Targeted Native Mussel Surveys in Lakes Within the Clinton River Watershed.

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We collectively acknowledge that Michigan State University occupies the ancestral, traditional, and contemporary Lands of the Anishinaabeg – Three Fires Confederacy of Ojibwe, Odawa, and Potawatomi peoples. In particular, the University resides on Land ceded in the 1819 Treaty of Saginaw. We recognize, support, and advocate for the sovereignty of Michigan's twelve federally recognized Indian nations, for historic Indigenous communities in Michigan, for Indigenous individuals and communities who live here now, and for those who were forcibly removed from their Homelands. By offering this Land Acknowledgement, we affirm Indigenous sovereignty and will work to hold Michigan State University more accountable to the needs of American Indian and Indigenous peoples.

Cover Photo: Surveying for native unionid mussels in Lakeville Lake, Clinton River watershed, August 2022. Inset photo: A young giant floater (*Pyganodon grandis*) with zebra mussels (*Dreissena polymorpha*) from Loon Lake, Clinton River watershed, August 2022 Photos by Peter Badra.

All photos within report were taken by Peter Badra unless otherwise noted.

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Introduction

Native freshwater mussels (Unionidae) play an important role in lake ecosystems across Michigan. Live individuals and shells provide habitat for aquatic insects, fish, and crayfish. They can comprise a relatively large proportion of benthic animal biomass in lakes, even when at low densities (0.03 individuals/m2, Strayer et al. 1981). They filter large quantities of water, feeding on bacteria, phytoplankton, and detritus (Vaughn et al. 2008), and provide food for birds, fish, and mammals. Historically, they were important as a food source for Native Americans and were used for tools and jewelry (Spinden 1908, Parmalee and Klippel 1974).

Unionid mussels are one of the most imperiled animal groups in North America (Williams et al. 1993, Master et al. 2000, Strayer 2008). Thirteen of the 44 unionid species native to Michigan are listed as state endangered, four are listed as state threatened, and 13 are considered species of special concern. Seven species in Michigan are federally listed as endangered or threatened. Mussel populations in lakes have been impacted by water quality degradation, habitat alteration, and invasive species, particularly zebra mussels (*Dreissena polymorpha*) (Williams et al., 1993, Watters 2000, Strayer 2008).

While the number of surveys for native unionid mussels in Michigan's rivers have greatly increased over the past 20+ years, surveys targeting mussels in lakes have been few and far between until just a few years ago. As a result, knowledge of the range and status of mussels in lakes has lagged far behind that in rivers. Less than 2% of Michigan's 11,000 inland lakes have been surveyed for native mussels (Michigan Mussel Committee 2022). This is in the context of severe and widespread impact of zebra mussels on native mussel populations across the state. Occurrence data for native mussels in lakes is growing in need as they are being increasingly used by local, state, and federal agencies and conservation organizations. This shortage of occurrence data makes it difficult to make informed decisions about conservation efforts and potential impacts to state and federally listed mussel species that occur in lakes.

The purpose of this project is to help build a more complete body of information on the occurrence of native unionid mussels in lakes in the Clinton River watershed. This watershed is the focus of these surveys due to the number of historical records for threatened and endangered mussels in the watershed and the number of lakes that are within highly developed areas. Occurrence information is especially in need now for use by DNR and EGLE staff in the permitting process for proposed projects in lakes. Models being developed to predict the likelihood of rare mussel species to occur in specific lakes are also limited by the little amount of mussel survey data available for these waterbodies. Survey results from this project will be integrated into a model of mussel occurrence developed at the Institute of Fisheries Research, by Dr. Kevin Wehrly and Arthur Cooper. This model is an important part of the Michigan Freshwater Mussel Survey Protocols for Lakes and Reservoirs (Michigan Mussel Committee 2022), which guides survey efforts related to permit applications. The distinction between lakes and reservoirs in Michigan is often blurred since many natural lakes have some water level control structures and some reservoirs were historically smaller natural lakes before their water levels were raised. This report uses the term lake, while recognizing the waterbodies surveyed often have water levels that are artificially controlled and may function as reservoirs to varying degrees.

Methods

A prioritized list of 15 lakes within the Clinton River watershed was created to target survey efforts (Figure 1). Input from DNR Fisheries and EGLE Water Resources Division staff and past records of rare and listed mussels were consulted in creating the list. All lakes were accessed via public DNR boat launches except for Deer Lake, which we obtained permission from Independence Township to use and Upper Silver Lake, which has a public dock maintained by the city of Pontiac. A 17-foot aluminum motorboat was used in larger lakes and a 13-foot canoe with trolling motor was used in some of the smaller lakes. In Upper Silver Lake a paddleboard was used for ease of launching (Figures 2-4). The perimeter of each lake was slowly traveled by boat, canoe, or paddleboard to visually search the lake bottom for shells and live unionid mussels. Calm, clear water at most of the lakes allowed for very good visibility and facilitated visual detection of mussels during the initial search of the lake perimeter between survey sites. Survey sites were placed at locations where shells or live unionid mussels were found, or if none were found, placed in areas of potential habitat and/or to have even distribution around the perimeter of the lake. Only one lake was surveyed per day to allow for

Figure 1. The Clinton River watershed in southeastern Michigan. Map provided by the Clinton River Watershed Council.

Figure 2. Motorboat at Loon Lake in August 2022 used to survey larger lakes in the Clinton River watershed that had boat ramps.

Figure 3. Canoe with trolling motor at Deer Lake in October 2022 used to survey smaller lakes in the Clinton River watershed.

Figure 4. Paddleboard at Upper Silver Lake in August 2022 used to survey this small lake with carry-in boat access.

watercraft, trailer, and sampling gear (waders, glass bottom buckets, etc.) to be cleaned and dried overnight. Surveys took place in the summer of 2021 and 2022. The necessary permits to survey for threatened and endangered mussel species in Michigan were obtained before the start of the project, including DNR Scientific Collector's Permit, DNR State Threatened and Endangered Species Permit, and USFWS Federal Threatened and Endangered Species Permit.

Semi-quantitative sampling was performed at each survey site, i.e., the amount of area searched was recorded along with the amount of time (person*minutes) spent searching. Survey sites were located in water depths of 1m or less. Glass bottom buckets were used to facilitate detection of shells and live mussels in water depths up to approximately 0.75m and snorkeling gear was used in water depths up to 1m (Figures 5 and 6). Occasional tactile searches through the substrate were made with hands to help ensure that buried unionids were not overlooked. At most sites, one surveyor snorkeled deeper habitat while one or two surveyors used glass bottom buckets in shallower habitat. At site 30 in Maceday Lake and site 38 in West Graham Lake, only snorkel gear was used to avoid disturbing substrate and decreasing visibility by wading with glass bottom buckets. These survey methods were chosen because of their efficiency in covering large areas of habitat and detecting mussels at low density. They produce positive presence data but are not the exhaustive sampling effort that would be required to determine absence of unionid mussels from all habitats in an entire lake. Live individuals were identified to species and planted back into the substrate anterior end down (siphon end up) in the immediate vicinity of where they were found. Unionid shells were also identified to species and returned.

Presence of non-native bivalves, zebra mussels and Asian clams (*Corbicula fluminea*), were noted when found. The number of zebra mussels attached to each live unionid mussel was also recorded. Incidental finds, including fishes and aquatic snails were noted for each site. Photographs of representative mussel shells and live individuals, as well as aquatic snails, were taken to document species found. Fish observed while snorkeling were photographed, when possible, to aid in species identification and provide documentation.

Habitat characteristics, including substrate composition, the presence of aquatic vegetation and woody debris, and water clarity were recorded. The substrate within each search area was characterized by estimating percent composition of each of the following six particle size classes (diameter); boulder (>256mm), cobble (256-64mm), pebble (64-16mm), gravel (16-2mm), sand (2-0.0625mm), silt/clay (<0.0625mm) (Hynes 1970). Water clarity was an estimation of visibility of a unionid shell in three categories: high (>2m), medium (1-2m), and low (<1m). Water chemistry measures were taken at selected sites. Conductivity and pH were recorded with an Oakton handheld meter, and total alkalinity and hardness were measured with LaMotte kits (Figure 7). Latitude and longitude of each survey site was recorded with a hand-held GPS unit.

Figure 5. Mussel surveyors using glass bottom buckets in Little Trout Lake, October 2022.

Figure 6. Mussel surveyor using snorkel gear in Lake Oakland with the boat in the background, August 2022. Photo by Marley Huijgen.

Figure 7. Using a kit to measure alkalinity of the water in Lakeville Lake, August 2022.

Results

Unionid mussel shells were found all 15 lakes surveyed except Lower Trout Lake, Price Lake, and West Graham Lake, and were present at 28 of the 48 sites surveyed. These shells provide a record of past native mussel community composition. Live unionid mussels were found in Orchard Lake, Maceday Lake, Lakeville Lake, Tan Lake, and Upper Silver Lake, for a total of six out of 48 sites surveyed (Tables 1 and 2). The three species found live were plain pocketbook (*Lampsilis cardium*), fatmucket (*Lampsilis siliquoidea*), and giant floater (*Pyganodon grandis*)(Figure 8). Shells of the federal listed as endangered snuffbox (*Epioblasma triquetra*) were documented at four of ten sites surveyed in Cass Lake, near a previously documented occurrence of the species (Figure 9). Three days were spent surveying Cass Lake, versus one day for each of the other lakes, because of its larger size and history of supporting the federally endangered snuffbox. Shells of the special concern rainbow (*Cambarunio iris*) were found at four sites in Lake Orion, Loon Lake, and East Graham Lake. Live zebra mussels were found in ten of the 15 lakes and were attached to at least some live unionids at all six sites where live unionid mussels were found (Table 3)(Figure 10). Of the 29 total live unionids documented, 12 (41.4%) had live zebra mussels attached, with a range of zero to 12 and an average of 1.72 zebra mussels per live unionid. Live Asian clams or their shells were noted in 11 lakes.

Six native aquatic snail species (and one terrestrial species, blunt ambersnail, *Oxyloma retusum*) were found, none of which are listed or species of special concern (Table 4). Two non-native invasive aquatic snail taxa (Chinese/Japanese mysterysnail, *Cipangopaludina sp.* and banded mysterysnail, *Vivaparus georgianus*) were found in several lakes. Ten fish species were noted including logperch (*Percina caprodes*), a suitable

host species for the federally endangered snuffbox, and the invasive non-native round goby (*Neogobius melanostomus*)(Figures 11- 13).

Substrate composition varied widely among lakes and sites (Table 5). Twenty-seven of the 48 sites surveyed had a substrate composition of three or more size classes, with gravel and other larger size classes in addition to sand and silt. Seven sites were heavily dominated by fine silt. Water clarity was very high at most sites until substrate was disturbed. In addition to allowing surveys to take place in slightly deeper habitats, snorkeling allowed for surveying sites with high amounts of fine particles with minimal disturbance of the lake bottom and minimal loss of visibility due to suspended particles. Very dense aquatic plant coverage (90-100% or solid chara mat) was present at 11 sites. Water chemistry measures taken at selected sites are reported in Table 6.

Figure 8. Two live plain pocketbook (*Lampsilis cardium*), bottom, and one live giant floater (*Pyganodon grandis*), top, from site 24 in Orchard Lake, August 17, 2022. Live zebra mussels (*Dreissena polymorpha*) are attached to the mussel on the lower right.

Table 1. Locations of unionid mussel survey sites in lakes within the Clinton River watershed, summer 2021 and 2022.

Site #	Waterbody	Access	Latitude (N)	Longitude (W)
1	Cass Lake	DNR Boat Launch	42.61406	-83.37310
2	"	"	42.61311	-83.36496
3	"	"	42.61464	-83.36194
4	"	"	42.61716	-83.35321
5	"	"	42.60868	-83.37230
6	"	"	42.59790	-83.38965
7	"	"	42.60091	-83.39213
8	"	"	42.60213	-83.38650
9	"	"	42.60011	-83.36857
10	"	"	42.602223	-83.357108
11	Lake Orion	"	42.70174	-83.24708
12	"	"	42.78331	-83.24109
13	"	"	42.77415	-83.24756
14	"	"	42.77690	-83.25193
15	"	"	42.77899	-83.25183
16	Lake Oakland	"	42.705886	-83.368107
17	"	"	42.703207	-83.353866
18	"	"	42.695917	-83.353734
19	"	"	42.699065	-83.359451
20	Stony Creek Lake	"	42.733023	-83.073830
21	"	"	42.732243	-83.078426
22	"	"	42.729959	-83.085834
23	Orchard Lake	"	42.594871	-83.368326
24	"	"	42.591403	-83.381152
25	Lower Trout Lake	"	42.740296	-83.218893
26	"	"	42.741092	-83.220813
27	Loon Lake	"	42.678397	-83.351222
28	"	"	42.682363	-83.356124
29	"	"	42.680707	-83.366184
30	Maceday Lake	"	42.703230	-83.432314
31	"	"	42.686079	-83.425745
32	Lakeville Lake	"	42.831628	-83.146301
33	"	"	42.833933	-83.158980
34	"	"	42.826025	-83.153961
35	Prince Lake	"	42.795502	-83.197502
36	"	"	42.797907	-83.197010
37	East Graham Lake	"	42.787650	-83.187406
38	West Graham Lake	"	42.788489	-83.190840
39	Tan Lake (aka Clear Lake)	"	42.815269	-83.298202
40	"	"	42.812188	-83.293333
41	"	"	42.815646	-83.296835
42	"	"	42.816075	-83.302233
43	Deer Lake	Independence Township Boat Ramp	42.732472	-83.427353
44	"	"	42.735175	-83.433696
45	"	"	42.729962	-83.427597
46	Upper Silver Lake	Hawthorne Park Dock	42.677148	-83.324717
47	"	"	42.677881	-83.328603
48	"	"	42.675901	-83.326133

Table 2. Unionid mussel species found at each survey site in lake within the Clinton River watershed, summer 2021 and 2022. Numbers of live unionid mussels and number shells of rare species are given in parentheses (S[#], L[#]). Presence of non-native bivalves is noted. (Fed. E= Federally listed as Endangered; SC= species of special concern) (zms= live zebra mussels [*Dreissena polymorpha*] attached to live unionid mussels)

		Cass Lake										Lake Orion				
Common Name	**Species**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Rainbow (SC)	*Cambarunio iris*											S(2)				
Snuffbox (Fed. E)	*Epioblasma triquetra*		S(1f)	S(1m)	S(1f, 1m)	S(1f, 2m)										
Spike	*Eurynia dilatata*		S(2)	S(~30)	S(4)	S(30+)			S	S(3)	S(1)					
Plain pocketbook	*Lampsilis cardium*															
Fatmucket	*Lampsilis siliquoidea*					S			S	S(2)		S				
Giant floater	*Pyganodon grandis*	S(1)										S				S(1)
Strange floater	*Strophitus undulatus*					S										
Approx. area searched (m^2)		120	320	100	130	320	120	280	280	280	420	480	360	360	280	180
Search time (person*minutes)		42	60	15	44	74	28	30	32	42	120	120	60	45	30	24
Asian clam	*Corbicula fluminea*				S	S			L			L	L			L
Zebra mussel	*Dreissena polymorpha*	L	S	L	S	L	L	L	L	L	L	L	L	L	L	L

Table 2. Continued.

		Lake Oakland				Stony Creek Lake			Orchard Lake		Lower Trout Lake	
Common Name	**Species**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**
Rainbow (SC)	*Cambarunio iris*											
Snuffbox (Fed. E)	*Epioblasma triquetra*											
Spike	*Eurynia dilatata*											
Plain pocketbook	*Lampsilis cardium*								L(1)zms, S(3)zms			
Fatmucket	*Lampsilis siliquoidea*				S(5)				L(1)zms	L(2)zms		
Giant floater	*Pyganodon grandis*						S(3)	S(1)		L(1)zms		
Strange floater	*Strophitus undulatus*											
Approx. area searched (m^2)		100	450	80	80	160	120	160	160	140	240	270
Search time (person*minutes)		30	26	25	45	70	40	50	70	60	108	165
Asian clam	*Corbicula fluminea*		S		L	L	S	S	L(1w/zms)	L		
Zebra mussel	*Dreissena polymorpha*		S		S	L	S	L	S	L		

Table 2. Continued.

Common Name	Species	Loon Lake			Maceday Lake		Lakeville Lake			Prince Lake		East Graham Lake
		27	28	29	30	31	32	33	34	35	36	37
Rainbow (SC)	*Cambarunio iris*	S(8)	S(6)									S(1)
Snuffbox (Fed. E)	*Epioblasma triquetra*											
Spike	*Eurynia dilatata*		S(4)									
Plain pocketbook	*Lampsilis cardium*											
Fatmucket	*Lampsilis siliquoidea*	S(8)	S(15)	S(1)		S(1)						
Giant floater	*Pyganodon grandis*	S(1)	S(1)	S(5)		L(1)zms		S(1)	L(5)zms			
Strange floater	*Strophitus undulatus*											
Approx. area searched (m^2)		300	600	450	100	600	400	500	200	75	75	100
Search time (person*minutes)		150	120	90	30	132	105	120	105	50	50	90
Asian clam	*Corbicula fluminea*	L	L	L		S	S					
Zebra mussel	*Dreissena polymorpha*		L	L	L	L	S	L	L			

Table 2. Continued.

Common Name	Species	West Graham Lake	Tan Lake				Deer Lake			Upper Silver Lake		
		38	39	40	41	42	43	44	45	46	47	48
Rainbow (SC)	*Cambarunio iris*											
Snuffbox (Fed. E)	*Epioblasma triquetra*											
Spike	*Eurynia dilatata*											
Plain pocketbook	*Lampsilis cardium*											
Fatmucket	*Lampsilis siliquoidea*		S(6)	S(5)	S(12)		S(2)zms	S(5)zms				
Giant floater	*Pyganodon grandis*		L(2)zms				S(1)zms	S(1)		L(16)zms		
Strange floater	*Strophitus undulatus*											
Approx. area searched (m^2)		314	350	300	350	150	1200	360	400	70	50	50
Search time (person*minutes)		30	150	60	90	60	100	30	35	60	15	15
Asian clam	*Corbicula fluminea*		L	L	L		S		S	S		
Zebra mussel	*Dreissena polymorpha*		L		L	S	L	S	L	L		

Table 3. Zebra mussel (*Dreissena polymorpha*) colonization frequency (%cu) and intensity (zm/u) for sites where live zebra mussels were found attached to live unionid mussels, Clinton River watershed, summer 2021 and 2022. (ucz = number of unionid mussels colonized by zebra mussels; %cu = percentage of unionids colonized by zebra mussels; zm/u = mean number of zebra mussels attached to each unionid mussel)

		Orchard Lake								Maceday Lake			
		23				24				31			
Common Name	**Species**	**u**	**ucz**	**%cu**	**zm/u**	**u**	**ucz**	**%cu**	**zm/u**	**u**	**ucz**	**%cu**	**zm/u**
Rainbow (SC)	*Cambarunio iris*												
Snuffbox (Fed. E)	*Epioblasma triquetra*												
Spike	*Eurynia dilatata*												
Plain pocketbook	*Lampsilis cardium*	1	1	100	2.0								
Fatmucket	*Lampsilis siliquoidea*	1	1	100	10.0	2	2	100	5.5				
Giant floater	*Pyganodon grandis*					1	1	100	3.0	1	1	100	5.0
Strange floater	*Strophitus undulatus*												
	Total	2	2	100	6.0	3	3	100	4.7	1	1	100	5.0

Table 3. Continued .

		Lakeville Lake				Tan Lake				Upper Silver Lake			
		34				39				46			
Common Name	**Species**	**u**	**ucz**	**%cu**	**zm/u**	**u**	**ucz**	**%cu**	**zm/u**	**u**	**ucz**	**%cu**	**zm/u**
Rainbow (SC)	*Cambarunio iris*												
Snuffbox (Fed. E)	*Epioblasma triquetra*												
Spike	*Eurynia dilatata*												
Plain pocketbook	*Lampsilis cardium*												
Fatmucket	*Lampsilis siliquoidea*												
Giant floater	*Pyganodon grandis*	5	2	40	0.6	2	1	50	6.0	16	3	18.8	0.25
Strange floater	*Strophitus undulatus*												
	Total	5	2	40	0.6	2	1	50	6.0	16	3	18.8	0.25

Table 4. Incidental finds, including aquatic snails (Gastropoda) and fish, observed during mussel surveys for each lake surveyed within the Clinton River watershed, summer 2021 and 2022.

Common Name	Species/Taxa	Cass	Orion	Oakland	Stony Creek	Orchard	Lower Trout	Loon	Maceday
Snails	Gastropoda								
Pointed campeloma	*Campeloma decisum*	x	x			x		x	
Chinese/Japanese mysterysnail	*Cipangopaludina sp.*	x					x		
Banded mysterysnail	*Vivaparus georgianus*		x				x		
Two-ridge rams-horn	*Helisoma anceps*	x							
Blunt ambersnail	*Oxyloma retusum*								
Physa	*Physella sp.*	x						x	
Marsh rams-horn	*Planorbella trivolvis*	x							
Bell-mouth ram's horn	*Planorbella campanulata*	x	x	x				x	x
Three-ridge valvata	*Valvata tricarinata*							x	
Fish									
Johnny darter	*Etheostoma nigrum*								
Green sunfish	*Lepomis cyanellus*								
Pumpkinseed	*Lepomis gibbosus*		x						
Bluegill	*Lepomis macrochirus*		x[R]	x[R]			x[R]		
Smallmouth bass	*Micropterus dolomieu*	x[R]						x[R]	x[R]
Largemouth bass	*Micropterus salmoides*	x[R]		x[R]	x[R]			x[R]	x[R]
Round goby	*Neogobius melanostomus*				x[SR]				
Blacknose shiner	*Notropis heterolepis*			x					x
Logperch	*Percina caprodes*							x[SR]	
Yellow perch	*Perca flavescens*			x[R]					

[R] Host fish species for the species of special concern rainbow (*Cambarunio iris*)

[SR] Host fish species for the federally endangered snuffbox (*Epioblasma triquetra*) and special concern rainbow.

Table 4. Continued.

Common Name	Species/Taxa	Lakeville	Prince	East Graham	West Graham	Tan	Deer	Upper Silver
Snails	Gastropoda							
Pointed campeloma	*Campeloma decisum*	x				x	x	
Chinese/Japanese mysterysnail	*Cipangopaludina sp.*				x			
Banded mysterysnail	*Vivaparus georgianus*				x	x		
Two-ridge rams-horn	*Helisoma anceps*		x	x		x	x	
Blunt ambersnail	*Oxyloma retusum*			x				
Physa	*Physella sp.*							
Marsh rams-horn	*Planorbella trivolvis*							
Bell-mouth ram's horn	*Planorbella campanulata*	x	x	x		x	x	
Three-ridge valvata	*Valvata tricarinata*			x				
Fish								
Johnny darter	*Etheostoma nigrum*						x	
Green sunfish	*Lepomis cyanellus*				x[R]			
Pumpkinseed	*Lepomis gibbosus*			x	x			
Bluegill	*Lepomis macrochirus*			x[R]	x[R]	x[R]		x[R]
Smallmouth bass	*Micropterus dolomieu*							
Largemouth bass	*Micropterus salmoides*		x[R]	x[R]	x[R]	x[R]	x[R]	x[R]
Round goby	*Neogobius melanostomus*							
Blacknose shiner	*Notropis heterolepis*		x	x	x	x	x	
Logperch	*Percina caprodes*						x[SR]	
Yellow perch	*Perca flavescens*				x[R]	x[R]		x[R]

[R] Host fish species for the species of special concern rainbow (*Cambarunio iris*)

[SR] Host fish species for the federally endangered snuffbox (*Epioblasma triquetra*) and special concern rainbow.

Table 5. Physical habitat characteristics recorded at mussel survey sites in lakes within the Clinton River watershed, summer 2021 and 2022. Percentage of each substrate particle size class was estimated visually at each mussel survey site. Diameter of each size class: boulder (>256mm), cobble (256-64mm), pebble (64-16mm), gravel (16-2mm), sand (2-0.0625mm), silt/clay (<0.0625mm). Water clarity is an estimation of visibility of a unionid shell in three categories: high (>2m), medium (1-2m), and low (<1m).

Site #	Lake	Boulder	Cobble	Pebble	Gravel	Sand	Silt	Aquatic Plants	Woody Debris	Water Clarity	Habitat Note
1	Cass					60	40	x		1-2m	Eroded shore
2	"			15	10	60	15			>2m	seawall
3	"			25	25	30	20			1-2m	seawall
4	"			25	25	40	10			>2m	
5	"			20	20	30	30	x	x	>2m	Eroded shore
6	"					50	50	x	x	>2m	
7	"				10	60	30			>2m	
8	"			10	20	60	10		x	>2m	
9	"			30	10	50	10			>2m	
10	"					95	5	x		1-2m	
11	Orion	10	20	20	20	20	10	x		>2m	
12	"		20	20	20	20	20	x	x	>2m	rip rap
13	"				20	50	30	x	x	>2m	
14	"		20*	20	20	20	20	x	x	>2m	* Rip rap
15	"	5	30	20	15	10	20	x	x	>2m	Eroded shore
16	Oakland						100	x	x	1-2m	
17	"						100	x	x	1-2m	~30cm deep silt
18	"					40	60	x		1-2m	Solid mat of chara
19	"				10	80	10	x		1-2m	
20	Stony Creek					90	10	x		>2m	
21	"					30	70	x	x	>2m	
22	"	1	1	8	10	60	20	x		>2m	
23	Orchard					70	30			>2m	
24	"					70	30	x		>2m	
25	Lower Trout	2		2	3	50	43	x	x	1-2m	Solid mat of chara
26	"		10	20	20	30	20	x		1-2m	Solid mat of chara
27	Loon			5	5	50	40	x	x	>2m	
28	"			10	10	60	20	x		>2m	
29	"					40	60	x	x	>2m	
30	Maceday						100	x	x	>2m	90% aquatic plant coverage
31	"				5	75	20			1-2m	
32	Lakeville				5	80	15	x		1-2m	
33	"					70	30	x	x	1-2m	
34	"		5	15	10	30	40		x	1-2m	
35	Prince						100	x	x	<1m	100% aquatic plant coverage
36	"						100	x	x	1-2m	100% aquatic plant coverage
37	East Graham			15	40	40	5	x		>2m	
38	West Graham						100	x	x	1-2m	100% aquatic plant coverage
39	Tan				5	20	75	x		1-2m	
40	"						100	x		>2m	Solid mat of chara
41	"					20	80	x		>2m	20% chara mat
42	"		5	5	10	10	70	x		1-2m	
43	Deer					50	50	x		>2m	
44	"				10	60	30	x		>2m	
45	"				10	60	30	x		>2m	
46	Upper Silver				10	50	40	x	x	>2m	90% aq. plants
47	"					40	60	x		>2m	100% aquatic plant coverage
48	"					40	60	x		>2m	100% aquatic plant coverage

Table 6. Water chemistry measures taken at select mussel survey sites in lakes within the Clinton River watershed, summer 2021 and 2022.

Site #	Lake	pH	Conductivity (µS)	Total Alkalinity (mg/l)	Hardness (Ca and Mg, mg/l)	Water Temp. (C)
16	Oakland	8.24	981	-	172	27.4
20	Stony Creek	7.70	667	184	188	26.1
23	Orchard	8.16	772	132	136	24.9
25	Lower Trout	8.45	829	80	148	26.6
27	Loon	8.47	941	144	176	26.3
30	Maceday	8.00	941	184	200	26.0
32	Lakeville	8.37	557	148	188	25.8
35	Prince	8.04	516	112	162	25.6
37	East Graham	8.04	784	146	200	25.3
39	Tan	8.34	588	140	184	25.0
46	Upper Silver	-	-	116	140	26.2

Figure 9. Female (left) and male (right) snuffbox (*Epioblasma triquetra*) shells, a federally endangered mussel species from site 5 in Cass Lake, September 16, 2022.

Figure 10. Giant floater (*Pyganodon grandis*) with live zebra mussels (*Dreissena polymorpha*) attached, found at site 31 in Maceday Lake, August 25, 2022.

Figure 11. Logperch (*Percina caprodes*), one of the host fish species of the federally endangered snuffbox (*Epioblasma triquetra*) photographed while snorkeling at site 28 in Loon Lake, August 24, 2022.

Figure 12. Johnny darter (*Etheostoma nigrum*) and an empty zebra mussel (*Dreissena polymorpha*) shell at site 43 in Deer Lake, October 6, 2022.

Figure 13. Blacknose shiner (*Notropis heterolepis*) photographed while snorkeling at site 29 in Loon Lake, August 24, 2022.

Discussion

The three unionid mussel species found live: plain pocketbook, fatmucket, and giant floater, and two mussel species found only as shell: rainbow and strange floater (*Strophitus undulatus*, aka creeper), are host generalists. Plain pocketbook has been found to successfully utilize 15 different host fish species (and one salamander species), fatmucket 20 host fish species, giant floater 41, rainbow 15, and strange floater 37. Two of the species found only as shell, snuffbox and spike (*Eurynia dilatata*), are relatively specialized in their host use and have only eight and nine known host fish species respectively (Watters et al. 2009). Host generalists may have greater chances of encountering suitable hosts depending on the local fish community and that might lead to them being more adapt at re-establishing populations in areas where they've been locally extirpated by zebra mussels.

The known hosts for the federally endangered snuffbox that occur in Michigan are logperch, mottled sculpin (*Cottus bairdii*), blackside darter (*Percina maculata*), and the non-native round goby, two of which were found in this survey. Logperch were relatively abundant when present, though they were not noted in Cass Lake where empty snuffbox shells were found. Round gobies were very abundant in Stony Creek Lake but were also not noted in Cass Lake. Rainbow is known to use seven fish species noted as incidental finds in this survey: green sunfish (*Lepomis cyanellus*), largemouth bass (*Micropterus salmoides*), smallmouth bass (*Micropterus dolomieu*), round goby, yellow perch (*Perca flavescens*), bluegill (*Lepomis macrochirus*), and logperch (Watters et al. 2009). Rainbow and at least one of its host fish species co-occur at all sites where rainbow were found (bluegill at Lake Orion site 11; smallmouth bass, largemouth bass, and logperch at Loon Lake site 27; logperch at Loon Lake site 28; bluegill and largemouth bass at East Graham Lake site 37). The fish species noted incidentally are hosts for a wide range of unionid mussels. For example, of the mussel species documented, Johnny darter is a known host of spike, fatmucket, giant floater, and strange floater; and green sunfish a known host of rainbow, spike, plain pocketbook, fatmucket, giant floater, and strange floater (Freshwater Mussel Host Database 2017). It should be emphasized that host suitability tests for unionid mussels are often done in laboratory situations and may not reflect actual host usage in the wild.

Mussel species with a higher number of mobile fish host species (e.g. plain pocketbook, fatmucket, and giant floater) may be quicker to return and re-establish populations in habitats where zebra mussels had previously extirpated local populations. In addition to being host generalists, the three unionid mussel species found live are also among the most adapt of the unionid mussels to living in a wide range of habitat conditions including high proportions of silt and still water lentic conditions. A young giant floater found at site 39 in Tan Lake indicates recent recruitment as well as ongoing impact from zebra mussels (Figure 14).

Glochidia are transported with their host fish until they transform into the adult form and drop off the fish. This allows unionid mussels, which are otherwise mostly sedentary, to migrate to new habitats and exchange genes among populations. Barriers to fish host movement also act as barriers to unionid mussel movement (Watters 1996). Since surface water connectivity is beneficial for fish (King et al. 2020) and mussels, assessing and mitigating barriers to the passage of fish among inland lakes and waterways in southeast Michigan may bring benefits for the conservation of these species.

Clear signs of historical and current impacts to native mussels by zebra mussel colonization were observed. In addition to the present-day high rate of zebra mussel colonization on live mussels found, there were also shells of varying states of wear (and presumably time since mortality) with zebra mussel byssal threads attached. Though some zebra mussels could have attached to the shells after the unionid mussels died, it is likely that at least some attached while the unionid mussels were alive and played a role in their demise. Live zebra mussels were found attached to recent dead unionid shells in Orchard Lake and Deer Lake (sites 23, 43, and 44), indicating recent impact on native mussels in addition to the current impact of zebra mussels attached to live native mussels found.

The condition of shells found ranged from recent dead (time since death approximately a few weeks) to heavily worn (time since death several months to many years). The decay of unionid shells is highly variable depending on a number of factors such as shell size and thickness, water chemistry (Ca, pH, and dissolved inorganic C), presence of current, and whether or not the shell is buried in sediments or exposed to abrasion on the surface of the substrate (Strayer and Malcom 2007, Ilarri et al. 2019). Most lakes in Michigan have not had documented surveys for native mussels. The mussel shells found in lakes that have been impacted by zebra mussels provide a slowly decaying record of past pre-invasion native mussel community composition. If lakes are not surveyed before shells deteriorate beyond the point of making accurate species identifications, information on pre-zebra mussel invasion community composition will be lost.

Lake St. Clair, the receiving waterbody of the Clinton River watershed, was the center of the North American zebra mussel invasion that began in the late 1980s. With recreational boats, trailers, and other watercraft as a vector for zebra mussel spread, inland lakes with boat access in southeastern Michigan were points of introduction and further spread. Lakes within the Clinton River watershed and their native mussel communities were among the earliest in North America to be impacted by zebra mussels. Unionid mussel communities in some of these lakes appear to have been extirpated by zebra mussels, while in others (e.g. Orchard, Maceday, Lakeville, Tan, and Upper Silver Lakes), unionid mussels persist in spite of ongoing impacts from zebra mussels. It's important to note that our surveys sampled a small fraction of the available habitat in each lake, so that zero unionid mussels found in a lake should not be assumed to mean unionid mussels are without a doubt absent from the lake. Lakes in northern lower peninsula of Michigan have more recently been exposed to the pressures of zebra mussels and subsequently are less further along the impact and decline timeline that begins at introduction. There is a north-south gradient of zebra mussel impact on native mussels based on the extra time it takes for zebra mussels to expand their range north from their point of introduction. Native unionid mussel species richness and density was higher in Round Lake near Petosky Michigan (Badra 2016 unpublished data) than in lakes in the Clinton River watershed with similar intensities of zebra mussel colonization. The Round Lake unionid mussel community has been subject to zebra mussel impact for less time than in southern lakes. Out of 21 inland lakes surveyed within Hiawatha National Forest in the Upper Peninsula of Michigan in 2015 and 2018, 12 had live native mussels and all 21 were apparently zebra mussel free (Cuthrel et al. 2015, Cuthrel et al. 2019).

There is evidence that certain northern Michigan lakes with low levels of calcium (below 28.3 mg/L) are resistant to zebra mussel invasion due to their physiological requirements yet are capable of supporting native unionid mussels. These types of lakes might then act as a refuge for native mussels from zebra mussels (Hollandsworth et al. 2011). Calcium concentrations in the 21 Upper Peninsula Lakes ranged from 4-124 mg/L. Calcium concentrations measured in the southeast Michigan lakes surveyed in this study are much higher (Table 6) and do not appear to be limiting factor for native or invasive mussels, or aquatic snails based on their widespread occurrence.

Impacts of zebra mussels on a particular lake or river ecosystem and associated benthic fauna can change over time. A 20-year study in the Hudson River, New York, showed an initial steep decline in density of all benthic animals due to zebra mussel invasion over an 8-year period, then a recovery to near pre-invasion densities. Over the study period zebra mussel survivorship decreasing over 100-fold (Strayer et al. 2011). The timeline of zebra invasion and impact on native unionid mussel communities might not necessarily end with complete extirpation of native mussels and a steady high-level presence of zebra mussels. Even in Lake St. Clair, ground zero for the invasion, unionid mussels persist in certain areas (Zanata et al. 2002, McGoldrick et al. 2009). Though the impact has been severe, there can still be opportunities for conservation of native mussels in southeast Michigan's inland lakes.

Projects in lakes such as dredging, filling, construction or placing of structures have the potential to negatively impact native mussels, including listed species. Knowing if rare mussels are present in a waterbody is an essential piece of information when assessing the potential impact of proposed projects on native species and

lake ecosystems. In many cases, listed mussels are not present at a given location, and projects can proceed without modifications. In some cases, when listed mussels are present at a proposed project site, mitigation such as modifying the project or relocating mussels can be carried out to minimize impacts to native mussels species while still allowing the project to proceed. The aim of these surveys is to provide information to support the conservation of the public trust ecosystems of inland lakes and the native mussel species that are part of them.

Figure 14. A young live giant floater (*Pyganodon grandis*) with live zebra mussels (*Dreissena polymorpha*) attached from site 29 in Loon Lake, August 24, 2022. This individual is approximately three years old, indicating recent recruitment in spite of impacts from zebra mussels.

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Appendix I.

Appendix I. Aquatic snails (Gastropoda) and fish observed incidentally during mussel surveys for each site.

		Cass Lake									
Common Name	**Species/Taxa**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Snails	Gastropoda										
Pointed campeloma	*Campeloma decisum*	x	x			x					
Chinese/Japanese mysterysnail	*Cipangopaludina sp.*	x				x	x				
Banded mysterysnail	*Viviparus georgianus*										
Two-ridge rams-horn	*Helisoma anceps*	x					x				
Blunt ambersnail	*Oxyloma retusum*										
Physa	*Physella sp.*	x									
Marsh rams-horn	*Planorbella trivolvis*	x									
Bell-mouth ram's horn	*Planorbella campanulata*	x									
Three-ridge valvata	*Valvata tricarinata*										
Fish											
Johnny darter	*Etheostoma nigrum*										
Green sunfish	*Lepomis cyanellus*										
Pumpkinseed	*Lepomis gibbosus*										
Bluegill	*Lepomis macrochirus*										
Smallmouth bass	*Micropterus dolomieu*	x[R]									
Largemouth bass	*Micropterus salmoides*										x[R]
Round goby	*Neogobius melanostomus*										
Blacknose shiner	*Notropis heterolepis*										
Logperch	*Percina caprodes*										
Yellow perch	*Perca flavescens*										

[R] Host fish species for the species of special concern rainbow (*Cambarunio iris*)

[SR] Host fish species for the federally endangered snuffbox (*Epioblasma triquetra*) and special concern rainbow.

Appendix I. Continued.

Common Name	Species/Taxa	Lake Orion					Lake Oakland				Stony Creek Lake		
		11	12	13	14	15	16	17	18	19	20	21	22
Snails	Gastropoda												
Pointed campeloma	*Campeloma decisum*	x		x	x								
Chinese/Japanese mysterysnail	*Cipangopaludina sp.*												
Banded mysterysnail	*Viviparus georgianus*		x	x	x								
Two-ridge rams-horn	*Helisoma anceps*												
Blunt ambersnail	*Oxyloma retusum*												
Physa	*Physella sp.*												
Marsh rams-horn	*Planorbella trivolvis*												
Bell-mouth ram's horn	*Planorbella campanulata*		x	x			x						
Three-ridge valvata	*Valvata tricarinata*												
Fish													
Johnny darter	*Etheostoma nigrum*												
Green sunfish	*Lepomis cyanellus*												
Pumpkinseed	*Lepomis gibbosus*	x											
Bluegill	*Lepomis macrochirus*	x[R]	x[R]				x[R]		x[R]				
Smallmouth bass	*Micropterus dolomieu*												
Largemouth bass	*Micropterus salmoides*						x[R]	x[R]	x[R]			x[R]	
Round goby	*Neogobius melanostomus*										x[SR]	x[SR]	
Blacknose shiner	*Notropis heterolepis*						x						
Logperch	*Percina caprodes*												
Yellow perch	*Perca flavescens*						x[R]						

[R] Host fish species for the species of special concern rainbow (*Cambarunio iris*)

[SR] Host fish species for the federally endangered snuffbox (*Epioblasma triquetra*) and special concern rainbow.

Appendix I. Continued.

Common Name	Species/Taxa	Orchard Lake		Lower Trout Lake		Loon Lake			Maceday Lake	
		23	24	25	26	27	28	29	30	31
Snails	Gastropoda									
Pointed campeloma	*Campeloma decisum*	x				x	x	x		
Chinese/Japanese mysterysnail	*Cipangopaludina sp.*			x	x					
Banded mysterysnail	*Viviparus georgianus*			x	x					
Two-ridge rams-horn	*Helisoma anceps*									
Blunt ambersnail	*Oxyloma retusum*									
Physa	*Physella sp.*					x				
Marsh rams-horn	*Planorbella trivolvis*									
Bell-mouth ram's horn	*Planorbella campanulata*					x		x		x
Three-ridge valvata	*Valvata tricarinata*					x				
Fish										
Johnny darter	*Etheostoma nigrum*									
Green sunfish	*Lepomis cyanellus*									
Pumpkinseed	*Lepomis gibbosus*									
Bluegill	*Lepomis macrochirus*			x[R]						
Smallmouth bass	*Micropterus dolomieu*					x[R]		x[R]	x[R]	
Largemouth bass	*Micropterus salmoides*					x[R]		x[R]	x[R]	
Round goby	*Neogobius melanostomus*									
Blacknose shiner	*Notropis heterolepis*							x	x	
Logperch	*Percina caprodes*					x[SR]	x[SR]			
Yellow perch	*Perca flavescens*									

[R] Host fish species for the species of special concern rainbow (*Cambarunio iris*)

[SR] Host fish species for the federally endangered snuffbox (*Epioblasma triquetra*) and special concern rainbow.

Appendix I. Continued.

Common Name	Species/Taxa	Lakeville Lake 32	Lakeville Lake 33	Lakeville Lake 34	Prince Lake 35	Prince Lake 36	East Graham Lake 37	West Graham Lake 38
Snails	Gastropoda							
Pointed campeloma	*Campeloma decisum*	x		x				
Chinese/Japanese mysterysnail	*Cipangopaludina sp.*							x
Banded mysterysnail	*Viviparus georgianus*							x
Two-ridge rams-horn	*Helisoma anceps*				x	x	x	
Blunt ambersnail	*Oxyloma retusum*						x	
Physa	*Physella sp.*							
Marsh rams-horn	*Planorbella trivolvis*							
Bell-mouth ram's horn	*Planorbella campanulata*	x	x		x	x	x	
Three-ridge valvata	*Valvata tricarinata*						x	
Fish								
Johnny darter	*Etheostoma nigrum*							
Green sunfish	*Lepomis cyanellus*							x
Pumpkinseed	*Lepomis gibbosus*						x	x
Bluegill	*Lepomis macrochirus*						x[R]	x[R]
Smallmouth bass	*Micropterus dolomieu*							
Largemouth bass	*Micropterus salmoides*				x[R]		x[R]	x[R]
Round goby	*Neogobius melanostomus*							
Blacknose shiner	*Notropis heterolepis*				x		x	x
Logperch	*Percina caprodes*							
Yellow perch	*Perca flavescens*							x[R]

[R] Host fish species for the species of special concern rainbow (*Cambarunio iris*)

[SR] Host fish species for the federally endangered snuffbox (*Epioblasma triquetra*) and special concern rainbow.

Appendix I. Continued.

		Tan Lake				Deer Lake			Upper Silver Lake		
Common Name	**Species/Taxa**	**39**	**40**	**41**	**42**	**43**	**44**	**45**	**46**	**47**	**48**
Snails	Gastropoda										
Pointed campeloma	*Campeloma decisum*		x	x	x	x					
Chinese/Japanese mysterysnail	*Cipangopaludina sp.*										
Banded mysterysnail	*Viviparus georgianus*	x	x	x	x						
Two-ridge rams-horn	*Helisoma anceps*	x					x				
Blunt ambersnail	*Oxyloma retusum*										
Physa	*Physella sp.*										
Marsh rams-horn	*Planorbella trivolvis*										
Bell-mouth ram's horn	*Planorbella campanulata*	x		x	x	x					
Three-ridge valvata	*Valvata tricarinata*										
Fish											
Johnny darter	*Etheostoma nigrum*					x					
Green sunfish	*Lepomis cyanellus*										
Pumpkinseed	*Lepomis gibbosus*										
Bluegill	*Lepomis macrochirus*				x[R]					x[R]	x[R]
Smallmouth bass	*Micropterus dolomieu*										
Largemouth bass	*Micropterus salmoides*		x[R]	x[R]	x[R]	x[R]				x[R]	x[R]
Round goby	*Neogobius melanostomus*										
Blacknose shiner	*Notropis heterolepis*		x			x					
Logperch	*Percina caprodes*					x[SR]					
Yellow perch	*Perca flavescens*		x[R]	x[R]	x[R]				x[R]		

[R] Host fish species for the species of special concern rainbow (*Cambarunio iris*)

[SR] Host fish species for the federally endangered snuffbox (*Epioblasma triquetra*) and special concern rainbow.