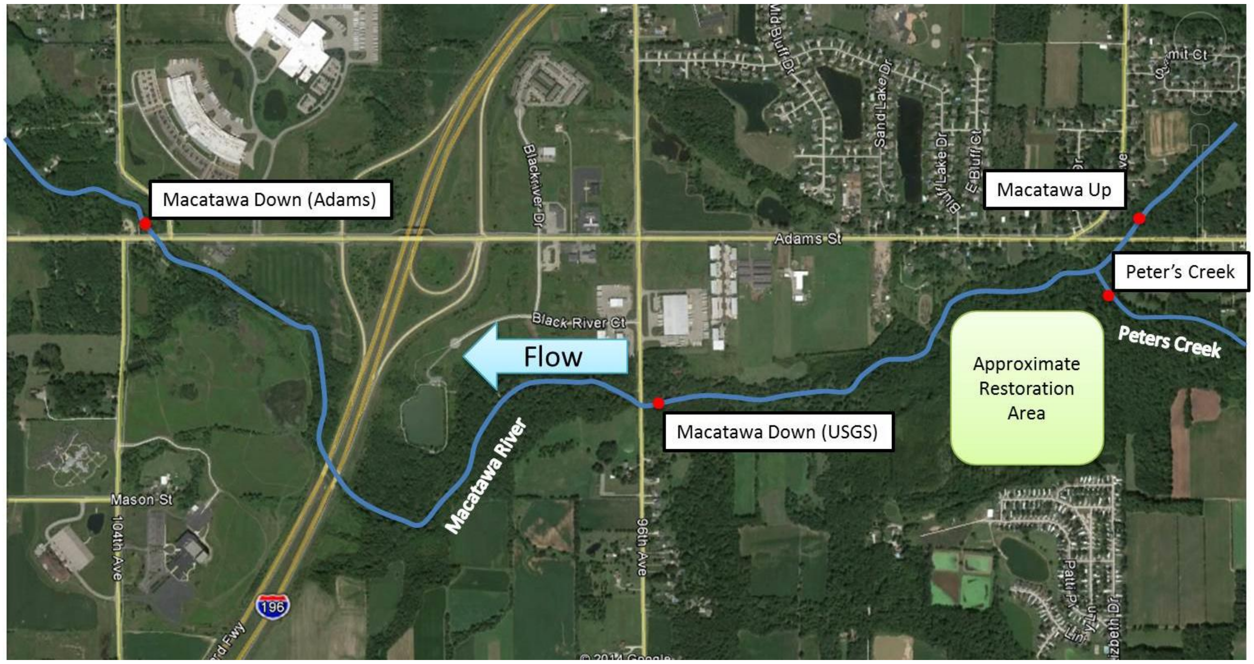


Figure 1. The Middle Macatawa wetland restoration study area. Sampling locations (n=4), located on Peter's Creek and the Macatawa River, are indicated with red dots.

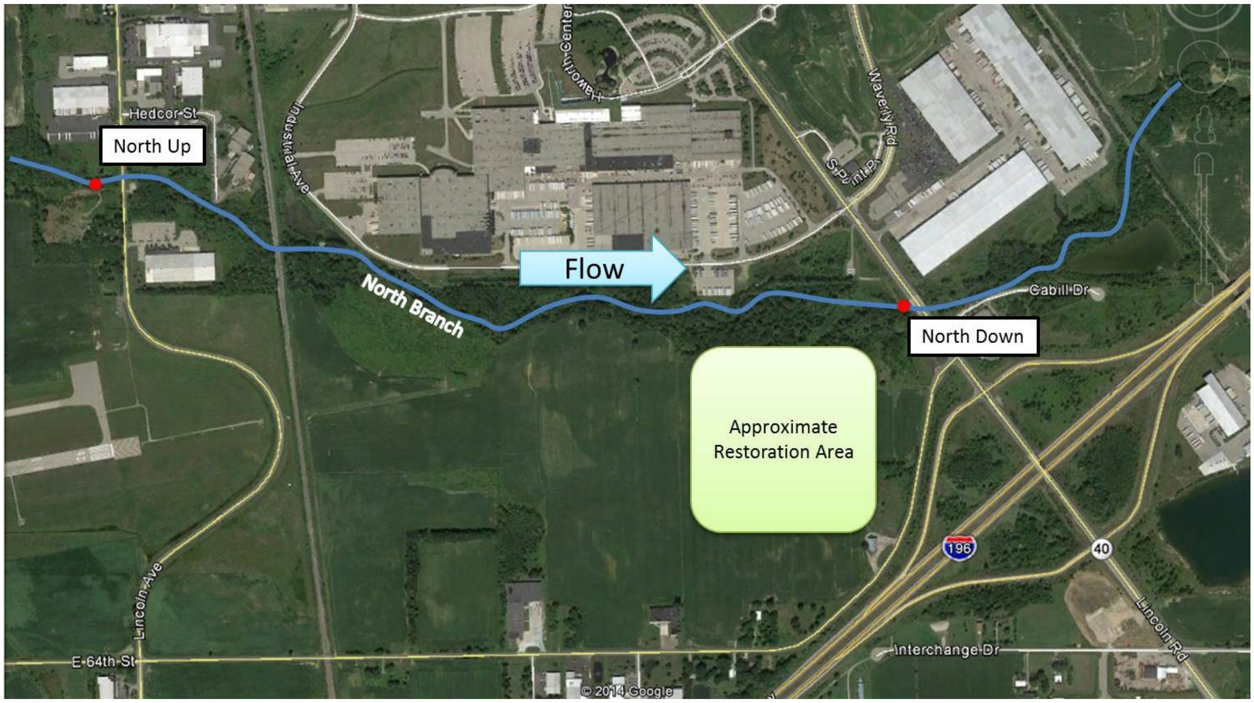


Figure 2. The Haworth wetland restoration study area. Sampling locations (n=2), located on the North Branch of the Macatawa River, are indicated with red dots.

2.3 Lake Macatawa: Long-Term Monitoring

Water quality monitoring was conducted at 5 sites during summer and fall 2013 and during spring, summer, and fall 2014 (Figure 3). The sampling sites correspond with Michigan Department of Environmental Quality (MDEQ) monitoring locations to facilitate comparisons with recent and historical data. At each sampling location, general water quality measurements (DO, temperature, pH, specific conductance, TDS, ORP, turbidity, chlorophyll *a*, and phycocyanin [cyanobacterial pigment]) were taken using a YSI 6600 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, and chlorophyll *a*. Samples also were taken for phytoplankton community composition and archived for possible future analysis.

Water for SRP analysis was syringe-filtered through 0.45-µm membrane filters into scintillation vials and frozen until analysis. SRP and TP were analyzed as previously described. Chlorophyll *a* samples were filtered through GFF filters and frozen until analysis on a Shimadzu UV-1601 spectrophotometer (APHA 1992).

The fish community was sampled in fall 2014. A full report on this effort is included in Appendix A.

Our pre-restoration analysis of lake monitoring data is focused on characterizing the water quality status of the lake, including comparisons to established water quality targets, and identification of seasonal trends. Understanding and documenting these baseline characteristics will facilitate the detection of future changes due to restoration.

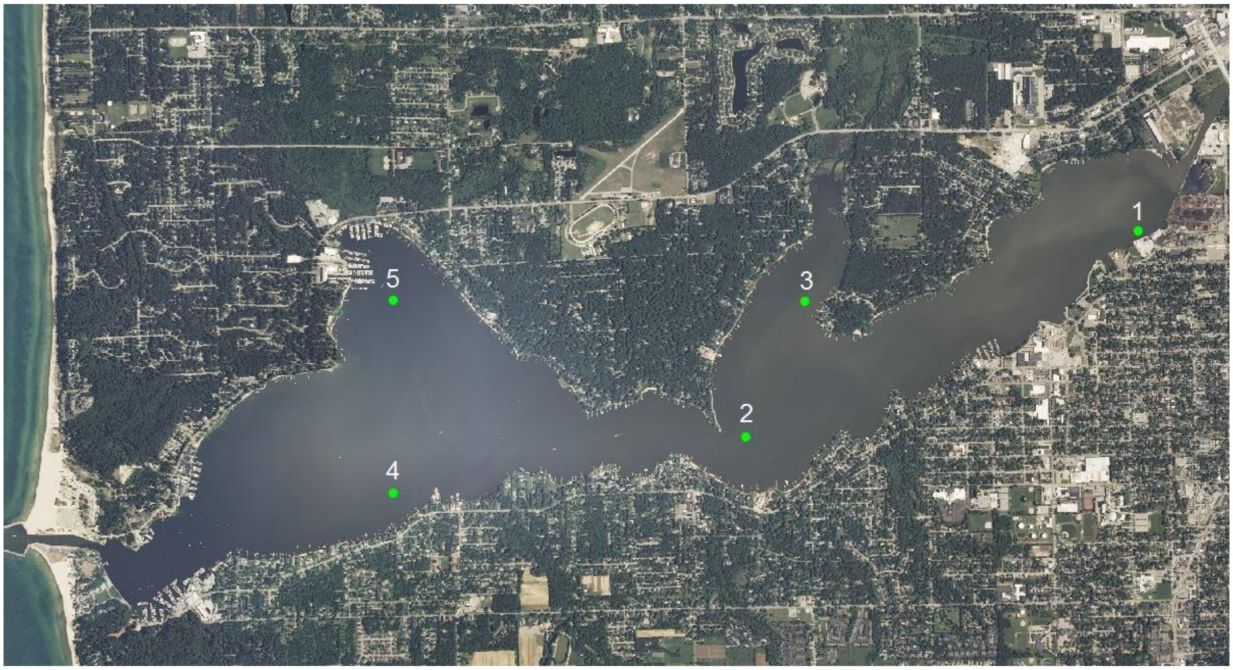


Figure 3. Map of Lake Macatawa showing the 5 sampling locations (green dots) for long-term water quality monitoring.

3. Results

3.1 Wetland Restoration: Middle Macatawa Property

General water quality parameters measured during the 2014 monitoring period reflect degraded water quality conditions and the effects of storm events at the Middle Macatawa sampling locations. In-stream concentrations of dissolved oxygen (DO) were high (i.e., good) during baseflow, but fell to the 5-6 mg/L range at most sites during storms (Table 2). DO concentrations < 5 mg/L are indicative of impaired water quality and can be harmful to aquatic life. Average specific conductance was greater than 600 µS/cm at all sites during baseflow, reflecting human-induced stress in the system (Table 2). Specific conductance and total dissolved solids (TDS), which is derived from specific conductance, were both lower during storms than baseflow (Table 2); this is expected due to dilution effects associated with rainwater's low conductivity. Average water temperature was 2-3 °C higher during storms than during baseflow (Table 2). Although this difference may be inflated due to a greater proportion of storms occurring during warmer months, the raw data generally show a 1-2 °C increase in water temperature during storms when compared to contiguous baseflow measurements.

Turbidity measurements provide an indication of sediment levels in the system. Elevated turbidity (> 10 NTU) was not uncommon during baseflow, while storm flow turbidity exceeded 250 NTU during the 15 October 2014 storm. Average turbidity was ~10-20 × higher during storms than baseflow (Table 2), but high variability and a low sample number (n=2 for storms) resulted in statistical significance in baseflow vs. storm flow turbidity only at the Macatawa Up and Macatawa Down (USGS) sites.

There were no statistically significant upstream-downstream differences in general water quality parameters during baseflow or storm conditions, with the exception of lower turbidity at the Macatawa Down (Adams) site than at the Macatawa Up site during baseflow ($p < 0.05$) (Table 2).

Similar to general water quality parameters, nutrient (N and P) concentrations also reflect degraded water quality conditions and the effects of storm events at the Middle Macatawa property. Average TP concentrations during baseflow conditions were greater than 100 µg/L in the Macatawa River and at all sites were significantly higher during storms ($p < 0.05$), when TP concentrations increased by ~5-8 × (Table 3; Figure 4). SRP concentrations also increased dramatically and significantly during storms (Table 3; Figure 4), although this increase was not significant at the Macatawa Down (Adams) site. Increased TP and SRP concentrations were observed during all monitored storms, with the exception of the 23 July 2014 storm, which had the shortest rainfall duration (Table 1; Figure 4). The TP and SRP increase during storms was most pronounced during the 15 October 2014 storm, which was the storm with the greatest rainfall total (Table 1; Figure 4). TP concentrations in the Macatawa River and Peter's Creek exceeded the 50 µg/L interim TMDL target for Lake Macatawa by ~2 × during baseflow and by 12-17 × during storms (Table 3), reaching as high as 1,700 µg/L in the Macatawa River (Figure 4B). No upstream-downstream differences in P concentrations emerged during the 2014 monitoring period (Table 3; Figure 4).

Nitrogen concentrations also were high at the Middle Macatawa property during the 2014 monitoring period (Table 3; Figure 6). The natural level of nitrate in surface water is typically low (less than 1 mg/L); excess nitrates 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. Average nitrate concentrations exceeded 3 mg/L in Peter's Creek and the Macatawa River during both baseflow and storms (Table 3). Peter's Creek had significantly greater nitrate than the Macatawa River sites during both baseflow and storms ($p < 0.05$), with concentrations above or approaching 10 mg/L during all but the spring baseflow events and the 15 October 2014 storm (Figure 6A). Average nitrate concentrations were greater at the Macatawa River downstream sites than at the Macatawa Up site (Table 3), suggesting an impact from Peter's Creek, but the difference was statistically significant only at the Macatawa Down (Adams) site ($p < 0.005$).

Ammonia levels of 0.1 mg/L usually indicate polluted surface waters, whereas concentrations > 0.2 mg/L can be toxic for some aquatic animals (Cech 2003). All ammonia concentrations measured at the Middle Macatawa sites were ≥ 0.1 mg/L and most were ≥ 0.2 mg/L (Figure 6B). Ammonia and TKN were very high (> 8 mg/L) in Peter's Creek during the 4 November 2014 baseflow sampling event, with concentrations ~10 × greater than other sampling dates, producing high variability in average concentrations at Middle Macatawa sites (excluding Macatawa Up) during baseflow and increased concentrations downstream (Table 3; Figure 6B,C). There were no statistically significant upstream-downstream differences in ammonia or TKN concentrations at the Middle Macatawa sites.

Nitrogen concentrations were influenced by high flow conditions, but not to the degree that was observed in P concentrations (Table 3). Ammonia and TKN were significantly higher during storms than during baseflow at the Macatawa Up site ($p < 0.05$) (Table 3); although the other sites also had increased TKN during storms, the differences from baseflow were not statistically significant (Figure 6C). There was evidence for increased nitrate with high flow only during the 12 June 2014 storm (Figure 6A).

3.2 Wetland Restoration: Haworth Property

General water quality parameters measured in the North Branch at the Haworth property showed impacts similar to those observed at the Middle Macatawa property. Storm events resulted in decreased DO concentrations and increased water temperatures (Table 2). Average specific conductance was greater than 850 µS/cm during baseflow, but decreased during storms due to dilution from rainwater (Table 2). Average turbidity was low (<7 NTU) at both Haworth sites during baseflow, but increased significantly during storms at both sites ($p < 0.05$), with average values greater than 60 NTU (Table 2). There were no statistically significant upstream-downstream differences in turbidity at the Haworth site.

Phosphorus concentrations in the North Branch at the Haworth property were indicative of a moderately nutrient-enriched system, with average baseflow TP concentrations of ~ 50 µg/L (Table 3). TP concentrations were significantly higher at the upstream than downstream site during baseflow ($p < 0.05$) (Table 3). Only the 15 October 2014 storm, which was the storm with the greatest rainfall total, elicited an increase in TP concentration; this increase was 7-10 ×

greater than average baseflow concentrations (Figure 5B). SRP concentrations were < 40 µg/L at the Haworth sites throughout the monitoring period, with the exception of the 15 October 2014 storm, when concentrations were greater than 120 µg/L (Figure 5A). There were no statistically significant differences in baseflow vs. storm flow P concentrations at either Haworth site.

Nitrogen enrichment less apparent at the Haworth property than at the Middle Macatawa property. Average nitrate concentrations were moderate (1 to 1.5 mg/L) during baseflow (Table 3). In contrast to the Middle Macatawa sites, nitrate at the Haworth sites was lower during storms than during baseflow (Table 3), but this difference was statistically significant only at the upstream site ($p < 0.05$). Average ammonia concentrations were low (≤ 0.06 mg/L) (Table 3), but did exceed 0.1 mg/L in June 2014 during baseflow and a storm (Figure 7B). TKN was the only nitrogen species that responded positively to flow, but this occurred only during the 15 October 2014 storm event (highest rainfall) (Figure 7C). The only statistically significant upstream-downstream difference in N concentrations was found for nitrate, which was greater at the upstream site than at the downstream site ($p < 0.001$) (Table 3).

Table 1. Precipitation summary for storm events monitored in 2014.

	Storm Event			
	6/12/14	**6/18/14**	**7/23/14**	**10/15/14**
Rainfall (in)	0.47	0.80	0.76	1.09
Duration (h)	10.23	3.03	1.63	10.05
Intensity (in/h)	0.05	0.26	0.47	0.11

Table 2. Average and standard deviation of select general water quality parameters recorded at each of the monitoring stations during baseflow (n=8, except for Macatawa Down [Adams] where n=6) and storm conditions (n=2). Water quality during storms was measured during only 2 of the 4 storms that were monitored: 23 July 2014 and 15 October 2014.

				Temp (C)		DO (mg/L)		SpCond (µS/cm)		TDS (g/L)		Turbidity (NTU)	
Year	**Flow**	**Property**	**Site**	**Avg.**	**St. Dev.**	**Avg.**	**St. Dev.**	**Avg.**	**St. Dev.**	**Avg.**	**St. Dev.**	**Avg.**	**St. Dev.**
2014	Base	Haworth	North Up	14.60	4.40	10.25	3.98	855	159	0.555	0.103	6.4	3.1
			North Down	14.38	4.62	9.48	3.19	881	184	0.573	0.120	6.4	2.8
		Middle Macatawa	Macatawa Up	14.15	5.18	9.23	2.06	683	170	0.444	0.110	16.4	15.5
			Peter's Creek (Up)	14.18	5.34	9.10	1.95	733	115	0.477	0.075	11.4	5.5
			Macatawa Down (USGS)	14.12	5.27	9.24	1.74	717	74	0.466	0.048	9.7	5.6
			Macatawa Down (Adams)	15.91	4.49	7.75	1.40	752	50	0.489	0.032	8.0	6.7
	Storm	Haworth	North Up	16.90	3.54	6.49	0.74	513	347	0.333	0.226	77.0	90.0
			North Down	16.99	3.54	6.55	0.89	536	158	0.348	0.103	65.0	74.2
		Middle Macatawa	Macatawa Up	17.71	4.55	5.89	0.06	519	228	0.338	0.148	183.0	142.0
			Peter's Creek (Up)	17.00	3.75	7.49	0.81	460	201	0.299	0.130	141.6	182.5
			Macatawa Down (USGS)	17.41	4.37	6.49	0.40	533	254	0.347	0.165	194.2	147.3
			Macatawa Down (Adams)	17.61	4.66	6.40	0.16	511	215	0.332	0.140	182.6	229.0

Table 3. Average and standard deviation of nutrient concentrations measured at each of the monitoring stations during baseflow (n=8, except for Macatawa Down [Adams] where n=6) and storm (n=4) events.

				TP (µg/L)		SRP (µg/L)		NO_3 (mg/L)		NH_3 (mg/L)		TKN (mg/L)	
Year	**Flow**	**Property**	**Site**	**Avg.**	**St. Dev.**	**Avg.**	**St. Dev.**	**Avg.**	**St. Dev.**	**Avg.**	**St. Dev.**	**Avg.**	**St. Dev.**
2014	Base	Haworth	North Up	54	21	19	13	1.58	0.41	0.06	0.04	0.80	0.13
			North Down	49	20	17	13	1.20	0.36	0.05	0.04	0.75	0.12
		Middle Macatawa	Macatawa Up	109	44	31	17	3.34	2.68	0.31	0.17	1.29	0.30
			Peter's Creek (Up)	84	39	27	19	8.21	2.51	1.27	3.05	2.21	3.24
			Macatawa Down (USGS)	106	27	40	24	4.90	1.41	0.60	1.08	1.62	1.10
			Macatawa Down (Adams)	113	26	51	25	5.43	1.38	0.65	1.16	1.67	1.28
	Storm	Haworth	North Up	193	240	60	71	0.79	0.56	0.06	0.05	1.20	0.82
			North Down	133	152	44	53	0.90	0.28	0.06	0.05	1.19	0.73
		Middle Macatawa	Macatawa Up	855	651	337	375	5.93	4.96	0.72	0.47	4.33	1.97
			Peter's Creek (Up)	685	453	254	261	10.28	6.14	0.49	0.39	3.45	1.96
			Macatawa Down (USGS)	625	458	271	284	5.79	5.63	0.46	0.29	2.59	1.09
			Macatawa Down (Adams)	583	519	241	238	5.85	5.19	0.45	0.32	2.87	1.52

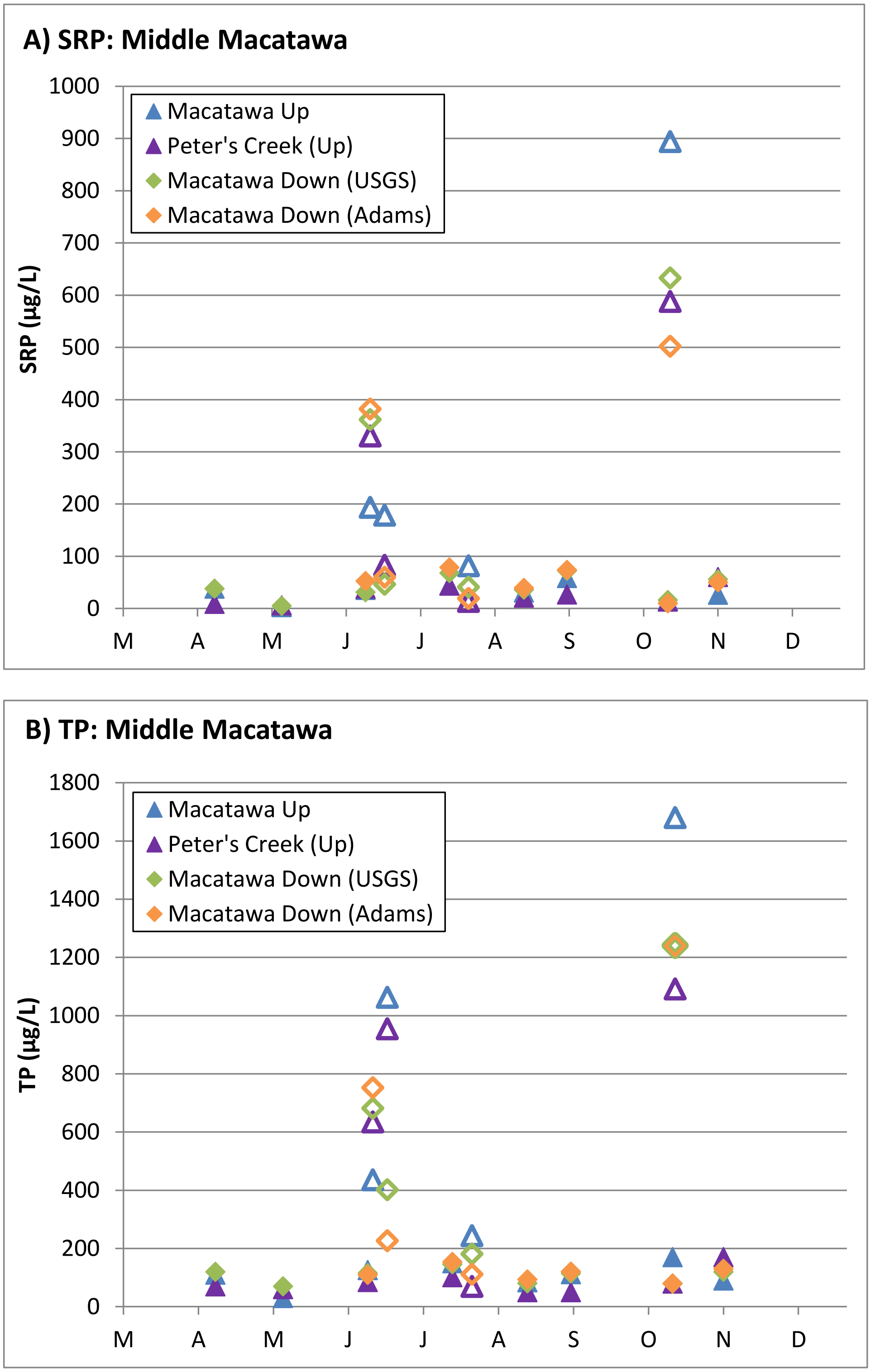


Figure 4. Soluble reactive phosphorus (SRP) (A) and total phosphorus (TP) (B) concentrations measured at the Middle Macatawa property from April through November 2014. Filled symbols represent baseflow conditions, open symbols represent storm conditions.

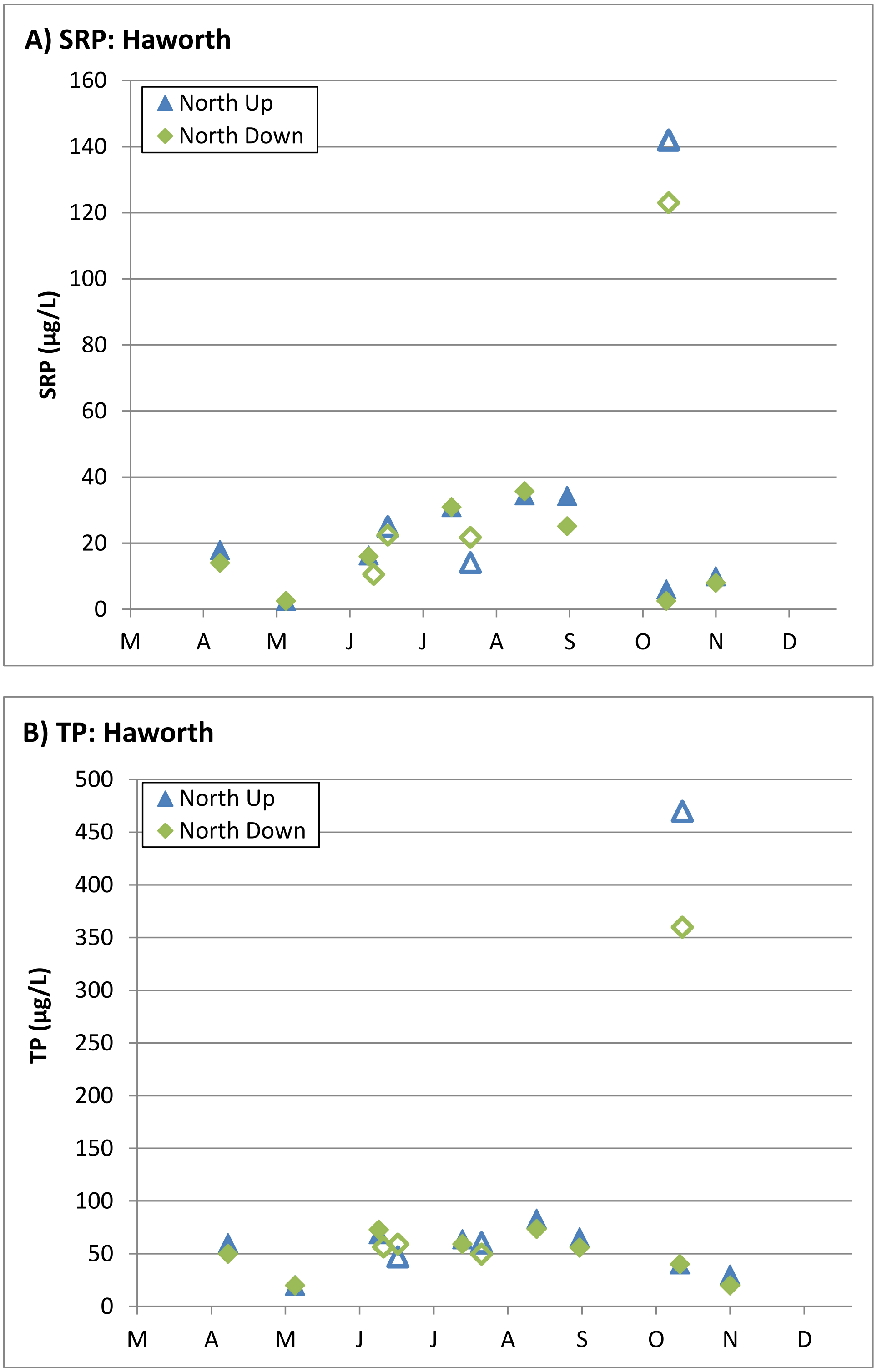
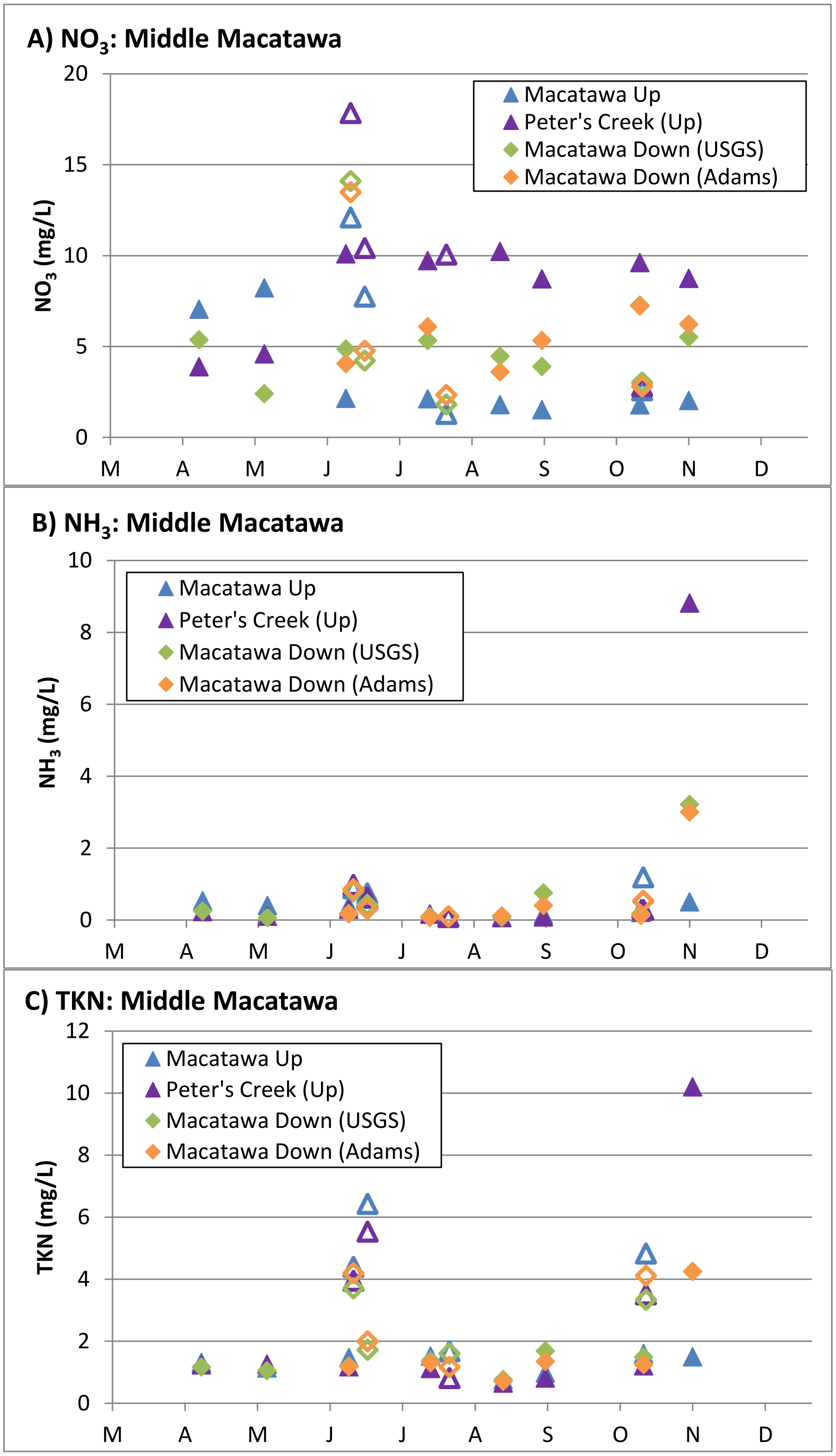


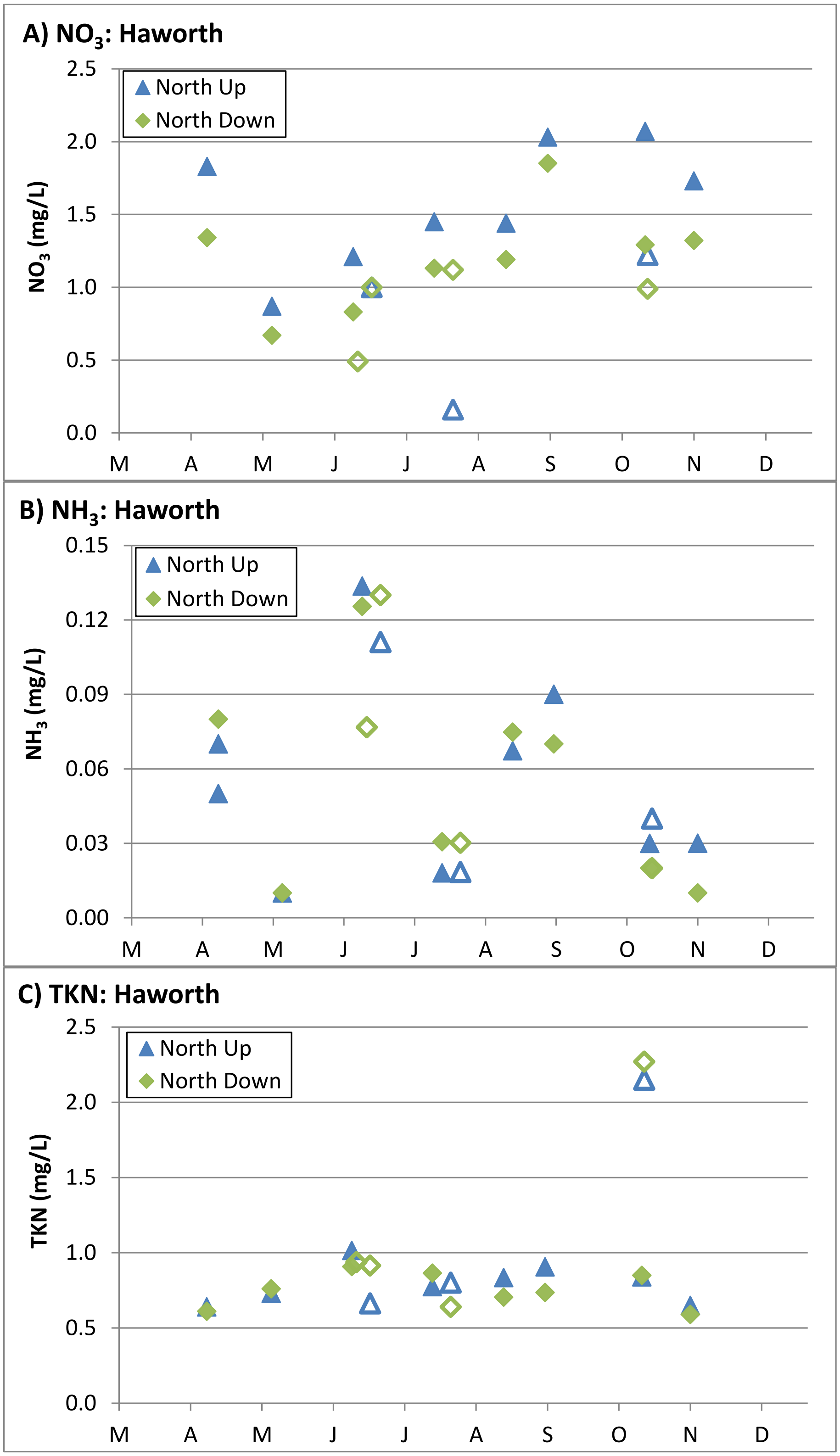
Figure 5. Soluble reactive phosphorus (SRP) (A) and total phosphorus (TP) (B) concentrations measured at the Haworth property from April through November 2014. Filled symbols represent baseflow conditions, open symbols represent storm conditions.


A) NO_3: Middle Macatawa

B) NH_3: Middle Macatawa

C) TKN: Middle Macatawa

Figure 6. Nitrate (NO_3) (A), ammonia (NH_3) (B), and total Kjeldahl nitrogen (TKN) (C) concentrations measured at the Middle Macatawa property from April through November 2014. Filled symbols represent baseflow conditions, open symbols represent storm conditions.


A) NO_3: Haworth

B) NH_3: Haworth

C) TKN: Haworth

Figure 7. Nitrate (NO_3) (A), ammonia (NH_3) (B), and total Kjeldahl nitrogen (TKN) (C) concentrations measured at the Haworth property from April through November 2014. Filled symbols represent baseflow conditions, open symbols represent storm conditions.

3.3 Lake Macatawa: Long-Term Monitoring

Seasonal water column mixing and stratification was evident from temperature and DO data. The water column was well-mixed (i.e., consistent temperature and DO with depth) during spring and fall monitoring events (Table 5). Thermal stratification was evident during the summer sampling in 2013 and 2014, with colder water temperatures at the near-bottom (Table 5). Hypolimnetic (i.e., deep-water) hypoxia was measured at all sites during summer 2013, but only at the two deepest sites (Sites 1 and 4; Table 4) during summer 2014 (Table 5).

Specific conductance was ≥ 600 µS/cm at sites 1, 2, and 3 during spring and summer 2014, but lakewide averages were ≥ 600 µS/cm only during spring 2014 (Table 5). As stated above, specific conductance values ≥ 600 µS/cm indicate human-induced stress in the system. Average turbidity values were elevated during all monitoring events in 2013 and 2014, with the highest values in the fall and the lowest in the spring (Table 5). The high turbidity was reflected in low water transparency, measured as Secchi disk depth, which ranged from 0.3 to 0.5 m throughout the monitoring period (Table 5). Secchi depths less than 1 m are characteristic of hypereutrophic lakes (Fuller and Minnerick 2008).

Total phosphorus concentrations were high during all monitoring events, with all samples equal to or exceeding the 50 µg/L interim TMDL target for Lake Macatawa; the only samples equal to the 50 µg/L target concentration were taken at sites 4 and 5 (surface) during spring 2014 (Figure 8C). Lakewide average TP concentrations were the greatest in summer 2013 and fall 2014 (160 to 180 µg/L) (Table 6). Site 1 had exceptionally high TP concentrations during those seasons, exceeding 250 µg/L at the water surface (Figure 8C). SRP was also very high at sites 1 and 2 during fall 2014, when concentrations were greater than 100 µg/L (Figure 8A, B). Phosphorus concentrations were frequently greater in near-bottom samples than in surface samples, suggesting possible P release from the sediments (i.e., internal P loading) (Figure 8A, B, C, D).

Chlorophyll *a* concentrations were also high during all monitoring events. During all seasons and at both sampling depths, lakewide average chlorophyll *a* exceeded the 22 µg/L hypereutrophic threshold commonly used by MDEQ in its assessments of Lake Macatawa (Holden 2014) (Table 6). Only 1 surface sample and 4 near-bottom samples were below this threshold during the monitoring period (Figure 8E, F). Similar to TP, excessively high chlorophyll *a* (> 200 µg/L) was measured at site 1 during summer 2013 (Figure 8E).

Table 4. Location and water column depth at Lake Macatawa long-term monitoring locations.

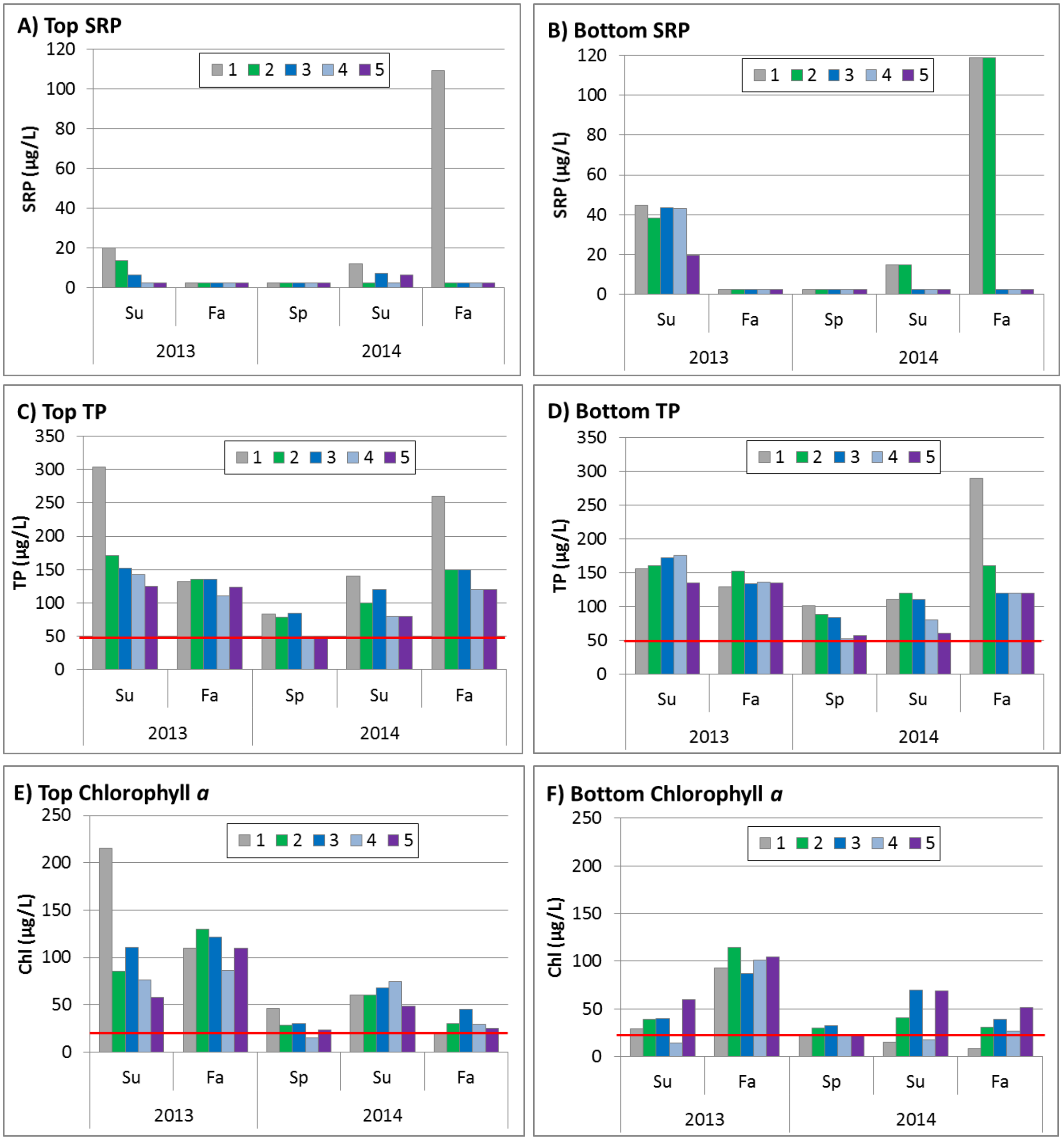
Site	Latitude	Longitude	Depth (m)
1	42.7912	-86.1195	7.5
2	42.7788	-86.1525	4.8
3	42.7871	-86.1474	3.2
4	42.7755	-86.1821	9.7
5	42.7875	-86.1820	4.0

Table 5. Lakewide average and standard deviation (n=5) of select general water quality parameters recorded during 2013 and 2014 monitoring events.

			Temperature (C)		DO (mg/L)		pH		SpCond (µS/cm)		ORP (mV)		TDS (g/L)		Turbidity (NTU)	
Year	**Season**	**Depth**	**Avg.**	**St. Dev.**	**Avg.**	**St. Dev.**	**Avg.**	**St. Dev.**	**Avg.**	**St. Dev.**	**Avg.**	**St. Dev.**	**Avg.**	**St. Dev.**	**Avg.**	**St. Dev.**
2013	Summer [8/1/13]	Top	21.32	0.49	10.72	2.21	8.42	0.47	473	64	382	40	0.31	0.04	22.1	1.8
		Mid	20.05	1.41	5.67	1.72	7.80	0.33	461	72	386	39	0.30	0.05	19.4	3.0
		Bottom	17.93	1.83	0.98	0.67	7.38	0.15	399	28	354	13	0.26	0.02	34.0	9.8
	Fall [10/15/13]	Top	16.20	0.31	9.80	0.78	8.38	0.37	491	68	406	9	0.32	0.04	26.0	2.8
		Mid	16.15	0.32	9.13	0.75	8.31	0.34	496	66	406	9	0.32	0.04	27.9	2.2
		Bottom	16.01	0.44	8.69	0.60	8.25	0.33	499	69	405	9	0.32	0.05	33.3	5.1
2014	Spring [5/8/14]	Top	12.54	0.84	11.67	0.47	8.54	0.16	605	107	395	30	0.39	0.07	13.4	1.9
		Mid	12.25	0.97	11.52	0.49	8.47	0.18	610	110	396	30	0.40	0.07	14.4	2.7
		Bottom	12.07	0.91	11.10	0.64	8.38	0.23	613	114	390	25	0.40	0.07	19.6	6.3
	Summer [7/29/14]	Top	21.56	1.65	10.15	1.78	8.27	0.47	562	100	352	16	0.37	0.06	17.5	2.6
		Mid	20.75	2.08	8.34	1.70	8.10	0.40	547	107	355	16	0.36	0.07	17.3	2.7
		Bottom	17.89	3.68	4.63	3.83	7.72	0.54	471	82	335	44	0.31	0.05	19.0	6.5
	Fall [10/7/14]	Top	13.36	0.37	9.31	0.75	8.12	0.23	530	52	367	18	0.34	0.03	29.1	5.3
		Mid	13.30	0.36	9.13	0.82	8.06	0.28	529	54	370	18	0.34	0.04	29.6	5.3
		Bottom	13.06	0.75	8.91	1.15	8.00	0.39	536	67	368	14	0.35	0.04	31.3	4.0

Table 6. Lakewide average and standard deviation (n=5) of nutrient concentrations, chlorophyll *a*, and Secchi depths measured during 2013 and 2014. Grand means (all sites and seasons pooled) were calculated for 2014 only.

			SRP (µg/L)		TP (µg/L)		Chl (µg/L)		Secchi depth (m)	
Year	**Season**	**Depth**	**Avg.**	**St. Dev.**	**Avg.**	**St. Dev.**	**Avg.**	**St. Dev.**	**Avg.**	**St. Dev.**
2013	Summer [8/1/13]	Top	9	8	178	70	108.95	62.33	0.30	0.00
		Bottom	38	10	162	15	36.43	16.72		
	Fall [10/15/13]	Top	3	0	128	13	111.32	16.38	0.30	0.00
		Bottom	3	0	136	9	99.81	10.48		
2014	Spring [5/8/14]	Top	3	0	68	16	28.50	11.37	0.50	0.10
		Bottom	3	0	76	21	25.64	4.76		
	Summer [7/29/14]	Top	6	4	104	26	62.25	9.87	0.40	0.10
		Bottom	5	5	96	25	42.10	26.51		
	Fall [10/17/14]	Top	24	48	160	58	29.97	9.28	0.40	0.00
		Bottom	26	52	162	74	31.10	15.91		
	Grand Mean	Top	11	27	111	53	40.24	18.69	0.45	0.08
		Bottom	11	30	111	57	32.95	18.16		


A) Top SRP

B) Bottom SRP

C) Top TP

D) Bottom TP

E) Top Chlorophyll *a*

F) Bottom Chlorophyll *a*

Figure 8. Phosphorus (soluble reactive phosphorus [SRP]: A, B; total phosphorus [TP]: C, D) and chlorophyll *a* (E, F) concentrations measured at the 5 monitoring stations in Lake Macatawa during 2013 and 2014. The red horizontal line on the TP figures (C, D) indicates the interim TMDL goal of 50 µg/L (Walterhouse 1999). The red horizontal line on the chlorophyll figures (E, F) indicates the hypereutrophic boundary of 22 µg/L used by MDEQ for assessing chlorophyll in Lake Macatawa (Holden 2014). Note scales change on y-axis of panels.

4. Summary

The results of the 2013-2014 monitoring effort confirmed what has been previously documented for Lake Macatawa and its watershed. Severely degraded conditions were observed in both the watershed and lake throughout the monitoring period.

MDEQ has reported a strong positive relationship between flow and TP concentrations in Macatawa watershed tributaries, with even minimal increases in flow resulting in substantial increases in TP concentration (Holden 2014). Tributary monitoring at the wetland restoration sites demonstrated the relationship between flow and degraded water quality, with storm events resulting in low dissolved oxygen, increased water temperature and nutrient concentrations, and very high turbidity. With TP concentrations climbing over 1,000 µg/L in the Macatawa River during storms, it is clear that the watershed is having a tremendous impact on Lake Macatawa during these episodic events. Indeed, modeled relationships by MDEQ revealed that flows > 100 cfs can cause TP concentrations to exceed 300 µg/L in Lake Macatawa (Holden 2014). High SRP concentrations in the Macatawa River during storms mean that a considerable fraction of the P entering Lake Macatawa is bioavailable and can be rapidly taken up by algae, often resulting in algal blooms.

Degraded baseflow conditions reflect the chronic human-induced stress that the system is experiencing. Nutrient concentrations and specific conductance were both consistently high during baseflow, with TP averaging more than 100 µg/L in the Macatawa River. Nitrogen was perhaps an even greater concern during baseflow, with extremely high concentrations originating in Peter's Creek leading to high concentrations in the Macatawa River downstream of the confluence. Although nutrient reduction efforts are focused on phosphorus, there is evidence for co-limitation of algal growth by both nitrogen and phosphorus in Lake Macatawa during summer and fall (Holden 2014). Co-limitation of algae by nitrogen and phosphorus is gaining greater recognition in water bodies throughout the world (Conley et al. 2009). Thus, the high nitrogen concentrations in Peter's Creek warrant future monitoring and consideration. There were no other site-specific trends observed in the tributary data that may influence future restoration evaluation.

MDEQ has been monitoring Lake Macatawa regularly (every 1-2 years) since 1996 to assess progress toward achieving the phosphorus TMDL target. They have consistently documented hypereutrophic conditions, including excessively high TP and chlorophyll concentrations, low DO, high turbidity, and shallow Secchi depths (Holden 2014). The 2013-2014 long-term monitoring results support MDEQ's findings. As noted also by MDEQ, the eastern basin (i.e., site 1) is more highly degraded than the rest of the lake, reflecting the localized negative impact of the Macatawa River (Holden 2014). The periodic increased P concentrations in near-bottom samples point to intermittent internal P loading from the sediments. However, given the excessive P loads entering the lake from Lake Macatawa, the external loads of P need to be controlled prior to considering any in-lake P mitigation.

These pre-restoration baseline conditions underscore the dire need for remediation in the Macatawa watershed. The magnitude of nutrient reduction that is necessary to satisfy the phosphorus TMDL and result in a healthy Lake Macatawa will require long-term and sustainable dedication, coordination, and cooperation among stakeholders and professionals. The successful execution of Project Clarity is a major step toward realizing the goals for Lake Macatawa. Continued monitoring as part of the project will document progress along the way.

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6. References

APHA. 1992. Standard Methods for Examination of Water and Wastewater. 18th Edition. American Public Health Association.

Bhagat, Y. and C.R. Ruetz III. 2011. Temporal and fine-scale spatial variation in fish assemblage structure in a drowned river mouth system of Lake Michigan. Transactions of the American Fisheries Society 140: 1429-1440.

Cech, T.V. 2003. Principles of water resources. Wiley, New York, NY.

Chu, X. and A.D. Steinman. 2009. Combined event and continuous hydrologic modeling with HEC-HMS. ASCE Journal of Irrigation and Drainage Engineering 135: 119-124.

Conley, D.J., H.W. Paerl, R.W. Howarth, D.F. Boesch, S.P. Seitzinger, K.E. Havens, C. Lancelot, and G.E. Likens. 2009. Controlling eutrophication: nitrogen and phosphorus. Science 323: 1014-1015.

Fuller, L.M. and R.J. Minnerick. 2008. State and Regional Water-Quality Characteristics and Trophic Conditions of Michigan’s Inland Lakes, 2001-2005: U.S. Geological Survey Scientific Investigations Report 2008-5188, 58p.

Holden, S. 2014. Monthly water quality assessment of Lake Macatawa and its tributaries, April-September 2012. Michigan Department of Environmental Quality, Water Resources Division. MI/DEQ/WRD-14/005

MWP (Macatawa Watershed Project). 2012. Macatawa Watershed Management Plan. Macatawa Area Coordinating Council, Holland, Michigan.

Steinman, A.D., M. Ogdahl, R. Rediske, C.R. Ruetz III, B.A. Biddanda, and L. Nemeth. 2008. Current status and trends in Muskegon Lake, Michigan. Journal of Great Lakes Research 34: 169-188.

U.S. EPA. 1993. Methods for Chemical Analysis of Inorganic Substances in Environmental Samples. EPA-600/4-79R-93-020/100.

Walterhouse, M. 1999. Total Maximum Daily Load for Phosphorus in Lake Macatawa, January 20, 1999. MDEQ Submittal to U.S. Environmental Protection Agency.

APPENDIX A

Long-Term Fish Monitoring of Lake Macatawa: Results from Year 1

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Introduction

This study was initiated to provide critical information on littoral fish populations that will be used to evaluate the performance of watershed restoration activities that are part of Project Clarity. Although we do not expect the benefits of the restoration activities in the watershed to be expressed in Lake Macatawa immediately, establishing baseline conditions in Lake Macatawa will be critical for evaluating ecological change over time. In autumn 2014, we initiated a long-term monitoring effort of the littoral fish assemblage of Lake Macatawa. Our fish sampling plan for Lake Macatawa is similar to our ongoing, long-term (since 2003) monitoring effort in Muskegon Lake (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 assess how the lake is responding to watershed restoration activities. Our primary objective for this first year of sampling was to characterize the pre-restoration (baseline) littoral fish assemblage. We made preliminary comparisons with our ongoing work in Muskegon Lake (see Ruetz et al. 2007; Bhagat and Ruetz 2011) as well as with six Lake Michigan drowned river mouths for which we have data (see Janetski and Ruetz 2014). However, the true value of this fish monitoring effort will come in future years as we examine how the littoral fish assemblage responds 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. 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). Fish 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).

Fish sampling.—At each study site, we sampled fish via fyke netting and boat electrofishing. Fyke nets were set on 8 September 2014 during daylight hours (i.e., between 1030 and 1330) and fished for about 24.6 h (range = 24.2-24.9 h). 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 the other fyke net was set perpendicular to the shoreline following the protocol used by Bhagat and Ruetz (2011). A description of the design of the fyke nets is reported in Breen and Ruetz (2006). We conducted nighttime boat electrofishing at each site on 11 September 2014. A 10-min (pedal time) electrofishing transect was conducted parallel to the shoreline at each site with two people at the front of the boat to net fish. 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 preserved to confirm identifications in the laboratory. We also measured water quality variables (i.e., temperature, dissolved oxygen, specific conductivity, total dissolved solids, turbidity, pH, oxidation-reduction potential, and chlorophyll *a*) in the middle of the water column using a YSI 6600 multi-parameter data sonde. We made one measurement at each fyke net and one measurement at the beginning of each electrofishing transect. 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 estimated the percent macrophyte cover for the length of each electrofishing transect during fish sampling.

Results and Discussion

We characterized water quality variables at each site during fish sampling (Tables 2 & 3). The mean water depth where we set fyke nets was 86 cm (Table 2). Water temperature was slightly (~2.9 °C) warmer when we conducted fyke netting compared with boat electrofishing (Tables 2 & 3). We observed few aquatic macrophytes during fish sampling. During fyke netting, % cover of macrophytes was zero at every site except site #2, which was estimated to be 1% cover. Similarly, during electrofishing transects, we visually estimated % macrophyte cover to be near zero, with estimates of 5% cover at sites #2 and #4 (and zero at the other two sites). The lack of macrophytes is presumably because of insufficient light penetrating the water column to allow the submersed plants to grow; both turbidity from inflowing sediment and abundant phytoplankton growth in the lake water column can reduce light penetration. Given the importance of aquatic macrophytes as habitat for fish (e.g., Radomski and Goeman 2001), their return is an important goal for the restoration of natural fish communities in Lake Macatawa.

Compared to six Lake Michigan drowned river mouths, water quality in Lake Macatawa was most similar to Kalamazoo Lake, especially with respect to high turbidity and specific conductivity (Janetski and Ruetz 2014). Turbidity and specific conductivity were higher in Lake Macatawa than Muskegon Lake, the drowned river mouth lake that we have the longest time series of water quality observations (Bhagat and Ruetz 2011). High levels of turbidity and specific conductivity often are associated with relatively high anthropogenic disturbance in Great Lakes coastal wetlands (Uzarski et al. 2005). Thus, the water quality we measured in Lake Macatawa appears on the degraded side of the spectrum among Lake Michigan drowned river mouths (see Uzarski et al. 2005, Janetski and Ruetz 2014).

We captured 1,127 fish comprising 28 species[2] in Lake Macatawa (Table 4). The most abundant fishes in the combined catch of both gears (fyke netting and boat electrofishing) were gizzard shad (39%), white perch (15%), yellow perch (9%), and spottail shiner (8%), which composed 71% of the total catch (Figure 2A). Gizzard shad—the most abundant species in our catch—is an important forage fish (especially smaller individuals), and high turbidity is one of the conditions associated with optimal habitat of this species (Becker 1983). Three of the 28 species we captured were non-native to the Great Lakes basin (Bailey et al. 2004)—alewife (2%), round goby (5%), and white perch (15%)—which composed 22% of the total catch (Table 4). More than twice as many individuals were captured in fyke netting than boat electrofishing (Table 4). Similarly, more fish species were captured in fyke netting (23 species) than boat electrofishing (19 species). Nine fish species were collected only by fyke netting, and five species were collected only by boat electrofishing. Thus, using both sampling gears provided a better characterization of the littoral fish assemblage of Lake Macatawa than either gear by itself. This finding was consistent with research in Muskegon Lake that found a similar pattern where small-bodied fishes were better represented in fyke netting and large-bodied fishes were better represented in nighttime boat electrofishing (Ruetz et al. 2007).

In fyke netting, gizzard shad (56%), white perch (10%), round goby (6%), and spottail shiner (6%) were the most abundant fishes captured, which composed nearly 78% of the total fish captured (Figure 2B). Janetski and Ruetz (2014) found that gizzard shad was associated with high turbidity among six drowned river mouths and was most abundant in Kalamazoo Lake, which is the drowned river mouth that had the most similar water quality to Lake Macatawa. In Muskegon Lake, both gizzard shad and white perch were associated with autumn sampling (as

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[2] We did not include the unknown species of sunfish captured during boat electrofishing in any of our reports of species richness (see Table 4).

opposed to spring or summer; Bhagat and Ruetz 2011), which corresponded to the time of our sampling in Lake Macatawa. Although gizzard shad was most abundant at each site, the next most abundant species varied among sites, with white perch being the next most abundant at site #1, bluegill at site #2, alewife at site #3, and round goby at site #4 (Table 5). There was variation in total catch among the sites, with site #4 having the highest catch and site #2 having the lowest catch (Table 5). As we continue our monitoring of Lake Macatawa, we will be able to assess whether these spatial patterns among sites are stable or dynamic over time.

In boat electrofishing, the most abundant fishes captured were white perch (27%), yellow perch (21%), pumpkinseed (12%), and spottail shiner (12%), which composed 71% of the total catch (Figure 2C). The fish assemblage was not dominated by a single fish species at every site in contrast to what was observed in the fyke netting. White perch was the most abundant species in the catch at sites #1 and #2, whereas spottail shiner was most abundant at site #3 and spottail shiner and yellow perch were most abundant at site #4 (Table 6). Total catch varied among sites, with the most fish captured at site #2 and the least at site #3 (Table 6). Finally, there was not a positive association in total catch across sites between the two gears (Tables 5 & 6).

In conclusion, the observations reported here provide the first year of a 5 year effort to characterize the littoral fish assemblage of Lake Macatawa. This monitoring effort will provide a baseline to assess how the fish assemblage responds to restoration activities in the Lake Macatawa watershed. Once we accumulate multiple years of observations, we will be able to make more robust inferences about the littoral fish assemblage of Lake Macatawa (both in terms of assessing the baseline and change over time) as well as how the assemblage compares with other drowned river mouth lakes in the region.

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References

Bailey, R.M., W.C. Latta, and G.R. Smith. 2004. An atlas of Michigan fishes with keys and illustrations for their identification. Miscellaneous Publications, Museum of Zoology, University of Michigan, No. 192.

Becker, G.C. 1983. Fishes of Wisconsin. University of Wisconsin Press, Madison.

Bhagat, Y., and C.R. Ruetz III. 2011. Temporal and fine-scale spatial variation in fish assemblage structure in a drowned river mouth system of Lake Michigan. Transactions of the American Fisheries Society 140:1429-1440.

Breen, M.J., and C.R. Ruetz III. 2006. Gear bias in fyke netting: evaluating soak time, fish density, and predators. North American Journal of Fisheries Management 26:32-41.

Janetski, D.J., and C.R. Ruetz III. 2014. Spatiotemporal patterns of fish community composition in Great Lakes drowned river mouths. Ecology of Freshwater Fish doi: 10.1111/eff.12161.

Michigan Department of Natural Resources (MDNR). 2011. Lake Macatawa Ottawa County. Fish Collection System (printed 6/11/2011). Accessed at http://www.the-macc.org/wp-content/uploads/History-of-Lake-Mactawa-and-Fish.pdf (on 12/1/2014).

Radomski, P., and T.J. Goeman. 2001. Consequences of human lakeshore development on emergent and floating-leaf vegetation abundance. North American Journal of Fisheries Management 21:46-61.

Ruetz, C.R., III, D.G. Uzarski, D.M. Krueger, and E.S. Rutherford. 2007. Sampling a littoral fish assemblage: comparing small-mesh fyke netting and boat electrofishing. North American Journal of Fisheries Management 27:825-831.

Uzarski, D.G., T.M. Burton, M.J. Cooper, J.W. Ingram, and S.T.A. Timmermans. 2005. Fish habitat use within and across wetland classes in coastal wetlands of the five Great Lakes: development of a fish-based index of biotic integrity. Journal of Great Lakes Research 31(Suppl. 1):171-187.

Table 1. Locations (latitude and longitude) for each fish sampling site; coordinates are the mean of the three fyke nets and the start and end of each boat electrofishing transect.

	Fyke netting		Boat Electrofishing			
			Start		End	
Site	Lat (°)	Long (°)	Lat (°)	Long (°)	Lat (°)	Long (°)
1	42.79566	86.12238	42.79533	86.12370	42.79612	86.11992
2	42.78934	86.14403	42.78811	86.14484	42.79020	86.14384
3	42.78639	86.17498	42.78535	86.17406	42.78721	86.17584
4	42.77973	86.19631	42.77896	86.19792	42.78045	86.19536

Table 2. Mean ± 1 standard error (*n* =3) of water quality variables at fish sampling sites in Lake Macatawa. Measurements were made during fyke netting on 8 September 2014. Site locations are depicted in Figure 1.

Site	Depth (cm)	Water Temperature (°C)	Dissolved Oxygen (mg/L)	% Dissolved Oxygen	Specific Conductivity (uS/cm)	Total Dissolved Solids (g/L)	Turbidity (NTU)	pH	Oxidation Reduction Potential	Chlorophyll *a* (ug/L)
1	89±1	24.15±0.02	10.69±0.07	127.5±0.9	591±1	0.385±0.000	23.9±1.8	8.19±0.01	323±4	36.3±3.3
2	97±1	24.51±0.06	15.09±0.33	181.1±3.9	503±0	0.327±0.000	25.3±3.1	9.06±0.01	286±5	35.4±7.3
3	79±1	23.26±0.03	13.76±0.18	161.4±2.1	432±0	0.281±0.000	24.6±0.8	9.18±0.01	303±1	17.4±0.6
4	79±2	23.87±0.02	12.61±0.17	149.5±2.0	416±0	0.270±0.000	19.0±0.1	9.11±0.01	242±6	11.4±0.6

Table 3. Water quality variables at fish sampling sites in Lake Macatawa. Measurements were made during nighttime boat electrofishing on 11 September 2014. Site locations are depicted in Figure 1.

Site	Water Temperature (°C)	Dissolved Oxygen (mg/L)	% Dissolved Oxygen	Specific Conductivity (uS/cm)	Total Dissolved Solids (g/L)	Turbidity (NTU)	pH	Oxidation Reduction Potential (mV)	Chlorophyll *a* (ug/L)
1	21.85	8.97	102.5	628	0.408	24.2	7.80	333	18.7
2	20.70	8.69	97.0	504	0.328	26.3	8.49	338	18.4
3	20.82	11.39	127.5	433	0.281	22.6	8.93	286	17.9
4	20.97	8.12	91.1	406	0.264	17.9	8.54	338	13.8

Table 4. Number and mean total length (TL; ranges reported parenthetically) of fish captured by fyke netting (*n* = 12 nets) on 9 September 2014 and boat electrofishing (*n* = 4 transects) on 11 September 2014 at four sites in Lake Macatawa.

		Total	Fyke netting		Electrofishing	
Common name	Scientific name	Catch	Catch	TL (cm)	Catch	TL (cm)
alewife	*Alosa pseudoharengus*	22	22	5.9 (3.3-10.0)	0	--
black bullhead	*Ameiurus melas*	1	1	2.6	0	--
yellow bullhead	*Ameiurus natalis*	1	1	25.0	0	--
bowfin	*Amia calva*	1	0	--	1	46.5
freshwater drum	*Aplodinotus grunniens*	2	0	--	2	15.3 (9.3-21.3)
quillback	*Carpiodes cyprinus*	2	1	12.9	1	29.5
white sucker	*Catostomus commersonii*	10	3	34.2 (21.1-40.9)	7	31.6 (18.5-46.5)
common carp	*Cyprinus carpio*	4	0	--	4	66.7 (61.2-74.0)
gizzard shad	*Dorosoma cepedianum*	445	433	8.6 (5.1-19.3)	12	11.2 (7.0-17.3)
northern pike	*Esox lucius*	1	1	84.0	0	--
banded killifish	*Fundulus diaphanus*	1	0	--	1	9.0
channel catfish	*Ictalurus punctatus*	4	4	52.6 (49.5-58.9)	0	--
brook silverside	*Labidesthes sicculus*	17	17	6.7 (5.4-7.8.8)	0	--
pumpkinseed	*Lepomis gibbosus*	57	15	15.6 (12.0-17.5)	42	13.8 (6.6-18.0)
bluegill	*Lepomis macrochirus*	42	34	4.4 (2.6-14.8)	8	13.4 (6.5-20.2)
unknown sunfish[1]	*Lepomis* spp.	1	0	--	1	17.1
longnose gar	*Lepisosteus osseus*	2	2	43.8 (40.5-47.0)	0	--
largemouth bass	*Micropterus salmoides*	30	10	15.7 (6.5-33.1)	20	18.3 (6.5-44.5)
white perch	*Morone americana*	174	78	11.5 (5.5-28.0)	96	10.6 (7.6-19.6)
golden redhorse	*Moxostoma erythrurum*	1	0	--	1	43.1
shorhead redhorse	*Moxostoma macrolepidotum*	1	1	42.4	0	--
round goby	*Neogobius melanostomus*	52	49	4.3 (2.5-8.0)	3	7.2 (6.9-7.5)
emerald shiner	*Notropis atherinoides*	23	9	8.6 (4.9-10.9)	14	9.5 (7.0-11.2)
golden shiner	*Notemigonus crysoleucas*	10	3	8.4 (4.1-11.3)	7	13.0 (8.8-21.5)
spottail shiner	*Notropis hudsonius*	86	44	7.8 (4.0-11.4)	42	10.0 (7.5-12.1)
yellow perch	*Perca flavescens*	97	23	11.7 (8.0-23.9)	74	10.4 (8.3-22.4)
bluntnose minnow	*Pimephales notatus*	19	15	6.9 (4.2-9.2.2)	4	8.1 (6.6-9.5)
black crappie	*Pomoxis nigromaculatus*	4	4	15.6 (5.3-24.5)	0	--
walleye	*Sander vitreus*	17	1	17.3	16	18.9 (16.0-22.5)
	Total	**1127**	**771**		**356**	

[1] Unknow sunfish was likely a hybrid between longear sunfish (*Lepomis megalotis*) and green sunfish (*L. cyanellus*).

Table 5. Number and mean total length (TL; range reported parenthetically) of fish captured by fyke netting (*n* = 3 nets per site) at four sites in Lake Macatawa on 9 September 2014. Site locations are depicted in Figure 1.

		Site #1		Site #2		Site #3		Site #4	
Common name	Scientific name	Catch	TL (cm)	Catch	TL (cm)	Catch	TL (cm)	Catch	TL (cm)
alewife	*Alosa pseudoharengus*	1	4.6	1	4.5	17	5.8 (3.3-10.0)	3	7.1 (4.9-9.5)
yellow bullhead	*Ameiurus natalis*	0	--	0	--	1	25.0	0	--
black bullhead	*Ameiurus melas*	0	--	1	2.6	0	--	0	--
quillback	*Carpiodes cyprinus*	0	--	1	12.9	0	--	0	--
white sucker	*Catostomus commersonii*	2	40.7 (40.5-40.9)	0	--	0	--	1	21.1
gizzard shad	*Dorosoma cepedianum*	139	8.6 (6.8-16.3)	28	9.7 (6.8-16.8)	106	9.2 (5.7-19.3)	160	8.0 (5.1-11.8)
northern pike	*Esox lucius*	0	--	0	--	0	--	1	84
channel catfish	*Ictalurus punctatus*	0	--	2	54.2 (49.5-58.9)	2	50.9 (50.3-51.5)	0	--
brook silverside	*Labidesthes sicculus*	1	7.8	0	--	7	6.5 (5.5-7.5)	9	6.7 (5.4-7.7)
pumpkinseed	*Lepomis gibbosus*	3	16.5 (15.5-17.5)	5	14.4 (12.0-16.8)	3	16.7 (16.5-17.1)	4	15.6 (13.5-17.2)
bluegill	*Lepomis macrochirus*	7	6.3 (2.9-14.8)	27	4.0 (2.6-11.4)	0	--	0	--
longnose gar	*Lepisosteus osseus*	2	43.8 (40.5-47.0)	0	--	0	--	0	--
largemouth bass	*Micropterus salmoides*	6	20.0 (7.8-33.1)	0	--	2	10.5 (7.9-13.0)	2	8.0 (6.5-9.5)
white perch	*Morone americana*	40	10.5 (7.5-19.3)	20	13.5 (5.5-28.0)	12	11.6 (5.5-21.9)	6	9.4 (7.4-13.6)
shorhead redhorse	*Moxostoma macrolepidotum*	0	--	1	42.4	0	--	0	--
round goby	*Neogobius melanostomus*	5	4.1 (2.5-8.0)	0	--	10	5.1 (4.0-7.1)	30	4.1 (2.9-6.0)
emerald shiner	*Notropis atherinoides*	2	5.2 (4.9-5.4)	1	9.6	4	9.7 (8.5-10.9)	2	9.3 (9.0-9.5)
golden shiner	*Notemigonus crysoleucas*	3	8.4 (4.1-11.3)	4	4.35 (3.4-6.0)	0	--	0	--
spottail shiner	*Notropis hudsonius*	1	11.4	8	8.1 (4.1-11.0)	9	9.2 (7.0-11.2)	26	7.1 (4.0-10.6)
yellow perch	*Perca flavescens*	8	14.0 (9.6-23.9)	0		3	16.6 (10.5-22.3)	12	8.9 (8.0-9.8)
bluntnose minnow	*Pimephales notatus*	2	7.7 (7.0-8.4)	7	6.6 (4.2-7.3)	1	6.0	5	7.0 (5.5-9.2)
black crappie	*Pomoxis nigromaculatus*	4	15.6 (5.3-24.5)	0	--	0	--	0	--
walleye	*Sander vitreus*	0	--	0	--	0	--	1	17.3
	Total	**226**		**106**		**177**		**262**	

Table 6. Number and mean total length (TL; range reported parenthetically) of fish captured by nighttime boat electrofishing (*n* = 1 transect per site) at four sites in Lake Macatawa on 11 September 2014. Site locations are depicted in Figure 1.

		Site #1		Site #2		Site #3		Site #4	
Common name	Scientific name	Catch	TL (cm)	Catch	TL (cm)	Catch	TL (cm)	Catch	TL (cm)
bowfin	*Amia calva*	0	--	0	--	0	--	1	46.5
freshwater drum	*Aplodinotus grunniens*	0	--	2	15.3 (9.3-21.3)	0	--	0	--
quillback	*Carpiodes cyprinus*	0	--	1	29.5	0	--	0	--
white sucker	*Catostomus commersonii*	0	--	1	27.0	2	44.7 (42.8-46.5)	4	26.3 (18.5-45.7)
common carp	*Cyprinus carpio*	0	--	2	64.1 (61.2-67.0)	0	--	1	74.0
gizzard shad	*Dorosoma cepedianum*	1	64.5	4	12 (11.0-13.2)	3	10.8 (7.0-16.3)	1	17.3
banded killifish	*Fundulus diaphanus*	4	9.2 (9.0-9.6)	0	--	1	9.0	0	--
pumpkinseed	*Lepomis gibbosus*	10	14.4 (10.8-17.5)	25	12.7 (6.6-15.9)	1	13.4	6	17.1 (16.2-18.0)
bluegill	*Lepomis macrochirus*	1	14.0	6	14.4 (12.7-20.2)	0	--	1	6.5
unknown sunfish[1]	*Lepomis* spp.	0	--	1	17.1	0	--	0	--
largemouth bass	*Micropterus salmoides*	2	17.7 (10.6-24.8)	7	20.4 (9.4-27.3)	4	21.8 (6.5-34.8)	7	14.3 (6.5-44.5)
white perch	*Morone americana*	43	10.2 (8.3-19.6)	41	11.4 (8.2-18.5)	6	8.3 (7.6-9.3)	6	11.4 (8.2-14.5)
golden redhorse	*Moxostoma erythrurum*	1	43.1	0	--	0	--	0	--
round goby	*Neogobius melanostomus*	0	--	0	--	0	--	3	7.2 (6.9-7.5)
emerald shiner	*Notropis atherinoides*	2	10.2 (10.0-10.3)	3	13.2 (10.2-19.0)	5	10.0 (9.0-11.2)	7	9.0 (7.0-10.2)
golden shiner	*Notemigonus crysoleucas*	1	11.1	0	--	1	21.5	2	9.4 (8.8-10.0)
spottail shiner	*Notropis hudsonius*	2	12.1	8	9.7 (8.2-12.1)	19	10.1 (7.5-22.4)	13	9.9 (8.0-11.9)
yellow perch	*Perca flavescens*	16	11.2 (9.3-18.1)	33	9.6 (8.3-11.2)	12	11.0 (9.1-22.4)	13	10.7 (8.5-18.0)
bluntnose minnow	*Pimephales notatus*	1	6.6	1	7	0	--	2	9.5 (9.4-9.5)
walleye	*Sander vitreus*	3	20.6 (17.2-22.5)	3	19.0 (18.7-19.2)	5	18.0 (16.8-20.5)	5	18.6 (16.0-21.0)
	Total	**87**		**138**		**59**		**72**	

[1] Unknow sunfish was likely a hybrid between longear sunfish (*Lepomis megalotis*) and green sunfish (*L. cyanellus*).

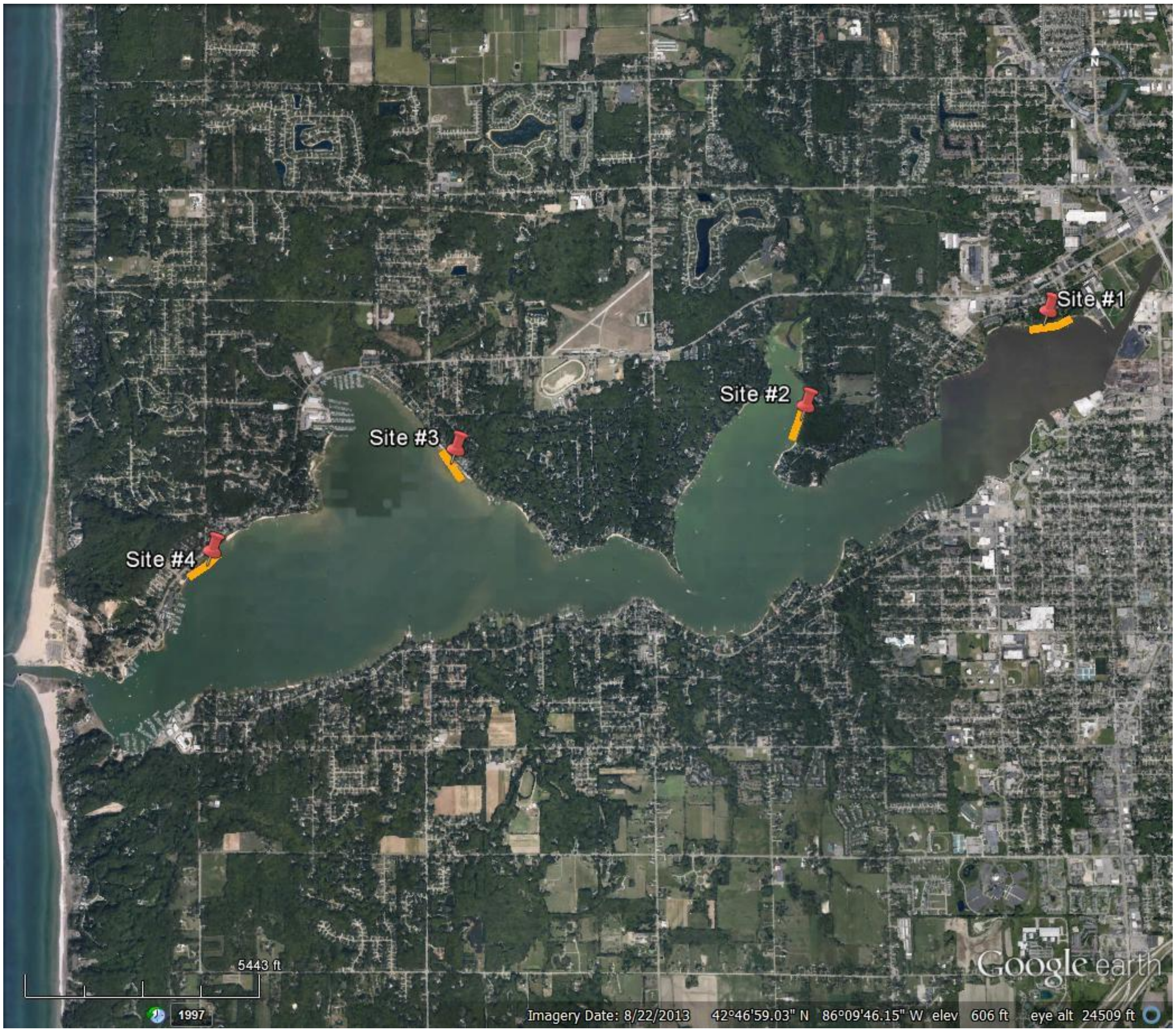

Figure 1. Map of Lake Macatawa (Ottawa County, Michigan) showing fish sampling sites. The orange transects depict where boat electrofishing was conducted at each site. Site #1 is closest to the Macatawa River and site #4 is closest to Lake Michigan.

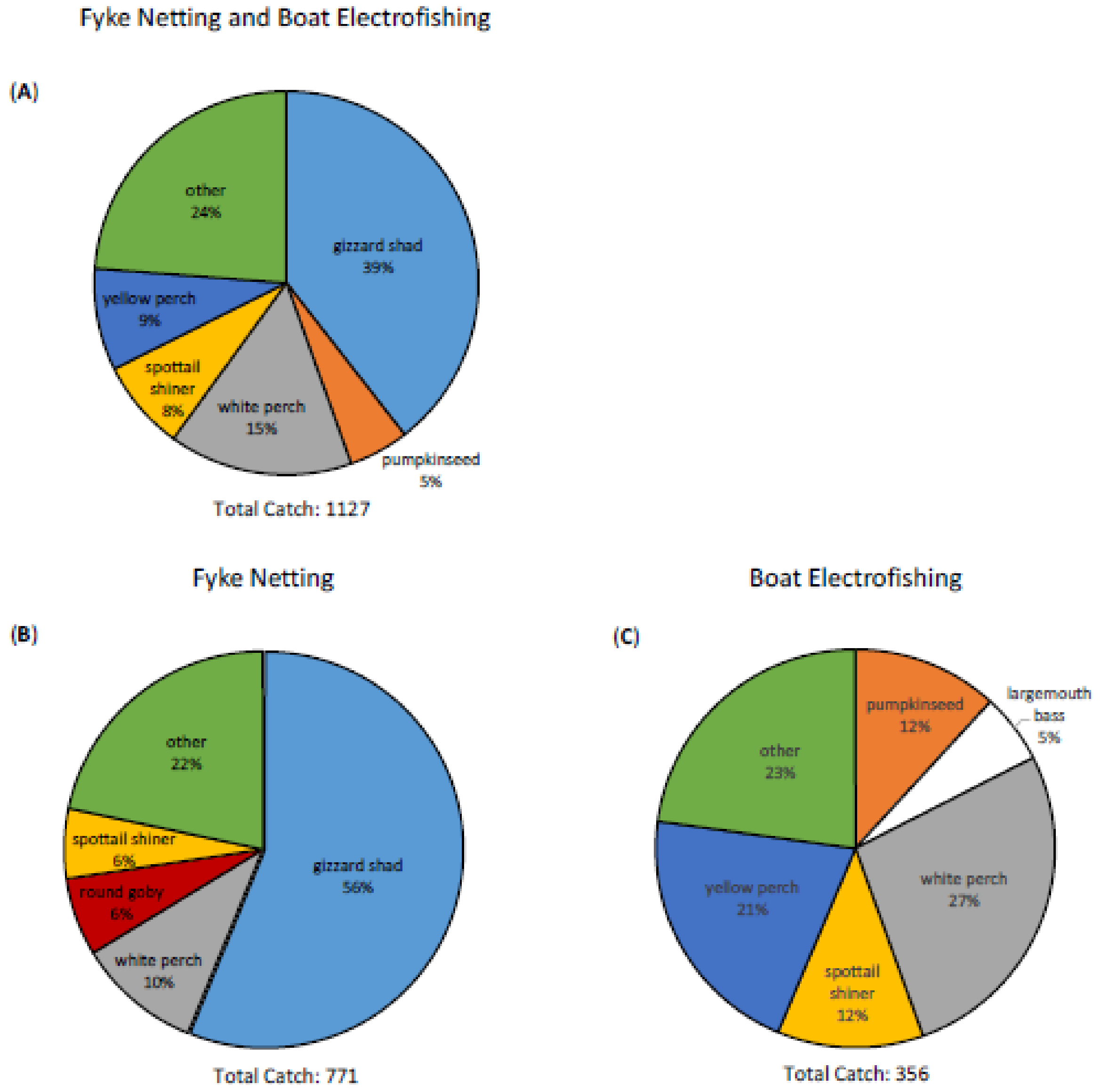

Figure 2. Fish species captured in littoral habitats of Lake Macatawa by (A) fyke netting and boat electrofishing (i.e., combined catch), (B) fyke netting (*n* = 12 nets), and (C) boat electrofishing (*n* = 4 transects) during September 2014. Catch data, including the species pooled in the "other" category, are reported in Table 4.