Muskegon River Veterans Memorial Park Fish and Wildlife Habitat Restoration Project Fisheries and Water Quality Monitoring

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Introduction

Muskegon Lake has a long history of industrial activity on its shoreline (Alexander 2006), and environmental impairment from these activities led to its listing as an Area of Concern (AOC) in 1985 (Carter et al. 2006, Steinman et al. 2008). In particular, shoreline alterations and the filling of shallow-water habitats resulted in the loss, degradation, and fragmentation of littoral and wetland habitats. The overall goal of this restoration project was to improve and reconnect shallow-water habitat by focusing restoration efforts on two ponds adjacent to the North Branch of the Muskegon River at Veterans Memorial Park in Muskegon County. Veterans Memorial Park is located at a site that was historically a wetland but now consists of a pond on the north and south sides of the Muskegon River, within a parkway at the east end of Muskegon Lake. Excavation and filling of the Muskegon River wetlands occurred in the early 1900s to establish the parkway and park. This construction resulted in the excavation of two ponds, the straightening of the river channel, and the filling of adjacent wetlands. In the late 1900s, installation of a water control structure reduced fish passage from the Muskegon River to the south pond and likely degraded its water quality.

The planned habitat restoration aims to improve habitat in both ponds and reconnect the river with the south pond. The main restoration activities included (1) removing a water-control structure that limited fish passage and water exchange between the south pond and the Muskegon River (i.e., the south pond had a direct connection to the Muskegon River post-restoration). (2) Improving the connection of the north pond to the Muskegon River. Although the north pond was connected to the Muskegon River prior to restoration, sediment was removed to improve fish passage. (3) *Typha* and other non-native invasive plants were removed from the shoreline of the north and south ponds. (4) Fish habitat structures were added to the north and south ponds.

The purpose of the associated monitoring effort was to provide pre- and post-restoration assessment of the fish community and water quality in response to habitat restoration at Veterans Memorial Park. In this report, we summarize the results of our pre-restoration monitoring that was conducted during autumn 2015 and post-restoration monitoring that was conducted during late-summer 2018. Habitat restoration was conducted in 2017-2018 and completed prior to post-restoration monitoring. Nevertheless, the post-restoration monitoring should be interpreted cautiously because it was completed shortly after habitat restoration and was conducted earlier in the year (August rather than October) than pre-restoration monitoring.

Methods

Study sites.—Veterans Memorial Park is located on the North Branch of the Muskegon River (Muskegon County, Michigan), which flows into Muskegon Lake and then Lake Michigan, and is located in the Muskegon Lake Area of Concern (Steinman et al. 2008). The park was created on property that was historically wetlands and contains a north pond and south pond (Figure 1). Fish and water quality sampling were conducted at 11 littoral sites in 2015 and 2018 (Table 1). Six sites were sampled at the south pond, three sites were sampled at the north pond, and two sites were sampled in Muskegon Lake near where the North Branch of the Muskegon River enters Muskegon Lake (Figure 1). A stratified random sampling approach was used on the south pond, where the south pond was broken into three main strata (strata #1, 2, and 3 in Figure 1), and a sampling site was randomly selected (among two approximately equal segments) on each side of the south pond in each strata. In the north pond, three sampling sites were randomly selected (i.e., among four shoreline segments). The site locations in Muskegon Lake (Figure 1) were selected in relatively close proximity to Veterans Memorial Park but in areas that would not experience any habitat restoration. The 2015 monitoring served as to evaluate pre-restoration conditions and 2018 monitoring served to evaluate post-restoration conditions.

Fish and environmental sampling.—We sampled fish via fyke netting at each study site during 5-8 October 2015 (pre-restoration monitoring) and 7-10 August 2018 (post-restoration monitoring). Fyke nets were set during daylight hours and fished an average of 23.75 h (range = 22.20-25.18 h) in 2015 and 25.09 h (range = 21.87-26.70 h) in 2018. Two fyke nets (4-mm mesh) were fished at each site; fyke nets were set with the mouths facing each other and parallel to the shoreline. A description of the design of the fyke nets is reported in Breen and Ruetz (2006), and the type of fyke nets we used tend to select for small-bodied fish (Ruetz et al. 2007). Each fish captured was identified to species, measured (total length), and released in the field; however, some specimens were preserved to confirm identifications in the laboratory.

Environmental conditions were measured at each fish sampling site. We measured water temperature (°C), dissolved oxygen (mg/L and % saturation), specific conductivity (µS/cm), total dissolved solids (g/L), turbidity (NTU), pH, and chlorophyll *a* (µg/L) in the middle of the water column using a YSI 6600 multi-parameter data sonde near the mouth of each fyke net. We measured water depth at the mouth of each fyke net and visually estimated the percent cover of submerged aquatic vegetation (SAV) and emergent aquatic vegetation (EAV) for the length of the lead between the wings of each fyke net. At each site, water was collected by a 1-L grab-sample at mid depth using an acid-washed polyethylene bottles following the protocol of Janetski and Ruetz (2015). Bottles for specific analytes were rinsed with sample water before collection. All samples were stored in the dark, on ice in the field and then processed further upon return to the laboratory. One 250-mL poly bottle was filled with raw water and stored frozen for analysis of total phosphorus (TP). Additionally, 500 mL of water was filtered using a 0.45-µm nitrocellulose filter and analyzed for chloride, nitrate, and soluble reactive phosphorus

(SRP). Chloride and nitrate concentrations were determined by ion chromatography on a Dionex ICS-2100. SRP and TP concentrations were determined using a SEAL Analytical AQ2 discrete analyzer.

Results and Discussion

Environmental sampling.—Across the 11 fish sampling sites, mean water depth was 88 cm with a mean water temperature of 16.0 °C in 2015 and water depth was 81 cm with a mean water temperature of 24.5 °C in 2018 (Table 2). The marked difference in water temperature between years is because sampling was conducted in August 2018 versus October 2015. This difference in water temperature could confound pre- versus post-restoration comparisons of the fish assemblage.

We found differences in environmental conditions among sampling locations (i.e., north pond, south pond, and Muskegon Lake) and between years (Tables 2-3). The differences among sampling locations were more pronounced in 2015 than 2018 (Figure 2). In general, water quality appeared to improve in the south pond after restoration. Prior to restoration, we found evidence of degraded water quality (see Uzarski et al. [2005] for comparison with Great Lakes coastal wetlands and Janetski and Ruetz [2015] for comparison with other drowned river mouth lakes) in the south pond. Specifically, turbidity and TP were markedly lower in the south pond between 2015 and 2018 while there was little difference between years in Muskegon Lake (Figure 2a and 2c), suggesting the differences were the result of habitat restoration (i.e., the reconnection of the south pond to the Muskegon River). Similarly, SRP showed the largest decrease between years in the south pond compared with the north pond or Muskegon Lake (Figure 2d). Specific conductivity, which is often considered an indicator of anthropogenic disturbance (Uzarski et al. 2005), was lower and less variable among sites in 2018 (Figure 2b).

The magnitude of the reduction in specific conductivity in the north and south ponds was similar and greater than observed in Muskegon Lake (Figure 2b). There was a reduction in Cl at all sites in 2018 (Figure 2f); however, the reduction was similar among sites, suggesting that habitat restoration was not the driving factor for this difference. Although we observed a reduction in nitrate concentrations in Muskegon Lake, nitrate concentrations were higher in both ponds (Figure 2e). The increase in nitrate in the ponds was likely the result of improving the connection with the Muskegon River (given that nitrate concentrations were highest in Muskegon Lake during both years of sampling).

We observed differences in SAV and EAV among sites and between years (Figure 3). These differences should be interpreted cautiously because the percentages of SAV and EAV are a function of where fyke nets are set, which was strongly influenced by water depth. Nevertheless, we observed more SAV in the south pond in 2018 than 2015 (Figure 3a). This observation could be the result of decreased turbidity in the south pond (Figure 2a), which likely allowed greater light penetration to the bottom for plant growth.

Fish sampling.—We captured 1285 fish comprising 23 species at the three (north pond, south pond, and Muskegon Lake) sampling locations in 2015 (Table 4) and 1818 fish comprising 17 species in 2018 (Table 5). The reported species richness for each year excludes unknown sunfish, which were likely a hybrid. The most abundant fishes across all sites and years were yellow perch (23%), largemouth bass (21%), pumpkinseed (19%), bluegill (13%), black crappie (10%), bullheads (4%), warmouth (3%), and rock bass (2%), which accounted for nearly 96% of the total catch (Tables 4-5). Of the 26 fish species captured over the two years, three species were non-native to the Great Lakes basin (Bailey et al. 2004)—goldfish (0.7%), round goby (0.4%), and common carp (0.1%)—which composed less than 2% of the total catch across years (Tables 4-5).

The pattern in total catch per unit effort (CPUE) among sites was mostly consistent between years (Figure 4). CPUE was highest in the south pond during both years of sampling. The only notable difference between years was in the north pond where CPUE was greater in 2018 than 2015. We hypothesize that this difference in CPUE between years in the north pond could have been the result of habitat restoration in that removal of *Typha* combined with a natural increase in water level caused us to set fyke nets in shallower water (mean depth where fyke nets were set was 96 cm in 2015 and 75 cm in 2018; Table 2) with abundant SAV (Figure 3a) that was not available for sampling in 2015. Dense *Typha* around the edge of the north pond in 2015 made setting fyke nets in shallow areas impossible (Figure A2). Nevertheless, our hypothesis regarding the relationship between CPUE and habitat restoration remains untested and should be interpreted cautiously.

We found differences in the fish assemblage between years and among sites (Figure 5). As noted above, differences between years should be interpreted cautiously because timing of sampling (August versus October). Previous research of the littoral fish assemblage in Muskegon Lake reported a seasonal pattern, although the largest difference was between spring and summer/autumn (Bhagat and Ruetz 2011). Moreover, the fish assemblage at our sampling sites in Muskegon Lake varied between years, with more rock bass, largemouth bass, and yellow perch (and less pumpkinseed) in 2018 than 2015 (Figure 5c). Given that Muskegon Lake was our "control" site (meaning no habitat restoration was performed at this site), inferring the effects of the restoration efforts at the north and south ponds should be done cautiously. Overall, we did not observe marked differences in the fish assemblage in the north pond between years (Figure 5a), which is not surprising given that restoration activities were of a lesser scope than in the south pond. However, the south pond showed differences between years. Largemouth bass and black crappie were much more common in the catch in 2018 than 2015 (Figure 5b). Most notably, bullheads were about 10% of the catch in the south pond in 2015 but were absent from the catch in 2018 (Figure 5b). Similarly, goldfish and to a lesser degree common carp (both species are non-native) were captured in the south pond in 2015 (Table 4) but were absent from the catch in 2018 (Table 5). Bullheads, goldfish, and common carp are rarely encountered in littoral habitats of Muskegon Lake (Bhagat and Ruetz 2011; Janetski and Ruetz 2015). These fishes (especially yellow bullhead, brown bullhead, black bullhead, and common carp) are known to tolerate poor water quality, such as high turbidity and low oxygen concentration (Becker 1983); their absence in the south pond following restoration is promising, suggesting that at least a component of the fish assemblage may be responding to the improved water quality in the south pond.

Another promising observation in terms of the fish assemblage in the south pond post-restoration was the dominance of species that are prized by recreational anglers (Becker 1983), with the five most frequently captured species being largemouth bass, yellow perch, black crappie, bluegill, and pumpkinseed (Table 5). Most of these individuals were small (Table 5) and likely young of the year, which could benefit anglers in future years as those fish grow to larger sizes. However, this observation should be evaluated carefully. First, the small-mesh fyke nets that we used are known to target small individual (Breen and Ruetz 2006). Second, the high proportion of small fish captured in 2018 could be due to the timing (August versus October) of sampling (e.g., Janetski et al. 2013).

In conclusion, the observations reported here suggest that habitat restoration improved the water quality of the south pond, which likely corresponded to improvements in the fish assemblage. We suspect that the changes in the south pond are primarily caused by the reconnection of the south pond to the Muskegon River. Nevertheless, the difference in the timing of sampling (i.e., August versus October) confounded pre- versus post-restoration comparisons.

We propose that conducting future monitoring would provide a stronger basis to evaluate the effects of habitat restoration because (1) the timing of post-restoration sampling could better mimic the timing of pre-restoration sampling (i.e., fish and water quality monitoring ideally should be done in October), and (2) monitoring completed after at least one annual cycle should be more representative of post-restoration conditions. Moreover, multiple years of post-restoration monitoring would be helpful in determining how much natural inter-annual variation occurs with respect to water quality, fish CPUE, and fish assemblage composition.

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References

Alexander, J. 2006. The Muskegon: the majesty and tragedy of Michigan's rarest river. Michigan State University Press, East Lansing.

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.

Carter, G.S., T.F. Nalepa, and R.R. Rediske. 2006. Status and trends of benthic populations in a coastal drowned river mouth lake of Lake Michigan. Journal of Great Lakes Research 32:578-595.

Janetski, D.J., and C.R. Ruetz III. 2015. Spatiotemporal patterns of fish community composition in Great Lakes drowned river mouths. Ecology of Freshwater Fish 24:493-504.

Janetski, D.J., C.R. Ruetz III, Y. Bhagat, and D.F. Clapp. 2013. Recruitment dynamics of age-0 yellow perch in a drowned river mouth lake: assessing synchrony with nearshore Lake Michigan. Transactions of the American Fisheries Society 142:505-514.

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.

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.

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. Latitude (N) and longitude (W) for each fish sampling in 2015 and 2018. Coordinates are the mean of the two fyke nets set at each site. Site locations are depicted in Figure 1.

		2015		2018	
Location	Site	Lat (°)	Long (°)	Lat (°)	Long (°)
Muskegon Lake	1	43.25666	86.25440	43.25686	86.25425
Muskegon Lake	2	43.25478	86.25063	43.25509	86.25033
North pond	B	43.26365	86.24769	43.26361	86.24771
North pond	C	43.26426	86.24669	43.26427	86.24743
North pond	D	43.26362	86.24648	43.26369	86.24651
South pond	1-B	43.26162	86.24448	43.26176	86.24452
South pond	1-D	43.26194	86.24522	43.26165	86.24503
South pond	2-B	43.26000	86.24223	43.25971	86.24204
South pond	2-D	43.26037	86.24376	43.26047	86.24399
South pond	3-A	43.25913	86.24117	43.25905	86.24092
South pond	3-D	43.25887	86.24184	43.25892	86.24196

Table 2. Mean ± 1 standard error (SE; n = 2) of environmental conditions measured during fyke netting for pre-restoration monitoring in October 2015 and post-restoration monitoring in August 2018. SAV is submerged aquatic vegetation, and EAV is emergent aquatic vegetation. Water depth was measured at each fyke net. Water quality variables were measured *in situ* with a YSI sonde. Negative turbidity measurements should be interpreted as zero. SAV and EAV were estimated visually.

Location	Site	Year	Depth (cm)	Water Temperature (°C)	Dissolved Oxygen (mg/L)	% Dissolved Oxygen	Specific Conductivity (µS/cm)	Total Dissolved Solids (g/L)	Turbidity (NTU)	pH	Chlorophyll *a* (µg/L)	SAV (%)	EAV (%)
Muskegon Lake	1	2015	74±7	17.58±0.24	8.40±0.45	88.1±4.5	432±1	0.285±0.003	1.1±0.9	7.98±0.06	3.4±0.1	50±10	0±0
Muskegon Lake	2	2015	78±5	16.05±0.01	9.14±0.06	92.8±0.6	432±0	0.281±0.000	1.3±0.5	8.15±0.02	3.4±0.1	40±10	0±0
North pond	B	2015	98±4	14.62±0.00	6.57±0.13	65.0±1.5	502±0	0.327±0.001	0.8±1.2	7.50±0.00	3.8±0.4	53±3	45±5
North pond	C	2015	95±6	14.64±0.03	5.63±0.21	55.6±2.1	520±0	0.338±0.000	-0.6±0.2	7.46±0.01	7.0±1.6	20±0	25±0
North pond	D	2015	96±2	14.67±0.00	6.11±0.13	60.3±1.3	496±1	0.323±0.001	-0.7±0.0	7.58±0.01	5.2±0.6	15±5	25±0
South pond	1-B	2015	81±8	16.58±0.60	12.38±0.07	127.3±1.4	544±1	0.354±0.001	26.9±1.6	8.15±0.04	18.3±0.3	0±0	50±0
South pond	1-D	2015	90±4	15.80±0.18	10.12±0.71	102.4±7.6	558±6	0.363±0.004	22.8±0.3	7.75±0.02	16.3±0.9	0±0	20±0
South pond	2-B	2015	92±13	16.57±0.23	13.97±0.06	142.7±1.2	540±0	0.351±0.000	29.7±0.8	8.47±0.02	19.3±0.9	0±0	0±0
South pond	2-D	2015	87±0	16.17±0.03	11.75±0.17	120.0±1.1	547±3	0.356±0.001	28.9±5.1	8.00±0.01	16.9±1.2	0±0	48±3
South pond	3-A	2015	87±3	16.78±0.06	14.58±0.26	149.5±3.4	536±0	0.348±0.000	25.3±1.4	8.54±0.01	14.6±2.0	0±0	0±0
South pond	3-D	2015	93±4	16.60±0.11	15.51±0.65	153.5±0.7	536±0	0.349±0.001	28.9±1.0	8.53±0.00	17.8±1.0	0±0	33±3
Muskegon Lake	1	2018	99±4	24.59±0.01	10.18±0.01	122.3±0.1	388±0	0.252±0.000	0.6±0.2	8.22±0.02	5.8±0.8	8±3	0±0
Muskegon Lake	2	2018	92±1	24.11±0.01	8.03±0.05	95.7±0.7	390±0	0.254±0.000	0.3±0.1	7.85±0.02	4.6±0.1	0±0	0±0
North Pond	B	2018	75±6	24.25±0.01	1.25±0.07	15.1±0.9	401±0	0.261±0.000	2.1±0.5	7.46±0.01	65.4±11.0	80±0	83±8
North Pond	C	2018	77±8	24.29±0.02	1.44±0.68	17.3±8.1	411±3	0.268±0.002	5.7±1.2	7.46±0.04	133.5±16.5	60±0	10±5
North Pond	D	2018	72±0	24.68±0.01	4.67±0.44	56.3±5.2	397±3	0.258±0.002	7.5±0.6	7.75±0.06	39.4±8.9	50±0	0±0
South Pond	1-B	2018	87±8	24.41±0.01	7.75±0.04	92.9±0.5	392±0	0.255±0.000	2.2±0.7	8.13±0.02	16.3±0.1	20±5	0±0
South Pond	1-D	2018	70±2	24.42±0.04	8.01±0.02	96.0±0.4	392±0	0.255±0.000	0.6±0.0	8.16±0.00	15.2±0.6	5±0	0±0
South Pond	2-B	2018	76±2	24.68±0.01	7.77±0.21	93.6±2.5	393±0	0.256±0.000	2.0±0.7	8.12±0.02	18.3±0.2	5±0	0±0
South Pond	2-D	2018	74±6	24.61±0.00	8.02±0.02	96.5±0.3	393±1	0.255±0.000	1.5±0.5	8.12±0.02	15.6±0.1	10±0	0±0
South Pond	3-A	2018	90±3	24.67±0.03	7.50±0.09	90.3±1.1	394±0	0.256±0.000	1.9±0.6	8.10±0.01	17.6±0.5	35±5	0±0
South Pond	3-D	2018	80±3	24.70±0.00	7.47±0.08	89.9±0.9	395±0	0.257±0.001	2.2±0.6	8.10±0.01	16.6±0.1	25±15	0±0

Table 3. Nutrient concentrations of water samples collected during fyke netting during pre-restoration (2015) and post-restoration (2018) sampling. Values denoted as "<" were below the specified detection limit.

		Cl (mg/L)		NO_3-N (mg/L)		SRP-P (mg/L)		TP-P (mg/L)	
Location	Site	2015	2018	2015	2018	2015	2018	2015	2018
Muskegon Lake	1	26	18	0.34	0.22	0.007	0.006	0.018	0.016
Muskegon Lake	2	26	20	0.49	0.25	<0.005	0.007	0.016	0.016
North pond	B	40	22	0.07	0.08	0.006	0.005	0.028	0.044
North pond	C	34	23	0.06	0.08	0.007	0.006	0.034	0.028
North pond	D	21	21	0.04	0.11	0.005	0.008	0.032	0.067
South pond	1-B	35	20	<0.01	0.14	0.008	0.005	0.124	0.016
South pond	2-B	34	20	<0.01	0.11	0.005	0.007	0.139	0.020
South pond	1-D	36	20	<0.01	0.17	0.016	0.005	0.119	0.023
South pond	2-D	35	20	0.05	0.13	0.017	0.005	0.143	0.016
South pond	3-A	34	20	<0.01	0.10	0.005	<0.005	0.123	0.025
South pond	3-D	35	20	<0.01	0.11	0.009	<0.005	0.133	0.014

Table 4. Number and mean total length (TL; ranges reported parenthetically) of fish captured by fyke netting (*n* = 22 nets) at three locations during pre-restoration monitoring in October 2015. The sampling locations were Muskegon Lake (*n* = 4 nets), north pond (*n* = 6 nets), and south pond (*n* = 12 nets).

		Total	Lake		North		South	
Common name	Scientific name	Catch	Catch	TL (cm)	Catch	TL (cm)	Catch	TL (cm)
rock bass	*Ambloplites rupestris*	10	10	9.0 (4.9-10.7)	0	--	0	--
black bullhead	*Ameiurus melas*	3	0	--	0	--	3	25.8 (21.1-29.0)
yellow bullhead	*Ameiurus natalis*	11	0	--	0	--	11	15.7 (6.9-24.1)
brown bullhead	*Ameiurus nebulosus*	106	0	--	0	--	106	10.4 (7.5-28.8)
bowfin	*Amia calva*	8	0	--	2	45.5 (45.1-45.9)	6	38.9 (35.0-41.4)
goldfish	*Carrassius auratus*	22	0	--	0	--	22	16.0 (12.8-30.1)
white sucker	*Catostomus commersonii*	2	0	--	0	--	2	27.8 (26.2-29.4)
common carp	*Cyprinus carpio*	2	0	--	0	--	2	40.1 (24.6-55.5)
gizzard shad	*Dorosoma cepedianum*	20	5	10.0 (9.5-10.4)	0	--	15	10.4 (8.6-11.3)
northern pike	*Esox lucius*	2	0	--	2	22.4 (12.1-32.6)	0	--
brook silverside	*Labidesthes sicculus*	3	3	7.0 (6.3-8.2)	0	--	0	--
pumpkinseed	*Lepomis gibbosus*	417	16	6.0 (4.0-12.2)	12	13.1 (6.5-16.9)	389	9.4 (5.5-17.3)
warmouth	*Lepomis gulosus*	13	0	--	11	14.9 (4.0-20.5)	2	13.4 (10.0-16.7)
bluegill	*Lepomis macrochirus*	165	2	11.0 (4.8-17.2)	22	12.0 (4.6-16.5)	141	9.7 (3.5-22.9)
unknown sunfish	*Lepomis* spp.*	6	0	--	4	18.1 (16.3-19.5)	2	14.6 (12.0-17.2)
largemouth bass	*Micropterus salmoides*	102	5	12.9 (6.9-26.8)	7	9.9 (6.7-17.6)	90	10.6 (5.6-25.5)
silver redhorse	*Moxostoma anisurum*	1	1	45.8	0	--	0	--
round goby	*Neogobius melanostomus*	6	6	5.2 (3.0-7.4)	0	--	0	--
golden shiner	*Notemigonus crysoleucas*	10	0	--	0	--	10	12.4 (10.6-14.7)
spottail shiner	*Notropis hudsonius*	1	0	--	0	--	1	6.7
mimic shiner	*Notropis volucellus*	4	4	4.5 (4.0-5.3)	0	--	0	--
yellow perch	*Perca falvescens*	348	3	14.0 (13.0-14.6)	2	18.1 (13.6-22.5)	343	10.7 (7.7-30.3)
bluntnose minnow	*Pimephales notatus*	2	2	4.3 (3.7-4.8)	0	--	0	--
black crappie	*Pomxsis nigromaculatus*	21	2	17.4 (16.3-18.5)	1	22.3	18	16.8 (14.2-18.6)
	Total	**1285**	**59**		**63**		**1163**	

*Unknown sunfish was likely a hybrid between pumpkinseed and warmouth.

Table 5. Number and mean total length (TL; ranges reported parenthetically) of fish captured by fyke netting (*n* = 22 nets) at three locations during post-restoration monitoring in August 2018. The sampling locations were Muskegon Lake (*n* = 4 nets), north pond (*n* = 6 nets), and south pond (*n* = 12 nets).

		Total	Lake		North		South	
Common name	Scientific name	Catch	Catch	TL (cm)	Catch	TL (cm)	Catch	TL (cm)
rock bass	*Ambloplites rupestris*	48	38	13.1 (7.2-18.3)	0	--	10	11.3 (4.7-15.3)
yellow bullhead	*Ameiurus natalis*	1	0	--	0	--	1	27.2
bowfin	*Amia calva*	9	1	67.9	2	44.7 (36.0-53.4)	6	49.6 (45.2-54.0)
brook silverside	*Labidesthes sicculus*	1	0	--	0	--	1	6.0
pumpkinseed	*Lepomis gibbosus*	188	1	8.0	65	5.6 (3.2-14.5)	122	9.8 (4.3-13.7)
warmouth	*Lepomis gulosus*	80	0		71	6.2 (2.5-16.9)	9	13.5 (7.1-20.5)
bluegill	*Lepomis macrochirus*	251	3	17.8 (16.9-18.6)	98	3.8 (2.3-13.9)	150	8.3 (3.0-13.9)
unknown sunfish	*Lepomis* spp.*	11	0	--	4	14.3 (11.5-20.3)	7	15.7 (14.7-18.9)
common shiner	*Luxilus cornutus*	1	0	--	0	--	1	11.4
smallmouth bass	*Micropterus dolomieu*	1	1	6.4	0	--	0	--
largemouth bass	*Micropterus salmoides*	548	11	7.4 (4.3-16.2)	28	5.8 (4.7-7.6)	509	6.4 (4.7-15.8)
silver redhorse	*Moxostoma anisurum*	2	1	58.5	0	--	1	36.4
shorhead redhorse	*Moxostoma macrolepidotum*	1	1	46.0	0	--	0	--
round goby	*Neogobius melanostomus*	5	4	6.2 (4.2-8.7)	0	--	1	7.3
golden shiner	*Notemigonus crysoleucas*	9	0	--	0	--	9	6.6 (6.1-6.9)
spottail shiner	*Notropis hudsonius*	1	1	6.2	0	--	0	--
yellow perch	*Perca falvescens*	374	9	7.0 (6.1-11.6)	35	6.6 (5.0-13.2)	330	7.4 (4.8-20.6)
black crappie	*Pomxsis nigromaculatus*	287	0	--	3	5.2 (5.2-5.2)	284	6.5 (5.5-7.7)
	Total	**1818**	**71**		**306**		**1441**	

*Unknown sunfish was likely a hybrid between pumpkinseed and warmouth.

Figure 1. Map of Veterans Memorial Park ponds (Muskegon County, Michigan) showing study sites in north pond, south pond, and Muskegon Lake. The latitude and longitude for each site is reported in Table 1.

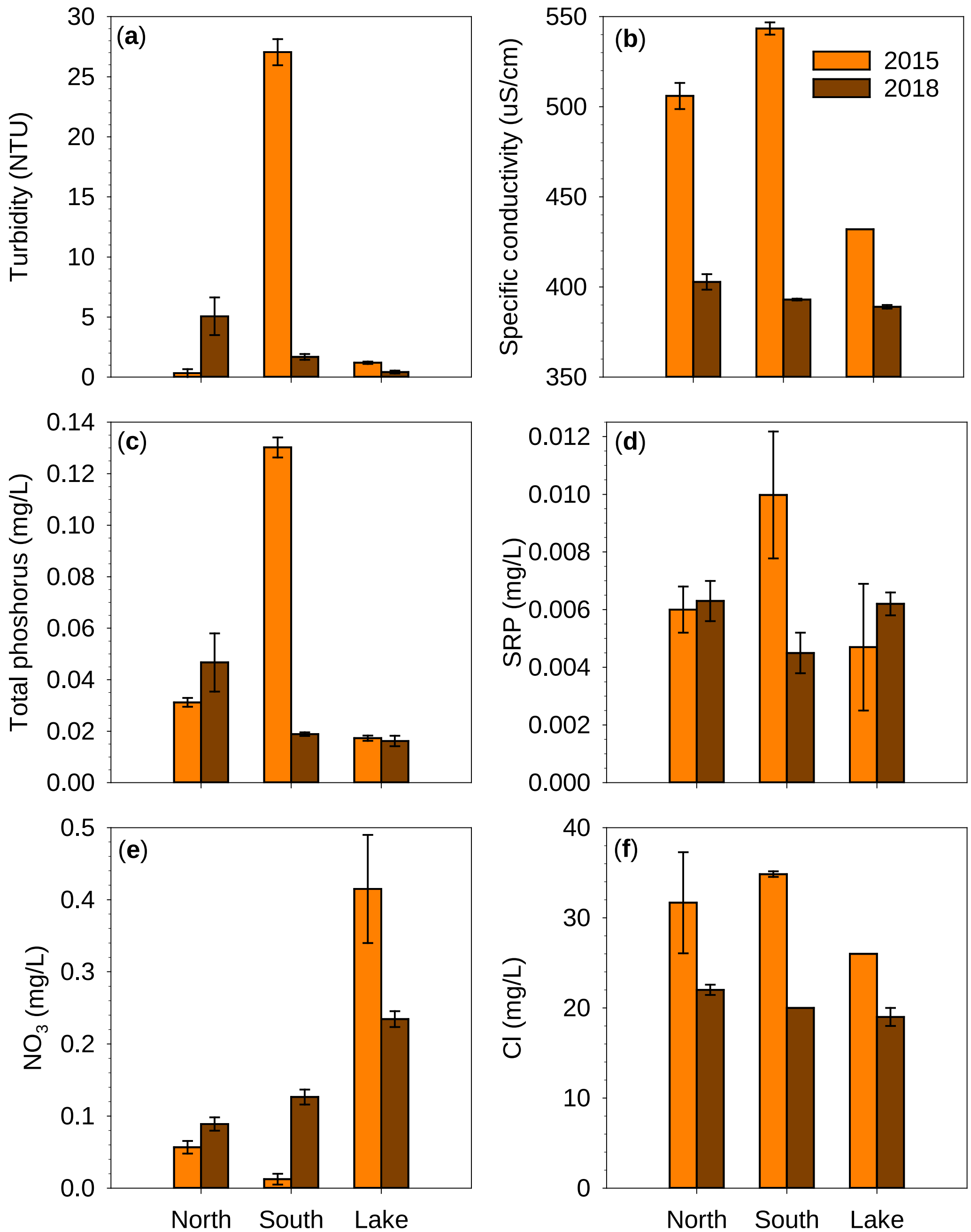

Figure 2. Mean (±1 SE) (**a**) turbidity, (**b**) specific conductivity, (**c**) total phosphorus (TP), (**d**) soluble reactive phosphorus (SRP), (**e**) nitrate (NO_3), and (**f**) chloride (Cl) in the north pond (*n* = 3 sites), south pond (*n* = 6 sites), and Muskegon Lake (*n* = 2 sites). Pre-restoration sampling was conducted in October 2015, and post-restoration sampling was conducted in August 2018. Note that negative values of turbidity were assumed to be zero for calculating mean and SE (see Table 2). If values were less than the detection limit for NO_3 or SRP, then a value of 0.5×detection limit was used to calculate means and SE.

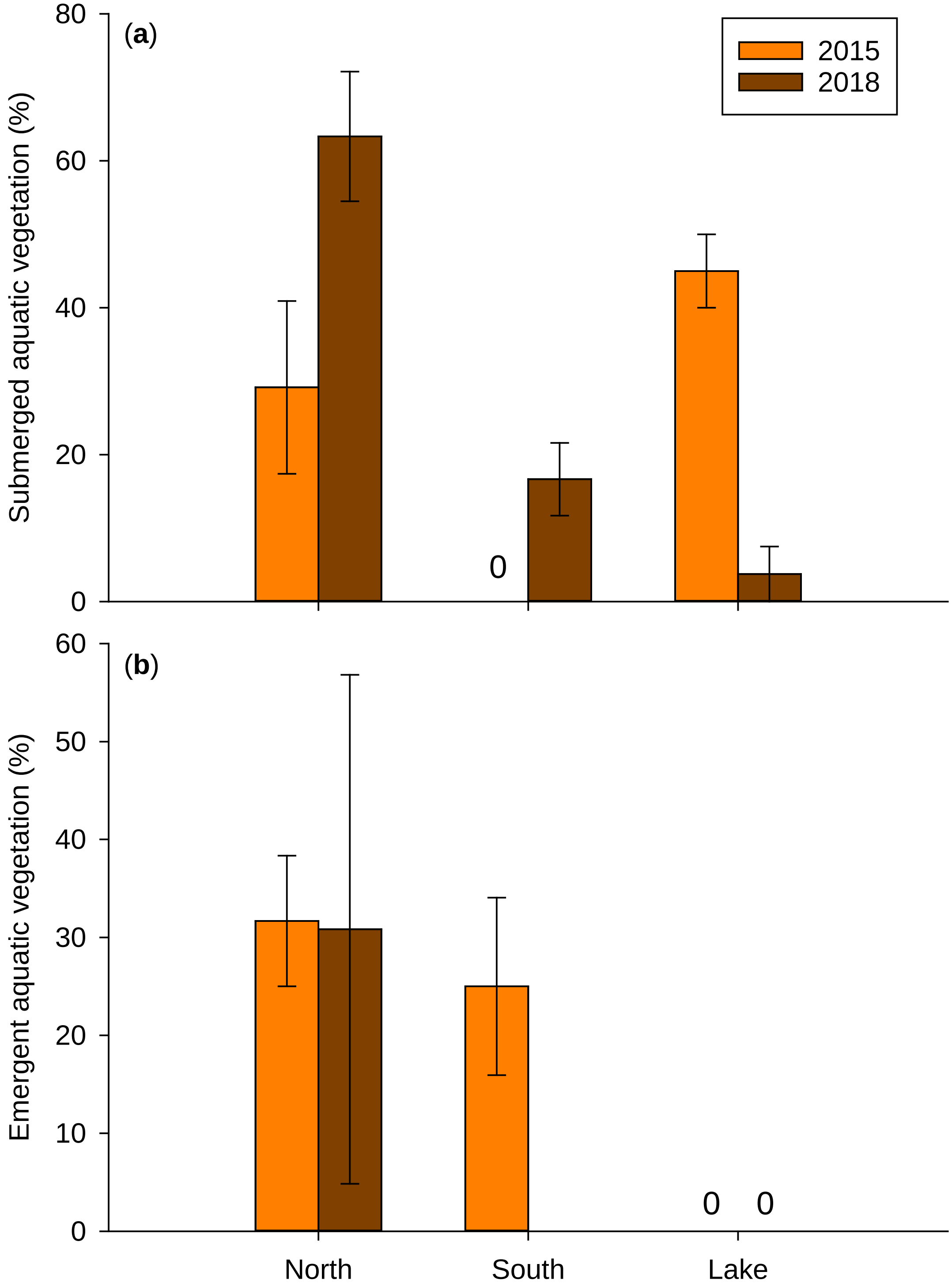

Figure 3. Mean (±1 SE) percent coverage of (**a**) submerged aquatic vegetation (SAV) and (**b**) emergent aquatic vegetation (EAV) in the north pond (n = 3 sites), south pond (n = 6 sites), and Muskegon Lake (n = 2 sites) in 2015 (pre-restoration) and 2018 (post-restoration). Zeros indicate the absence of SAV or EAV at a sampling location. Estimates were made at fyke-net locations.

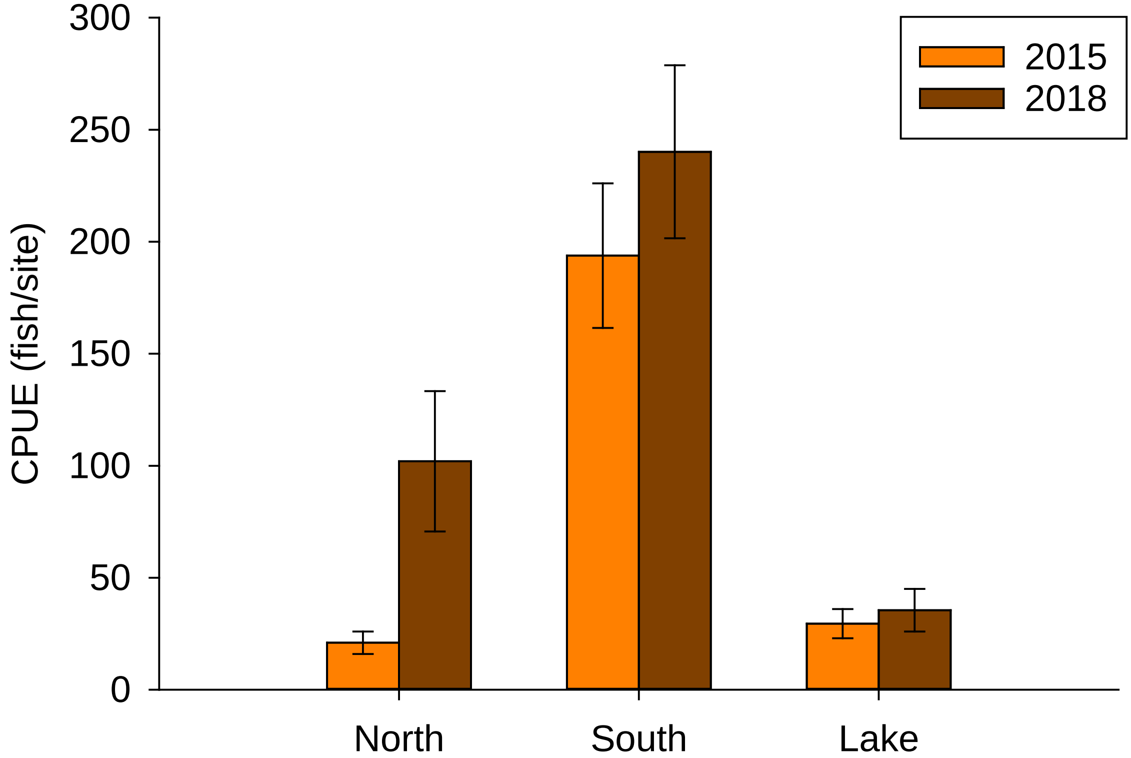

Figure 4. Mean (±1 SE) total catch per unit effort (CPUE) in the north pond (*n* = 3 sites), south pond (*n* = 6 sites), and Muskegon Lake (*n* = 2 sites) in 2015 (pre-restoration) and 2018 (post-restoration). Two fyke nets were fished at each site; thus, CPUE is the total number of fish captured in two fyke nets at a site.

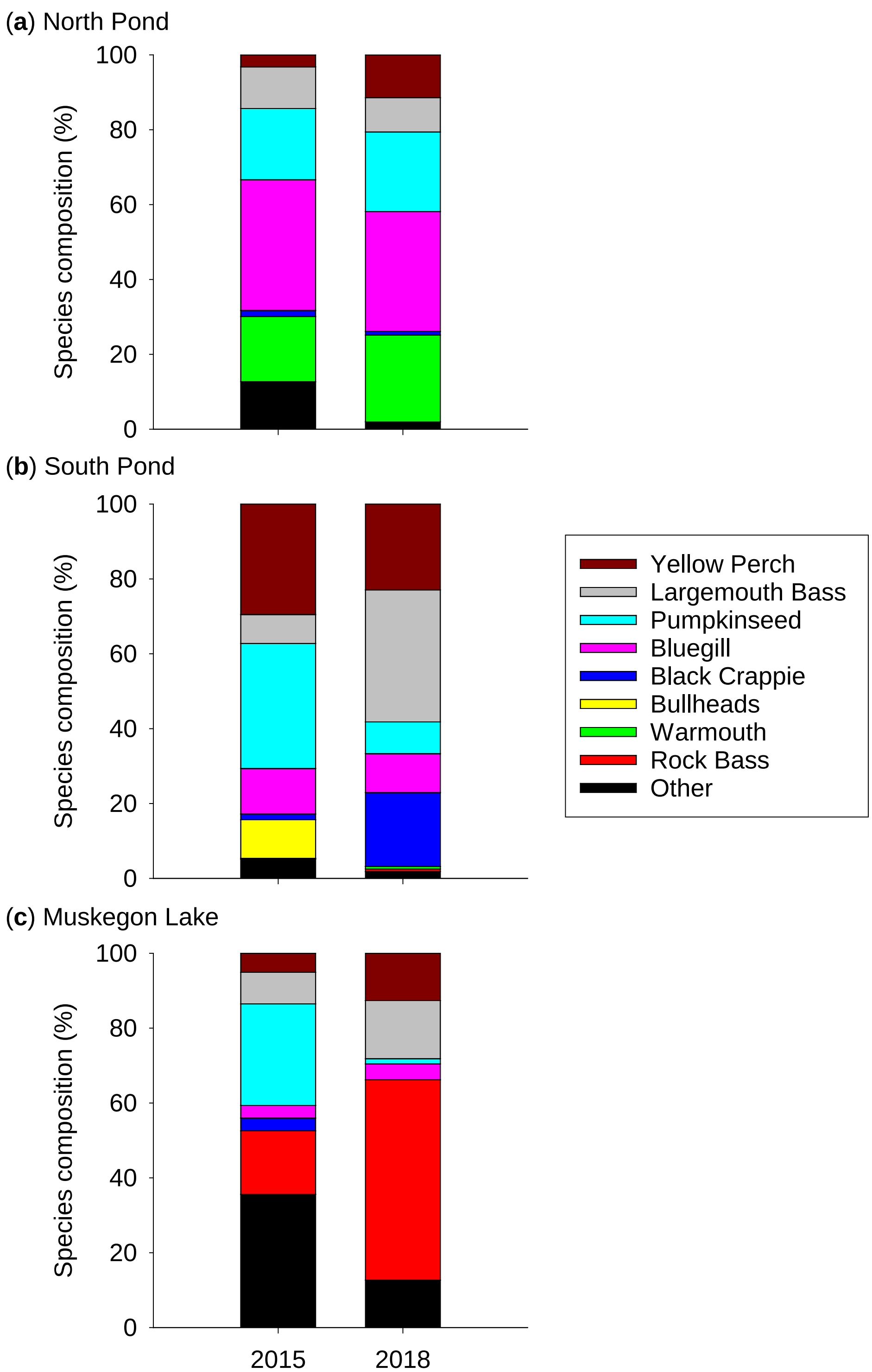

Figure 5. Fish species composition in the (**a**) north pond (*n* = 3 sites), (**b**) south pond (*n* = 6 sites), and (**c**) Muskegon Lake (*n* = 2 sites) in 2015 (pre-restoration) and 2018 (post-restoration). "Other" includes all species not listed in the legend (see Tables 4-5). Two fyke nets were fished at each site. The number of fish captured varied among the three sampling locations (i.e., north pond, south pond, and Muskegon Lake) and between years (Tables 4-5).

Appendix

Table A1. Site duplicates for environmental variables measured with the YSI sonde during fyke netting. Two fyke nets (i.e., net #1 and net #2) were set at each site. Note that primary measurements reported here for the south pond in 2018 were made later in the day than the measurements reported in Table 2 because we forgot to measure duplicates while setting fyke nets earlier in the day. For all other observations, primary measurements were reported in Table 2. Net number is reported for each observation; recall that two fyke nets are set at each site (i.e., there is a net 1 and net 2 at each site).

Location	Site	Net	Sample Type	Date	Water Temperature (°C)	Dissolved Oxygen (mg/L)	Dissolved Oxygen (%)	Specific Conductivity (µS/cm)	Total Dissolved Solids (g/L)	Turbidity (NTU)	pH	Chlorophyll *a* (µg/L)
Muskegon Lake	1	1	Primary	6-Oct-2015	17.82	7.95	83.6	431	0.287	0.2	7.92	3.3
Muskegon Lake	1	1	Duplicate	6-Oct-2015	17.81	8.29	87.1	431	0.280	0.1	7.91	3.7
North pond	D	1	Primary	6-Oct-2015	14.67	5.98	59.0	497	0.323	-0.7	7.57	5.7
North pond	D	1	Duplicate	6-Oct-2015	14.67	6.01	59.2	497	0.323	-0.4	7.62	4.9
South pond	1-D	1	Primary	7-Oct-2015	15.62	9.41	94.8	564	0.367	23.0	7.76	15.4
South pond	1-D	1	Duplicate	7-Oct-2015	15.57	9.55	95.8	562	0.365	23.6	7.72	15.6
South pond	3-A	2	Primary	7-Oct-2015	16.72	14.83	152.8	536	0.348	26.6	8.55	16.6
South pond	3-A	2	Duplicate	7-Oct-2015	16.71	14.94	154.0	536	0.348	27.1	8.55	16.3
Muskegon Lake	2	1	Primary	8-Aug-2018	24.12	8.08	96.3	390	0.254	0.2	7.83	4.6
Muskegon Lake	2	1	Duplicate	8-Aug-2018	24.14	8.07	96.2	390	0.254	0.3	7.86	6.7
Muskegon Lake	2	2	Primary	8-Aug-2018	24.10	7.98	95.0	390	0.254	0.4	7.87	4.5
Muskegon Lake	2	2	Duplicate	8-Aug-2018	24.09	8.15	97.0	390	0.253	0.4	7.92	5.6
North pond	C	1	Primary	8-Aug-2018	24.31	2.12	25.4	414	0.269	6.8	7.50	150.0
North pond	C	1	Duplicate	8-Aug-2018	24.30	2.23	26.6	414	0.269	11.0	7.49	191.5
North pond	C	2	Primary	8-Aug-2018	24.26	0.76	9.2	408	0.266	4.5	7.42	117.0
North pond	C	2	Duplicate	8-Aug-2018	24.25	0.75	8.8	409	0.266	4.5	7.40	125.0
South pond	2-B	1	Primary	10-Aug-2018	25.13	8.17	99.2	393	0.256	2.6	8.16	19.2
South pond	2-B	1	Duplicate	10-Aug-2018	25.18	8.12	98.7	393	0.256	4.0	8.16	20.2
South pond	2-B	2	Primary	10-Aug-2018	25.31	8.20	99.9	393	0.256	2.1	8.17	19.8
South pond	2-B	2	Duplicate	10-Aug-2018	25.25	8.23	100.2	393	0.255	3.1	8.17	19.7
South pond	3-A	1	Primary	10-Aug-2018	24.94	7.79	94.3	394	0.256	2.2	8.12	21.4
South pond	3-A	1	Duplicate	10-Aug-2018	24.98	7.83	94.8	394	0.256	2.4	8.12	21.7
South pond	3-A	2	Primary	10-Aug-2018	24.94	7.82	94.6	394	0.256	2.1	8.11	20.4
South pond	3-A	2	Duplicate	10-Aug-2018	25.07	7.93	96.2	393	0.256	3.0	8.13	20.9

Table A2. Site duplicates for nutrient concentrations of water samples collected during fyke netting. Values denoted as “<” were below the specified detection limit.

Location	Site	Sample Type	Date	Cl (mg/L)	NO_3-N (mg/L)	SRP-P (mg/L)	TP-P (mg/L)
Muskegon Lake	1	Primary	5-Oct-2015	26	0.34	0.007	0.018
Muskegon Lake	1	Duplicate	5-Oct-2015	25	0.33	0.005	0.020
North pond	D	Primary	5-Oct-2015	21	0.04	0.005	0.032
North pond	D	Duplicate	5-Oct-2015	36	0.07	0.005	0.035
South pond	1-D	Primary	7-Oct-2015	36	<0.01	0.016	0.119
South pond	1-D	Duplicate	7-Oct-2015	38	0.05	0.018	0.119
South pond	3-A	Primary	7-Oct-2015	34	<0.01	0.005	0.123
South pond	3-A	Duplicate	7-Oct-2015	34	<0.01	0.005	0.125
Muskegon Lake	2	Primary	7-Aug-2018	20	0.25	0.007	0.016
Muskegon Lake	2	Duplicate	7-Aug-2018	20	0.25	0.006	0.018
North pond	C	Primary	7-Aug-2018	23	0.08	0.006	0.028
North pond	C	Duplicate	7-Aug-2018	24	0.08	<0.005	0.026
South pond	2-B	Primary	9-Aug-2018	20	0.11	0.007	0.020
South pond	2-B	Duplicate	9-Aug-2018	20	0.11	0.006	0.020
South pond	3-A	Primary	9-Aug-2018	20	0.10	<0.005	0.025
South pond	3-A	Duplicate	9-Aug-2018	20	0.11	<0.005	0.029

Figure A1. Photos of site 2-C at the south pond during pre-restoration fyke netting in 2015 (above) and post-restoration fyke netting in 2018 (below). Note the absence of *Typha* along the edge of the south pond post-restoration.

Figure A2. Photos of site C at north pond during pre-restoration fyke netting in 2015 (above) and post-restoration fyke netting in 2018 (below). Note the removal of the *Typha* along the edge of the pond. Higher water levels in 2018 caused fyke nets to be set in shallower water than was not available for sampling in 2015 because of the dense *Typha*.