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## The flathead catfish invasion of the Great Lakes

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### ABSTRACT

A detailed review of historical literature and museum data revealed that flathead catfish were not historically native in the Great Lakes Basin, with the possible exception of a relict population in Lake Erie. The species has invaded Lake Erie, Lake St. Clair, Lake Huron, nearly all drainages in Michigan, and the Fox/Wolf and Milwaukee drainages in Wisconsin. They have not been collected from Lake Superior yet, and the temperature suitability of that lake is questionable. Flathead catfish have been stocked sparingly in the Great Lakes and is not the mechanism responsible for their spread. A stocking in 1968 in Ohio may be one exception to this. Dispersal resulted from both natural range expansions and unauthorized introductions. The invasion is ongoing, with the species invading both from the east and the west to meet in northern Lake Michigan. Much of this invasion has likely taken place since the 1990s. This species has been documented to have significant impacts on native fishes in other areas where it has been introduced; therefore, educating the public not to release them into new waters is important. Frequent monitoring of rivers and lakes for the presence of this species would detect new populations early so that management actions could be utilized on new populations if desired.

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### Introduction

Flathead catfish *Pylodictis olivaris* are native to the central portion of the United States including the Mississippi, Missouri, Ohio, Tennessee, Arkansas, and Rio Grande river drainages. They are not native east of the Appalachians or west of the Rocky Mountains (Fuller et al., 1999; Page and Burr, 2011; U.S. Geological Survey (USGS) 2017a). Few of many historical publications record its presence in the Great Lakes. Osburn (1901), Dymond (1922), and Hubbs (1926) mentioned only a single record from McCormick (1892) for the Great Lakes (Lake Erie, Lorain County, Ohio). However, there are no specimens to support this record (Hubbs, 1926). Trautman (1957) cited the 1892 report in his early book, but Greene (1935) stated that Trautman believed the 1892 record was erroneous. A few publications such as Bailey and Smith (1981), Underhill (1986), and Bailey et al. (2004) list this species as native to Lake Michigan tributaries and to Lake Erie and its tributaries, although flathead catfish were not listed for the Great Lakes and connecting waters by Evermann (1902). Furthermore, none of the following Great Lakes publications list flathead catfish for the Great Lakes Basin: Cope (1864, 1865), Jordan (1877), Bollman (1890), Kirsch (1893), Eigenmann and Benson (1893), Hay (1894), Jordan and Evermann

(1896, 1898), Evermann (1902), Michael (1904), Forbes and Richardson (1920), and Greene (1935). The historical publications do list their presence in the Ohio and Mississippi Basins. More recently, the species is not listed as present in the Great Lakes Basin in Illinois or Indiana by Smith (1979), Simon and Stewart (1999), Simon and Moy (1999), and Simon (2011). There are no verified records for Lake Erie in Pennsylvania. Cooper (1983) mapped a historical record for Lake Erie in Pennsylvania but did not provide any specifics. Stauffer Jr. et al. (2016) apparently thought this record erroneous and did not map it in the updated version of the state fish book. The species has not been recorded in Lake Ontario (Carlson et al., 2016; Crossman and Van Meter, 1979; Evermann and Kendall, 1901; Underhill, 1986).

Because of this species' habitat preferences (i.e., deeper water and in holes or under debris), flathead catfish can be difficult to sample. Therefore, we examined historical literature to determine how it had been recorded within its native range. Forbes and Richardson (1920) listed this species from Illinois and gave a description of its native range, which did not include the Great Lakes or the state of Michigan. Evermann and Cox (1896) listed this species for the Missouri River Basin, as did Eigenmann and Benson (1893) for the Ohio River Basin in Indiana. Therefore, it seems reasonable that it would have appeared in early publications about Great Lakes drainages had it occurred there, because even early observers correctly listed it when present.

Our objectives in this paper are to: 1) determine if flathead catfish are native to the Great Lakes; 2) if not; what were the likely means of

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introduction, 3) determine when introduction likely occurred; and 4) provide the current distribution of this species in the Great Lakes.

## Methods

Location data of flathead catfish occurrences were obtained from the Nonindigenous Aquatic Species (NAS) Database (Fuller and Nielson, 2015; U.S. Geological Survey (USGS) 2017a), the National Fish Habitat Partnership (2016), FishNet (<http://fishnet2.net>), VertNet (<http://vernet.org>), and the Global Biodiversity Information Facility (GBIF) (<http://gbif.org>). In addition, the following museums that are not members of GBIF were searched: American Museum of Natural History, Academy of Natural Sciences Philadelphia, New York State Museum Fish Collection, the Field Museum in Chicago, and the Cleveland Museum of Natural History. Numerous state and federal agency fisheries biologists were contacted to obtain knowledge and occurrence records.

Many reports came from the Michigan Master Anglers Database held by Michigan Department of Natural Resources (MDNR). We recognize there may be some errors due to untruthful reports from some anglers and that these only represent trophy-sized catches since 1973. The species may have been in these locations prior to entry in the Master Anglers Database. All available on-line management reports dating back to 1966 from MDNR (1966–2017) and Wisconsin Department of

Natural Resources (WDNR) (1966–2017) were reviewed for information on flathead catfish in the Great Lakes Basin. All flathead catfish reports from the MDNR's Fish Collection System were included.

Reports of charter boat catch from Michigan waters of the Great Lakes 1989–1999 were consulted (Rakoczy et al., 1989–1999), however, we found these only tracked salmonids, yellow perch *Perca flavescens*, and walleye *Sander vitreus*. U.S. Fish Commission Reports from 1886 to 1903 were reviewed for any stockings in the Great Lakes as was the Great Lakes Fish Stocking Database (Great Lakes Fishery Commission, 2015). The National Oceanic and Atmospheric Administration's (NOAA) Great Lakes Environmental Research Laboratory and U.S. Geological Survey's Great Lakes Research Center were contacted for any Great Lakes flathead catfish data, and the NOAA database of Great Lakes commercial fishery landings was searched (NOAA, 2018). Fisheries dependent and independent data were also obtained from Michigan Department of Natural Resources, Ohio Environmental Protection Agency (OEPA), the Northeast Ohio Regional Sewer District, Ohio Department of Natural Resources (ODNR), Ohio State Museum of Biological Diversity, and Wisconsin Department of Natural Resources. We have compiled all occurrence data (including dates, locations, geographic coordinates, and data source) acquired from these sources into the U.S. Geological Survey's Nonindigenous Aquatic Species Database. They are also available as a data release from <https://doi.org/10.5066/F7V69HSC>.



**Fig. 1.** Flathead catfish distribution records in the Great Lakes Basin 1890–1969. Squares represent collections before 1949, circles represent collections 1950–1959, triangles represent collections 1960–1969. Flathead catfish may not still be present in all locations.

## Results

The information presented below is a generalization of the invasion of the Great Lakes Basin. Details are presented in Electronic Supplementary Material (ESM) Appendix S1.

Aside from McCormick's dubious record which may have been a misidentification of channel catfish *Ictalurus punctatus*, the only population of flathead catfish in the Great Lakes Basin at the turn of the 20th century was a small population in the Huron River, a Lake Erie tributary in Ohio. Trautman (1957) and Van Meter and Trautman (1970) reported that a few fish were taken annually from here since at least 1890 (Fig. 1). The first specimens found from the Lake Michigan drainage were single specimens recorded in the Kalamazoo and Grand rivers in Michigan in the 1920s and in Lake Macatawa, Michigan, in the early 1940s. There were three collections from the Ohio side of Lake Erie and two from the Huron River, Ohio, in the 1940s. By the end of the 1940s, flathead catfish had been documented in five rivers: two in Lake Erie and three in Lake Michigan (Fig. 1).

In 1953, a single fish was collected from the Wolf River in Wisconsin, making this the first report, (or possibly the second, if you include a questionable report from Cahn (1927)) from the western side of Lake Michigan). By the end of the 1950s, flathead catfish were found in a total of six tributary rivers: two in Lake Erie and four in Lake Michigan (Fig. 1). A new Lake Michigan tributary, the White River in Michigan,

was invaded in the 1960s. A 1968 stocking of the Huron River, Ohio, was the first and only agency-authorized stocking in the Lake Erie drainage (Fig. 1). In the 1970s, the first record from the Canadian side of Lake Erie was reported; two more Lake Michigan drainages were invaded (Muskegon and Manistee, Michigan); and flathead catfish reappeared in Lake Macatawa, Michigan, after a 30-year absence (Fig. 2). In the 1980s, flathead catfish were recorded for the first time in 60 years in the Kalamazoo River, Michigan; a second fish was recorded from the Canadian side of Lake Erie; the first occurrence was recorded in Lake St. Clair, demonstrating movement between Lakes Erie and Huron; and a new Lake Michigan drainage record was recorded (St. Joseph River, Michigan) (Fig. 3).

The first occurrences from Lake Huron were recorded during the 1990s, a new drainage in Lake Erie was recorded (Maumee, Ohio), the Michigan Department of Natural Resources stocked flathead catfish in six drainages where they already occurred, and the first record from Lake Superior drainage was reported (Fig. 4). Between 2000 and 2009, the second fish was reported for Lake Huron after a 12-year hiatus; the first records from northern Lake Michigan were reported; and seven new tributary rivers of Lakes St. Clair, Michigan, and Huron were invaded (Clinton, Boardman-Charlevoix, Au Sable, Thunder Bay, and Saginaw in Michigan; Milwaukee in Wisconsin; Sandusky in Ohio; and Kankakee in Illinois). By the end of the first decade of the 2000s, flathead catfish had been recorded in a total of 21 Great Lake tributary



Fig. 2. Flathead catfish distribution records in the Great Lakes Basin until 1979. New locations (1970–1979) are marked by triangles; locations prior to (1970) are marked by circles. Flathead catfish may not still be present in all locations.



**Fig. 3.** Flathead catfish distribution records in the Great Lakes Basin until 1989. New locations (1980–1989) are marked by triangles; locations prior to (1980) are marked by circles. Flathead catfish may not still be present in all locations.

ivers: six in Lake Erie, nine in Lake Michigan, one in Lake Superior, three in Lake Huron, one in Lake St. Clair; and in lakes Erie, St. Clair, Huron, and Michigan (Fig. 5). As many as 10 unauthorized angler stockings may have been responsible for spread of this species in early 2000s (see discussion). In the past eight years, flathead catfish have invaded the Kawkawlin (Michigan), the Black and Rocky (Ohio) rivers, and were found in Calumet and Little Calumet (Illinois) rivers, which connect the Mississippi Basin to the Great Lakes Basin. They have now been recorded in a total of 24 tributary rivers: seven in Lake Erie, eleven in Lake Michigan, one in Lake Superior, four in Lake Huron, one in Lake St. Clair (Fig. 6).

Despite this expansion, flathead catfish remain sparse or difficult to find in Great Lakes waters. The USGS Great Lakes Research Center did not contain a single flathead catfish collection in 52, 524 trawl records and 7, 349 gill net catches, extending over 40 years in the Great Lakes (J. Schaeffer, USGS, personal communication, 2017). Likewise, there were no records from 1971 to 2015 in NOAA's commercial catch data (NOAA, 2018), and the Michigan Department of Natural Resources has never caught one in their trawl surveys on the Great Lakes.

### Discussion and Conclusions

Piecing together the history of the invasion was difficult as relatively little data were available to document occurrences through time, which

shows the inherent issues with historical fisheries analysis. For instance, sometimes, newspaper articles were the only information that could be found to document an occurrence. Many of the first drainage records in Michigan came from angler entries in the Master Angler Database. State agency survey and other reports were valuable, but are not done frequently enough or potentially did not use appropriate sampling gear to determine dates of first invasions of flathead catfish accurately, sometimes even to the decade of invasion. Often, old reports are unavailable or no longer exist. Because of the large size of this species, few specimens are kept in museums. Generally, only smaller specimens (e.g., 1–2 lbs.) are retained for space reasons (Smith, 1979). This study shows the importance of biological surveys, state reports, and museum specimens to document occurrences.

The likelihood of flathead catfish capture in various survey efforts was considered. Adults are benthic and often found under debris, or in depressions (Jackson, 1999). These types of habitats can be difficult to survey, but, juveniles are found in shallow streams (Jackson, 1999) and could be caught with a seine or other nets. Low-frequency electrofishing has been determined to be the most effective means of sampling flathead catfish (Bonvechio et al., 2011; Stauffer and Koenen, 1999). This technique was not available decades ago and could have helped detect this species. However, angling and commercial fishing have taken place in these lakes and rivers since the area was inhabited and would likely have found populations soon after establishment, even without



**Fig. 4.** Flathead catfish distribution records in the Great Lakes Basin until 1999. New locations (1990–1999) are marked by triangles; locations prior to (1990) are marked by circles. Flathead catfish may not still be present in all locations.

scientific sampling. Commercial fishers have been the only ones to find flathead catfish in northern Lake Erie. They were also the first to record them in that lake using pound nets (Trautman, 1957). Presumably the species would have been found by commercial fishers or recreational anglers in other lakes too if they were present.

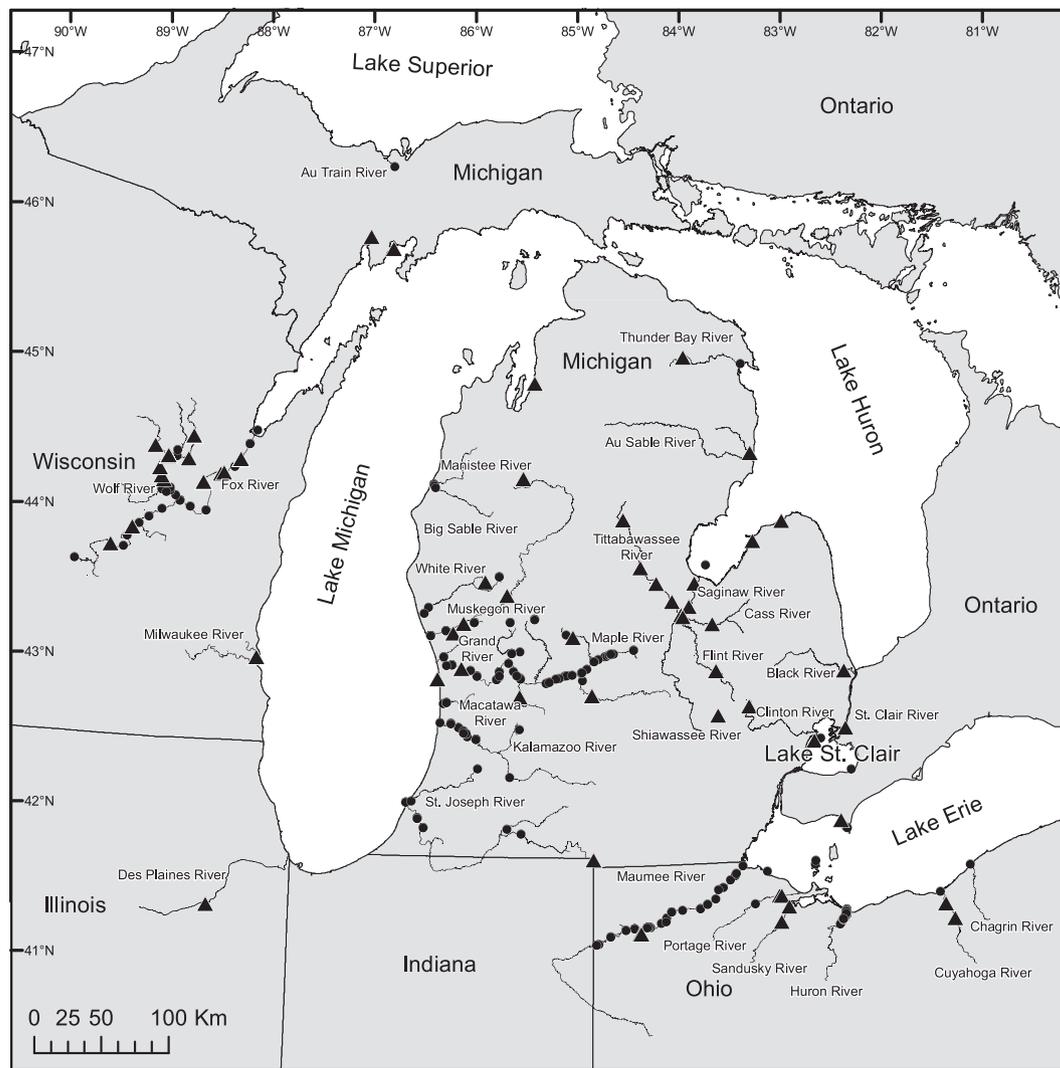
#### Are flathead catfish native to the Great Lakes?

Based on our analysis, flathead catfish are likely not native to the Great Lakes Basin and are invading the middle Great Lakes and their tributaries. With a few exceptions, most drainages have been invaded in recent decades (Figs. 7 and 8; Table 1). Aside from Lake Michigan, flathead catfish remained absent or did not spread for 100 years (Fig. 8). Lake Michigan has shown a steady invasion since the 1920s (Fig. 8).

The origin of the late 1800's–early 1900s Lake Erie and Huron River populations is uncertain. There are three possibilities. They may have been relict populations, stragglers that gained access through historic shipping canals from the Ohio Basin, or they may have been introduced in the late 1800s. Goodchild (1994) believed the fish in Lake Erie to be a relict population. However, it doesn't then seem likely they would only occur in a single river in the Lake Erie drainage. Hubbs (1926) believed that fish found in Lake Erie were not from a native population, but were stragglers that had gained access through shipping canals from the Ohio Basin. Although this is possible, we don't believe this is likely because

there were no canals that connected to the Huron River where the main population was. Had they gained access through canals from the Ohio Basin, they would have occurred in the Cuyahoga or Maumee rivers in Ohio early on, which were connected by canals (Loomis, 1993; Trevorrow, 1973). Greene (1935) stated that flathead catfish apparently did not use the Maumee [Canal] outlet as they were not documented in the Maumee River until recently. The Cuyahoga River canal connection could explain the 1938 collection at Cleveland, although the canal system was abandoned in 1913 after it became severely damaged by heavy spring flooding (ODNR, 2017). If the canals were blocked by this damage, movement of flathead catfish would have been impeded, invalidating this explanation.

Alternatively, there were many fish stockings that took place in the 1800s (Fuller et al., 1999; U.S. Fish Commission Reports, 1896–1903), and the introduction of flathead catfish to the Great Lakes may have been one of those stockings. The US Army Corps of Engineers (1974) reports a personal communication from ODNR biologist Darrell Allison that, “The fish is not native to the Huron River, but a small sustaining population developed from fish that were stocked in the late 1890s.” However, we failed to find any reference to an early stocking of flathead catfish in the U.S. Fish Commission Reports from 1896 to 1903, which mention only stocking of channel catfish at that time. It is possible that it was an undocumented state stocking event, a private undocumented stocking, or was documented somewhere we did not find.



**Fig. 5.** Flathead catfish distribution records in the Great Lakes Basin until 2009. New locations (2000–2009) are marked by triangles; locations prior to 2000 are marked by circles. Flathead catfish may not still be present in all locations.

Based on our analysis, the 1920s collections of flathead catfish from western Michigan are not native either. As previously discussed, historical literature supports this view. In theory, flathead catfish may have come through the Chicago Sanitary and Ship Canal from the Mississippi River system into Lake Michigan and found their way to tributaries on the west coast of Michigan. A hydrologic connection was made between the Mississippi Basin and the Great Lakes Basin around 1910 with the creation of the Chicago Sanitary and Ship Canal (Moy et al., 2011). Greene (1935) supported the view that flathead catfish used the Chicago Sanitary and Ship Canal. However, no records exist that indicate use of this route until 2010, when a few flathead catfish were collected from the Des Plaines and Little Calumet rivers and Lake Calumet in Illinois (Asian Carp Regional Coordinating Committee, 2012). Smith (1979) did not display any records for this route. Furthermore, before the collection of the Lake Macatawa fish in 1922, the Chicago Sanitary and Ship Canal and the Chicago River were extremely polluted with the city of Chicago's sewage and industrial wastes. Additionally, the early canal had locks on it, which are poor fishways (Kim and Mandrak, 2016). Therefore, we don't consider movement through this canal likely.

We think it more likely that the initial introductions in Lake Macatawa and the Grand River in Michigan were from unauthorized stocking events. This would explain the highly localized nature and the apparent lack of records for the next 20 years, although we

recognize the lack of records may be due to failure document them. Even after 1942, few records exist anywhere along Lake Michigan for the next several decades (see change between Figs. 4 and 5).

#### What pathways and routes were used to invade the Great Lakes?

##### Authorized stockings

Flathead catfish have not been widely stocked for sport in the Great Lakes Region. The only public fisheries agency stocking that took place in Ohio was in 1968 in the Huron River (K. Kayle, Ohio Department of Natural Resources, personal communication, 2017), a location where flathead catfish were already found. Michigan DNR stocked flathead catfish in Manistee Lake in 1995 to enhance the population for sport fishing and has also stocked the species in six isolated inland lakes for controlling overpopulation issues with bullhead *Ameiurus* spp. and sunfish *Lepomis* spp. However, flathead catfish are unlikely to have escaped to other we consider these stockings unlikely sources for the species' dispersal.

##### Canals and locks

Many species of fish have moved between drainage divides by using canals (Aron and Smith, 1971; Eshenroder, 2014; Mills et al., 1993).



**Fig. 6.** Flathead catfish distribution records in the Great Lakes Basin until 2017. New locations (2010–2017) are marked by triangles; locations prior to 2010 are marked by circles. Flathead catfish may not still be present in all locations.

Canals were recognized as corridors for the spread of non-native fishes and invertebrates since as early as 1874 (Daniels, 2001) and have been implicated as either the primary or secondary vector for at least 140 species introduced into the Great Lakes (Mills et al., 1999). However, the mere presence of a canal holds no guarantee that fish will move through it (Daniels, 2001).

As already discussed, canals from the Ohio Basin may have provided the initial access to Lake Erie. The Chicago Sanitary and Ship Canal is another potential route to the Great Lakes. However, because of the poor water quality conditions, it is unlikely that this canal was a fish passage route to Lake Michigan until late in the 20th century. Although, the canal it is currently used by flathead catfish based on collections in the past decade (ESM Appendix S1), it may not have been an initial access route for invasion.

The population of flathead catfish in the Wolf–Fox river drainage could have gained access from the canal in Portage, Wisconsin, which links the Mississippi Basin (Wisconsin River) to the Great Lakes Basin (Wolf–Fox drainage) (Becker, 1983; WDNR, 2016). Historically, there was a low point where the two drainages would connect during flood events and was a major navigation route for Native Americans and early explorers. Shortnose gar *Lepisosteus platostomus* and bullhead minnow *Pimephales vigilax* are believed to have used this canal to move into the adjacent non-native drainage (Becker, 1983). However, considering the lack of records both up- and down-river from lakes

Poygan and Winnebago prior to its discovery there, this location is more likely an angler introduction. There is no indication that they moved down river from the canal connection or upriver from the Lake Michigan source.

#### Natural dispersal

Much of the flathead catfish movement from the initial areas of introduction and spread through the Great Lakes themselves, appears to have been volitional. Goodchild (1994) hypothesized that flathead catfish dispersed around the western side of Lake Erie to reach the north shore on their own, rather than being introduced there. Mandrak (1989) apparently erroneously concluded there is small potential for this species to further invade the Great Lakes. Whether they were native to Lake Erie or not, once they grew in numbers and made use of the Detroit River connection to Lake St. Clair, they likely continued through the St. Clair River to Lake Huron.

Since their arrival in Lake Michigan, flathead catfish appear to be expanding northward. Wisconsin DNR is uncertain of the origin of the population in the Milwaukee River (S. Hogler, WDNR, personal communication, 2017). The state did not stock them. That means they were either introduced by anglers or moved there on their own. Movements of individual flathead catfish are highly variable by river system. Although individuals can move great distances (up to 188 km) (Piette and Niebur,



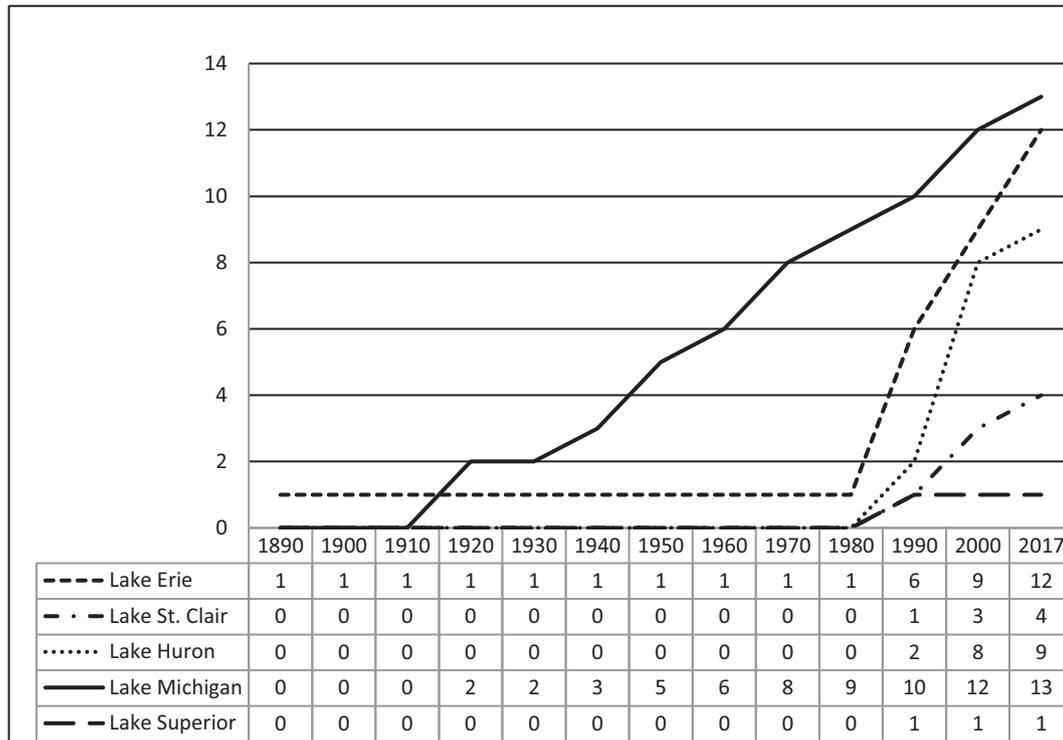


Fig. 8. Cumulative number of eight-digit hydrologic units with records, by Great Lake.

Table 1

Occurrences of flathead catfish by decade, river, and Great Lake.

Decade		1890	1900	1910	1920	1930	1940	1950	1960	1970	1980	1990	2000	2010
Lake Erie	Lake Erie					<b>X</b>	<b>X</b>			<b>X</b>	<b>X</b>		<b>X</b>	<b>X</b>
	Huron	<b>X</b>					<b>X</b>							
	Cuyahoga	<b>?</b>				<b>X</b>							<b>X</b>	<b>X</b>
	Maumee											<b>X</b>	<b>X</b>	<b>X</b>
	Chagrin											<b>X</b>		
	Portage											<b>X</b>	<b>X</b>	
	Sandusky												<b>X</b>	<b>X</b>
	Black													<b>X</b>
	Rocky													<b>X</b>
Lake St. Clair	Lake St. Clair										<b>X</b>	<b>X</b>	<b>X</b>	<b>X</b>
	Clinton												<b>X</b>	
Lake Huron	Lake Huron											<b>X</b>	<b>X</b>	
	Saginaw												<b>X</b>	<b>X</b>
	AuSable												<b>X</b>	<b>X</b>
	Thunder Bay												<b>X</b>	
	Kawkawlin													<b>X</b>
Lake Michigan	Lake Michigan										<b>X</b>			
	Kalamazoo				<b>X</b>						<b>X</b>			
	Grand				<b>X</b>	<b>?</b>	<b>?</b>	<b>?</b>	<b>X</b>	<b>X</b>	<b>X</b>	<b>X</b>	<b>X</b>	<b>X</b>
	Macatawa						<b>X</b>			<b>X</b>				
	Wolf/Fox				<b>?</b>			<b>X</b>						
	White								<b>X</b>		<b>X</b>			
	Muskegon									<b>X</b>	<b>X</b>	<b>X</b>	<b>X</b>	<b>X</b>
	Manistee									<b>X</b>				
	St. Joseph										<b>X</b>		<b>X</b>	
	Boardman-Charlevoix												<b>X</b>	
	Milwaukee													<b>X</b>
	Big Sable													<b>X</b>
	Lake Superior	AuTrain											<b>X</b>	
Des Plaines													<b>X</b>	<b>X</b>
MS/GL Rivers <sup>a</sup>	Kankakee												<b>X</b>	<b>X</b>
	Calumet													<b>X</b>
	Little Calumet													<b>X</b>
	Total Rivers	1	1	1	3	4	5	5	6	9	10	14	21	28

? - questionable records, see text in on-line supplement for explanation of each.

Questionable records were not counted in totals.

Once a drainage has had a record, it is included in subsequent counts.

First decade of verified occurrences for each drainage are in bold.

<sup>a</sup> Rivers that connect the Mississippi River Basin with the Great Lakes Basin.

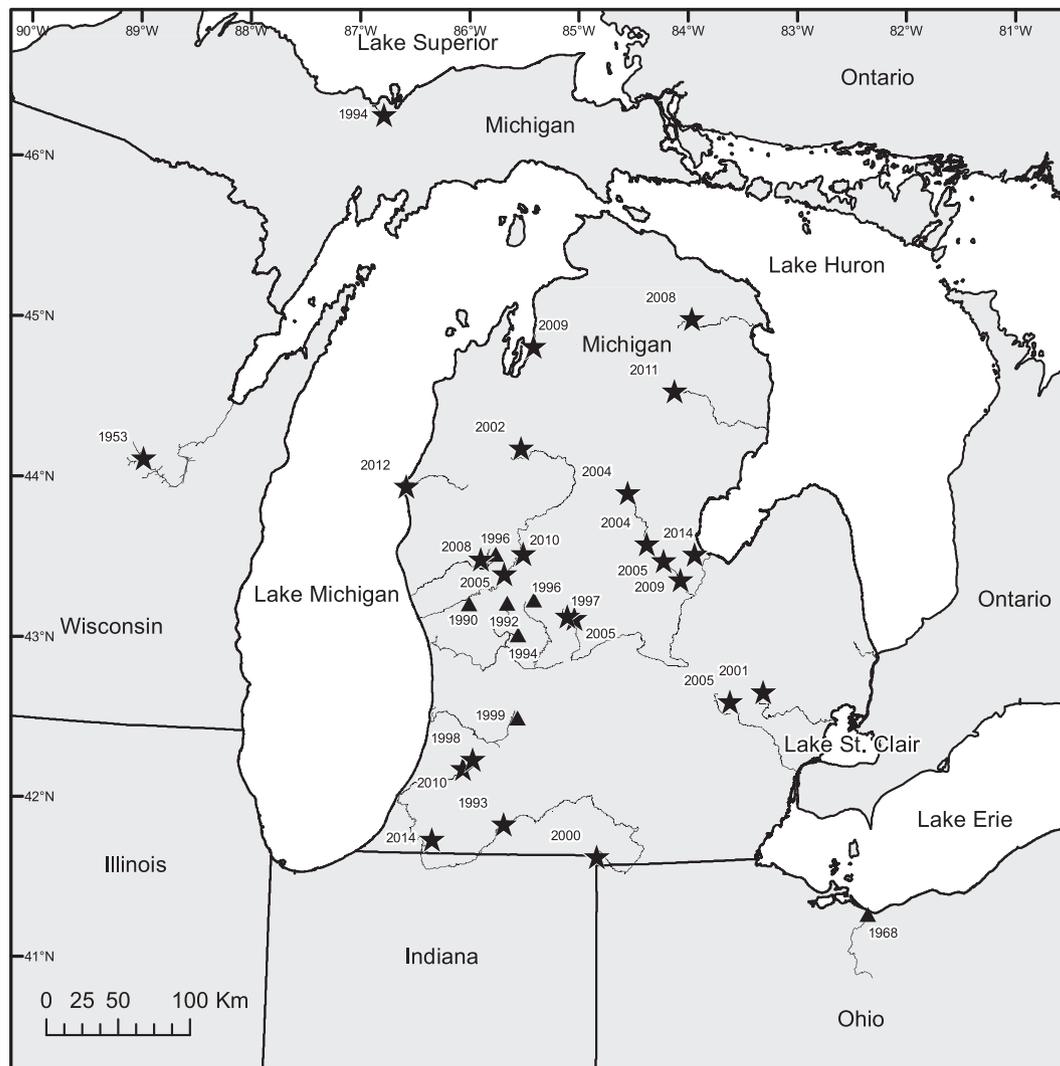


Fig. 9. Suspected unauthorized angler stockings (stars) and agency stockings (triangles) of flathead catfish in the Great Lakes region. Flathead catfish may not still be present in all locations.

of Michigan. Although no flathead catfish have been collected from the North Channel of Lake Huron or from the Ste. Marie River, they could be expected there in the next few years. The Canadian shore of Lake Huron has many large coastal lakes that appear to resemble the drowned river mouths that flathead catfish have invaded in Michigan and Wisconsin. If they reach this point, passage through Sault Ste. Marie to Lake Superior may occur.

We considered the possibility that water temperatures may be the limiting factor in the northward expansion of flathead catfish. The minimum temperature for flathead catfish to spawn is 19–22 °C (Jackson, 1999; McInerney and Held, 1995; Turner and Summerfelt, 1971). Extremely low survivorship and no recruitment of channel catfish young were found at water temperatures below 21 °C on the Laramie River in Wyoming (Patton and Hubert, 1996), apparently because spawning temperatures were not reached until late summer, and the young did not have time to reach a size to allow overwintering. One might assume that flathead catfish would respond similarly. Except for south-central Lake Michigan, water temperatures are too cold in Lake Michigan, northern Lake Huron, and Lake Superior for flathead catfish to spawn in the lakes (NOAA Sea Grant, 2017). However, USGS water temperature data (July 15 and August 15 data from 2004 to 2017) for the northern Lake Michigan tributaries of AuSable, Escanaba, Menominee, Ontonagon and Sturgeon showed summer temperatures warm enough for spawning (USGS 2017b), indicating flathead catfish may not be

limited in their northward dispersal by temperature. We found that western Lake Erie and Lake Ontario also have suitable temperatures for spawning. Because water temperatures are below 21 °C in most of Lake Superior (USGS 2017b), this will likely restrict their ability to colonize much of that lake. However, several drowned rivermouths on the western and northern portions of Lake Superior may have suitable flathead catfish habitat.

Because there may be collection records beyond those we were able to find, flathead catfish may be more widespread than we have indicated here; and based on our review, we suspect that they will continue to spread through natural dispersal mechanisms and with human assistance. Although no direct effects have been documented from flathead catfish in the Great Lakes Basin, and are unlikely to occur as long as populations remain small, there is some evidence that flathead catfish could have localized effects on native fish populations. A study by Laarman and Schneider (1986) found bullheads became very rare in Manistee Lake over the course of the 12-year survey. Although Laarman and Schneider did not report any flathead catfish, this species was recorded from that lake towards the end of the study by others. A nascent population of flathead catfish could explain the decline in bullheads (Dobbins et al., 2012; Odenkirk et al., 1999; Thomas, 1995). Agencies may want to monitor fish assemblages in areas with introduced flathead catfish populations to allow for the implementation of any desired management actions.

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## Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.jglr.2018.07.001>.

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# The Flathead Catfish Invasion of the Great Lakes

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Appendix S1. The information presented here is the detailed account of the collections and range expansions the Fuller and Whelan (2018) paper are based upon.

Table S1 and Figures S1 to S8 appear in order at the end of this file

## **The History of Spread**

The story of the flathead catfish in the Great Lakes Basin begins in 1890. The information presented below is chronological by decade based on the initial few records for each Great Lake drainage. Within the description of movement during a decade, information is presented by each relevant Great Lake and drainages thereof, as chronologically as possible based on the first occurrence. The accompanying maps presented in the figures are key to understanding the spread. All data acquired by the sources listed has been compiled into the U.S. Geological Survey's (USGS) Nonindigenous Aquatic Species Database. Each map displays all recorded collections until the end of the selected decade. Locations specifically referenced in the text are depicted by triangles and are labeled with a letter corresponding to the text (Table S-1). When number of rivers are discussed, they refer to a direct tributary to a Great Lake, and do not include smaller tributaries thereof.

## Pre–1900

### Lake Erie

#### Huron River, Ohio

A small population was reported in the Huron River, Ohio, since at least 1890, where a few fish were taken annually (Trautman 1957; Van Meter and Trautman 1970) (Figure S1-a).

## 1920s–1940s

During this time, there were five more reports from the Ohio side of Lake Erie. The first specimens were found from the Lake Michigan drainage at the mouths of the Kalamazoo and Macatawa rivers, and in the Grand River in Michigan. They were found in five rivers; two in Lake Erie and three in Lake Michigan; and in Lake Erie (Figure S1). Details are as follows:

### Lake Erie

Only four (Goodchild 1994) or five (Crossman and Leach 1979; Trautman 1957) specimens were collected from the south shore of Lake Erie between 1938 and 1978 (Figure S1-b, c, d, e, f). Three were from Lake Erie: 1940 (OSUM 1866)(b), 1942 (OSUM 6664)(c), 1948 (OSUM 8471)(d), and one was from the lower Huron River, Ohio, in 1948 (OSUM 8467)(e). The fifth specimen probably refers to the one mentioned by Trautman (1957), collected at the mouth of the Cuyahoga River at Cleveland, Ohio (f), that was deposited in the Cleveland Museum of Natural History. No date was given for that collection, but it may have been 1938 based on Trautman's statement "five collected since 1938" and the fact that none of the museum specimens are from

1938. However, the Cleveland museum has no record of the specimen. The only flathead catfish specimen in their collection is a 1991 young-of-year fish from the Muskingum drainage in Ohio, in the native range (Roberta Muehlheim, Assistant Curator, personal communication, 2017).

By 1941, Hubbs and Lagler (1941) listed the “Shovelhead catfish” rare in Lake Erie. Hubbs’ statement is likely that of occurrence, not nativity, since Hubbs previously stated he believed they gained access from the Ohio Basin via canals (Hubbs 1926). Trautman (1957) reported catches of large flathead catfish from the Huron River including a 52-pound fish from 1947(g) (reported by Meyers, 1947).

## **Lake Michigan**

From the 1920s to the 1950s, the state of Michigan conducted systematic seine surveys in streams and to a lesser extent in rivers. Electrofishing equipment, developed in the 1930s, was primarily used to survey trout streams. Early lake survey work used a variety of nets and was the source of the 1942 Lake Macatawa collection below (K. Wehrly, Michigan Department of Natural Resources (MDNR), personal communication, 2017).

### Kalamazoo River, Michigan

The first specimen was found in the Kalamazoo River near the mouth at Saugatuck in 1922 (Figure S--h). This specimen was vouchered (UMMZ 51272) and is the first record from the Lake Michigan drainage. It was listed as present at the mouth of the Kalamazoo River by Hubbs and Greene (1928), likely based on the 1922 specimen.

### Fox River, Wisconsin

Cahn (1927) listed flathead catfish as collected in the Fox River, Wisconsin [Great Lakes Basin].

However, he did not give any further information in the text, there is no voucher specimen, and Greene (1935) did not record any specimens from the Lake Michigan drainage. Therefore, we consider this record to be questionable.

### Grand River, Michigan

Flathead catfish were first recorded from the Grand River at Grand Rapids by Hubbs and Greene (1928) (Figure S1-i). They reported that a specimen from that location was mounted in the Kent Scientific Museum. Because they were not recorded for the state by Michael (1904), the collection took place between 1904 and 1928.

We lack any survey data from 1928 (Hubbs and Green) to 1967, however, a 1976 newspaper article from the Rockford Register claims the interviewed angler had been fishing for flathead catfish for 40 years on the Grand River, placing them in the river as early as 1936 (Editor 1976). The fish community was greatly limited in this river by water pollution until about 1970 (GEW).

### Macatawa River, Michigan

A specimen was taken in 1942 (UMMZ 196980) in Lake Macatawa, Ottawa County (Figure S1-j). This was only the third record for western Michigan. In a summary of surveys for that lake, Brown and Lievens (1942) listed “Shovelhead Catfish” as rare. They were not listed among the species found in a 1942–1945 creel survey of Lake Macatawa (Lievens 1946).

## **1950s**

In the 1950s, the state of Michigan began to shift from systematic/comprehensive surveys to focus on sampling waters with stocked fish. During this time electrofishing was used in

wadeable streams and trapnets were used in lakes (K. Wehrly, MDNR, personal communication, 2017).

At least one more flathead catfish was collected from the Huron River in the 1950s, in the same area as previously recorded. The first, or possibly the second (if you include Cahn's report), fish was collected from the Fox drainage in Wisconsin. This is the first occurrence on the western side of Lake Michigan. They were found in a total six rivers; two in Lake Erie; four in Lake Michigan; and in Lake Erie (Figure S2). Details are as follows:

## **Lake Erie**

### Huron River, Ohio

Trautman (1957) reported a 47-pound fish from the Huron River in 1951 (reported by Kidney 1951). Trautman (1981) mapped two additional specimens caught between 1957 and 1981 (the two editions of Trautman's book) in the lower Huron River, but these specimens are not vouchered at OSUM (Figure S2-a).

## **Lake Michigan**

### Fox River, Wisconsin

Aside from the questionable mention by Cahn (1927), the first record for the Great Lakes Basin in Wisconsin was from 1953 at Lake Poygan on the Wolf River (Figure S-2-b) (Becker 1964; WDNR 2017). Five specimens were collected in 1953 by a Wisconsin Conservation Department employee conducting surveys of the lake with trap nets (Becker 1964). Although the Wolf and Fox rivers have a long record of sampling, very little sampling occurred in the Fox River in the

1930s and 1940s. Only two samples were taken in the Wolf River in the 1940s, and only one sample in the Fox in the 1950s (Fago 1992). The introduction may have gone undetected for many years before 1953. Eleven more fish were collected from Lake Poygan and Lake Winnebago in surveys conducted from 1958 to 1961. Thirteen were collected by commercial fisherman from 1957 to 1959 (Becker 1964).

The population in the Wolf – Fox river drainage could have gained access from the canal in Portage, Wisconsin, which links the Mississippi Basin (Wisconsin River) to the Great Lakes Basin (Wolf – Fox drainage) (Becker 1983; WDNR 2016). The upper canal stopped operating in 1951, the upper locks were closed in the 1960s (Becker 1983), and there is no fish movement through this route since the early 1960s (D. Bartz, WDNR, personal communication, 2017). Most of the non-native species began appearing in the late 1950s (Becker 1983). If flathead catfish did take this route, they must have migrated through the canal in the 1940s to early 1950s. Although the Fox River may have provided another source for Lake Michigan, it was not the original source (for the 1922 and 1942 collections in western Michigan).

## 1960s

In the 1960s, the first, and only, stocking in the Lake Erie drainage took place; a new drainage was invaded (the White); and flathead catfish spread upriver in the Grand and Maple rivers. They were found in a total six rivers; two in Lake Erie; four in Lake Michigan; and in Lake Erie (Figure S3). Details are as follows:

## **Lake Erie**

### Huron River, Ohio

Ohio DNR stocked 5 200 fingerlings in the Huron River near Huron in 1968 (Figure S3-a) (K. Kayle, Ohio Department of Natural Resources (ODNR), personal communication, 2017). This is the only state stocking in the Great Lakes Basin recorded since 1930s when ODNR began keeping records.

## **Lake Michigan**

### White River, Michigan

There are very few records for this region. There were five collections, for a total of eight fish, in June 1965 from White Lake, Muskegon County (MDNR unpublished data) (Figure S3-b).

### Grand River, Michigan

There were no survey efforts in the lower Grand River from 1928 to 1967 (K. Wehrly, MDNR, personal communication, 2017). Flathead catfish were regularly collected in surveys conducted by the Michigan Department of Conservation (MDOC) (precursor to MDNR) in both the Grand River and its tributary, the Maple River, from 1967 to 1989 (Lincoln 1974; MDOC fish collection data sheets; Nelson and Smith 1978, 1981; Willson 1970). There is one voucher specimen (UMMZ 186652) from the Maple River, Gratiot County, in 1967 (Figure S3-c). There are a number of records from Grand River watershed in the MDNR Master Anglers Database (MDNR 2016).

## 1970s

In the 1970s, the first record from the Canadian side of Lake Erie was reported; two more drainages were likely invaded (Muskegon and Manistee); flathead catfish may have disappeared from the Kalamazoo River; they reappeared in Lake Macatawa after a 30-year absence; and they spread in the Fox drainage of Wisconsin. They were found in a total nine rivers; two in Lake Erie; seven in Lake Michigan; and in Lake Erie (Figure S4). Details are as follows:

### **Lake Erie**

In 1978, a single fish was collected on the Canadian side of western Lake Erie by a commercial fisherman (Figure S4-a). This specimen was deposited in the Royal Ontario Museum collection (ROM 34561) and was described as a possible waif from the southern side (US waters) of Lake Erie (Crossman and Leach 1979).

A survey of the lower Portage River, Ohio (Hoke and Norrocky 1975), failed to find this species.

### **Lake Michigan**

The state of Michigan began sampling large rivers in the 1970s and 1980s using rotenone along with electrofishing.

#### Kalamazoo River, Michigan

There have been no more records of flathead catfish in the Kalamazoo since the original 1922 record. Flathead catfish were not found in MDNR surveys from 1949 to 1970 (M. Diana,

MDNR, personal communication, 2017). Nor were they found in a 1971 survey of the river conducted by MDNR (MDNR 1972). During the 1971 survey, the entire length of the river was sampled all the way to the mouth at Saugatuck using electrofishing gear and fyke nets. If flathead catfish were there, they should have been recorded. They also were not collected in trawl surveys in Lake Michigan off Saugatuck in 1964 (Wells 1968).

We do not have any suitable survey data on the lower Kalamazoo between 1922 and 1971, only a 1937 seining survey (K. Wehrly, MDNR, personal communication, 2017). However, there were severe water quality issues in the Kalamazoo River extending back to the 1940s and 1950s (K. Wehrly, MDNR, personal communication, 2017).

#### Muskegon River, Michigan

Flathead catfish were not found in a 1950 survey of Muskegon Lake (Peterson 1951). The lake was heavily polluted from a paper mill and other industrial and municipal wastes at the time. Flathead catfish were not found in an electrofishing survey of the river in 1966, nor in netting and electrofishing surveys in 1967, 1970, and 1971 (K. Wehrly, MDNR, personal communication, 2017).

The first collection we found from the Muskegon drainage was from Muskegon Lake in 1973 (Figure S4-b), which coincided with the first year of the Master Angler Program (MDNR 2015). After being found in surveys in 1976, they were not found again in netting and electrofishing surveys from 1977 to 1981 (K. Wehrly, MDNR, personal communication, 2017).

#### Macatawa River, Michigan

MDNR internal correspondence lists no more specimens from this river from 1942 until 1973,

when one was caught in March of that year (Figure S4-c). There were no survey efforts of Lake Macatawa from 1942 until 1974. Electrofishing surveys in 1974 and 1975 failed to find any flathead catfish. None were found in annual netting and electrofishing surveys conducted from 1976 to 1980 (K. Wehrly, MDNR, personal communication, 2017). A 1976 newspaper article about fishing in Lake Macatawa (Martonosi 1976) makes no mention of flathead catfish. Bailey et al. (2004) show only a single vouchered specimen for this drainage; the one from 1942, and does not indicate its presence farther upriver.

#### Fox River, Wisconsin

There is little pre-1970's fish information on the Fox River and Green Bay because the fishery was nearly non-existent due to poor water quality conditions before the Clean Water Act (S. Hogler, WDNR, personal communication, 2017). The first record we have below Lake Winnebago is in 1975 (S. Hogler, WDNR, personal communication, 2017) (Figure S4-d). This point and another collection from 1979 were not mapped by Becker (1983). Johnson and Becker (1970) classified flathead catfish as reported occasionally from the lower Wolf and upper Fox rivers and their lakes. A single fish was collected from the Embarrass River, a tributary to the Wolf River, in 1979 (Figure S4-e) (WDNR 2017).

#### Manistee River, Michigan

They were first reported from the south end in Manistee Lake in 1979 (UMMZ 203899) (Figure S4-f) and have had many captures since then (MDNR 2015). Flathead catfish were not reported in a 1957 survey of Manistee Lake (Taube 1958), perhaps because of poor water quality (GEW). Manistee Lake is a Great Lakes drowned rivermouth lake, immediately adjacent to Lake Michigan, and is connected to the lake by a channel. The original fish may have entered

Manistee Lake from Lake Michigan, or the occurrence may be the result of an unauthorized stocking.

A 1972–1984 assessment of Manistee Lake conducted by Laarman and Schneider (1986) did not find any flathead catfish in their surveys. However, they did mention that bullheads *Ameiurus* spp. became very rare in Manistee Lake, but did not present data on these species. Black *A. melas*, yellow *A. natalis*, and brown *A. nebulosus* bullheads are all present in the river. If flathead catfish were becoming established in the latter half of the study, that could explain the decline in bullheads. Flathead catfish are known to target bullheads and cause population declines (Dobbins et al. 2012; Odenkirk et al. 1999; Thomas 1995). The study also appeared to show a decline in pumpkinseed sunfish *Lepomis gibbosus*. Flathead catfish are known to prey heavily on redbreast sunfish *L. auritus* in other areas where they are introduced (Bonvechio et al. 2009; Kansas Fishes Committee 2014; Thomas 1995). It is possible that they may also favor pumpkinseed sunfish in this instance. Both redbreast and pumpkinseed sunfish are snail eaters (Jenkins and Burkhead 1994). Laarman and Schneider (1986) noted that large decreases in bluegill sunfish, pumpkinseed sunfish, and northern pike were offset by an increase in yellow perch. Yellow perch are a mid-water column species that would be less susceptible to predation by demersal flathead catfish.

## 1980s

In the 1980s, flathead catfish were recorded for the first time in 60 years in the Kalamazoo River; a second fish was recorded from the Canadian side of Lake Erie; the first occurrence was recorded in Lake St. Clair, demonstrating movement between Lakes Erie and Huron; and a new Lake Michigan drainage was invaded (St. Joseph River). They were found in a total ten rivers:

two in Lake Erie and eight in Lake Michigan; and in lakes Erie, St. Clair, and Michigan (Figure S-5). Details are as follows:

## **Lake Michigan**

The state of Michigan began sampling large rivers in the 1970s and 1980s using rotenone and electroshocking.

### White River, Michigan

We only located one more record from the White River, submitted to Master Angler Program in 1981 (Figure S5-a) (MDNR 2016). Fish likely gained access to this Great Lakes drowned rivermouth lake from Lake Michigan.

### Kalamazoo River, Michigan

Flathead catfish were collected for the first time since 1922 in the Kalamazoo River in 1982 (Figure S5-b) (Towns 1984). MDNR conducted rotenone surveys at 14 stations along the entire river length that year. Flathead catfish were only found below Allegan Dam, near the mouth of the river, at Saugatuck (Towns 1984; UMMZ 212199, UMMZ 212206). Many young-of-year fish were captured indicating flathead catfish reproduction.

### St. Joseph River, Michigan

The first record of flathead catfish from the St. Joseph River was in coastal Berrien County in 1982 (Figure S5-c). The fish was caught by an angler and submitted to the Master Angler Program. They had not been present in the river previously (Ned Fogle and David Johnson,

personal communication to W.C. Latta, MDNR, 2016). The water quality in the river had been historically badly degraded by industrial and municipal wastes but improved in the 1970s (Towns 1988), perhaps allowing this species to invade from Lake Michigan. Reports were common from the river in the next several years. The species occurs from the Berrien Springs Dam to the mouth of the river at Lake Michigan, a distance of 37.6 km. None were found in a rotenone survey of the upper St. Joseph (down to Sturgis Dam) and Nottawa Creek in 1987 (Towns 1988).

### Fox River, Wisconsin

Becker (1983) displayed a map with a few records in the Wolf – Fox drainage derived from literature and reports, including ones in the upper Fox River (Figure S5-d), but none downriver of Lake Winnebago. However, by the late 1980s, flathead catfish were common in the stretch between De Pere Dam and southern Green Bay (in Lake Michigan) (Figure S5-e) (S. Hogler, WDNR, personal communication, 2017). These range increases were likely due to improvement in water quality.

### **Lake Erie**

Both VanMeter and Trautman (1970) and Trautman (1981) only listed a population in the Huron River, and did not mention or map any other Ohio rivers with populations.

A second fish was collected on the Canadian side of Lake Erie in 1986 (ROM 58428) (Figure S5-f).

## **Lake St. Clair**

The first documented flathead catfish to appear in Lake St. Clair was taken on the Canadian side in 1989 (ROM 57057) (Figure S5-g) (Goodchild 1994).

## **1990s**

In the 1990s, the first occurrences from Lake Huron were recorded; a new drainage in Lake Erie was invaded (Maumee); a second fish from Lake St. Clair was caught; the MDNR stocked flathead catfish in six drainages where they already occurred; and the first record from Lake Superior drainage was reported. They were found in a total 14 rivers: 5 in Lake Erie, 8 in Lake Michigan, and 1 in Lake Superior; and in lakes Erie, St. Clair, Huron, and Michigan. Michigan ended its use of large river rotenone surveys in 1991 (Figure S6). Details of reports are as follows:

## **Lake Huron**

Based on stocking records back to 1873, the state of Michigan has never stocked flathead catfish in the eastern part of the state (GEW personal communication). They are not listed in creel surveys from Saginaw Bay in 1983–1984 (Ryckman 1986). None have been collected in MDNR Saginaw Bay gill net sampling since it began in 1989 or from any MDNR Lake Huron fisheries survey work that began in the late 1960s (Fielder et al. 2000; Fielder and Thomas 2006; D. Fielder, MDNR, personal communication, 2016). A publication by Dobiesz et al. (2005) did not mention this species in Lake Huron from 1970 to 1999. Michigan Department of Natural Resources has not caught any in Lake Erie, St. Clair, or Lake Huron up to Saginaw Bay since

they began sampling in 1967 (M. Thomas, MDNR, personal communication, 2016).

The first-time flathead catfish were recorded from Lake Huron was in 1991, when two fish were taken and submitted to the Master Angler Program (MDNR 2015): one from Saginaw Bay (Figure S6-a), and the second from Thunder Bay River (Figure S6-b) (MDNR 2016).

## **Lake Erie**

Surveys of Michigan's Huron River (Hay-Chmielewski et al. 1995) and the River Raisin (Dodge 1998) (also in Michigan) failed to find this species. Both are tributaries to western Lake Erie.

### Maumee River, Ohio

The first specimen was collected from the Maumee River by the Ohio Environmental Protection Agency (EPA) in 1992 in Defiance County, Ohio (OSUM 113115) (Figure S6-c). By the end of the decade they had been collected from the mouth to the Indiana state line (Ohio EPA 2017).

### Chagrin River, Ohio

In 1994, a single flathead catfish was collected at the mouth of the Chagrin River in Lake County (Ohio EPA 2017) (Figure S6-d). This is the farthest east in Lake Erie this species has been reported (Ohio EPA 2017; USGS 2017).

### Portage River, Ohio

The first record from the Portage River was in 1995 upstream of Woodville in northwest Sandusky County (Figure S6-e). Three individuals were captured in a single day from the same location (Ohio EPA 2017).

## **Lake St. Clair**

A second fish was collected from Lake St. Clair in 1996, this time on the U.S. side of the lake (Figure S6-f) (MDNR 2015).

## **Lake Michigan**

### Muskegon River, Michigan

Flathead catfish were regularly collected from the Muskegon River after the 1973 collection.

O'Neal (1997) depicted them only at Muskegon Lake.

Michigan DNR stocked them in very low densities in Sand and Baptist lakes to control overpopulated sunfish populations in the Muskegon drainage beginning in 1990 (Figure S6-g, h).

Baptist Lake is in southeastern Newaygo County and Sand Lake is in southwestern Newaygo County. Both lakes are isolated with little chance of escapement to the Muskegon River.

### St. Joseph River, Michigan

Although flathead catfish were not found in a rotenone survey in 1987 (Towns 1988), they were recorded in the upper St. Joseph River in St. Joseph County (Figure S6i) by 1993, when one was submitted to the Master Angler Program (MDNR 2016). This occurrence is above the Berrien Springs Dam indicates they must have been an angler introduction. The only fish passage available at the Berrien Springs Dam, the lowermost barrier dam from Lake Michigan, is a pool-weir fishway with an 18-inch vertical jump (to prevent sea lamprey passage) that was installed 1977. The fishway was designed for salmonids, and passage of other species is very limited (GEW). Wesley and Duffy (1999) did not report them present upriver of the Berrien Springs Dam.

Because they already occurred in the drainage, MDNR stocked them in very low densities in Sand Lake, St. Joseph County (Figure S6-j) in 1997 to control bullheads (MDNR stocking records).

#### Grand River, Michigan

Michigan DNR stocked flathead catfish in very low densities in Myers Lake, Kent County (Figure S6-k), and Cowden Lake, Montcalm County (Figure S6-l), in 1994 and 1996 for control of bullheads (MDNR unpublished fish stocking records).

#### Manistee River, Michigan

Michigan DNR stocked flathead catfish in Manistee Lake in 1995, where they were already known to be present (Figure S6-m). Flathead catfish were not listed in a 1998 assessment of the river (Rozich 1998), however, no direct sampling took place. The report was based on past knowledge of the fish community and apparently, flathead catfish were overlooked by the author of this report. The Manistee Lake location was mapped by Bailey et al. (2004).

#### Pere Marquette–White River drainage, Michigan

MDNR stocked flathead catfish in 1996 in very low densities in Brush Lake, Newaygo County to control overpopulated sunfish. Brush Lake is in the headwaters of the Pere Marquette River (Figure S6n) and is not connected to a river.

None of these locations was mapped by Bailey et al. (2004).

### Kalamazoo River, Michigan

The only time MDNR stocked flathead catfish in the Kalamazoo drainage was in in Hall Lake on the western edge of Barry County (Figure S6-o) in 1999. This stocking was in very low densities for the control of overpopulated sunfish populations (GEW). There are no earlier stockings to account for the population in the lower reach of the river (MDNR unpublished fish stocking data).

## **Lake Superior**

### AuTrain, Michigan

A single fish was captured by MDNR during sampling in Cole Creek Pond, Alger County, in the Upper Peninsula in 1994 (Figure S6-p) (MDNR 2017). This pond is in the AuTrain River watershed which drains into Lake Superior. This was likely an unauthorized introduction, as the pond is at the very headwaters of the AuTrain River drainage. There is only a small creek connecting the pond to Au Train Lake, which appears to be a more suitable area for flathead catfish if they occur in that area. Although a 2002 survey using fyke, trap, gill nets, and seines failed to capture any flathead catfish from that lake (Waybrant 2004).

## **2000s**

In 2002, Michigan instituted a randomized survey design for lakes and wadeable streams. The DNR has a fleet of electrofishing boats that are used for sampling large rivers and lakes. However, one should keep in mind that early electrofishing surveys used alternating current (AC) shocking units and are not comparable to the direct current (DC) units with lower pulse rate

controls used over the past 10 years (K. Wehrly, MDNR, personal communication 2017).

However, Vokoun and Rabeni (1999) report that both methods are effective for catfish.

Between 2000 and 2009, the second fish was reported for Lake Huron, after a 12-year hiatus; there were two new records from Saginaw Bay; two records from northern Lake Michigan; and records from seven new drainages (Clinton, Au Sable, Thunder Bay, Saginaw, Milwaukee, Boardman–Charlevoix, and Sandusky rivers). They were collected for the first time at the junction of the Kankakee and Des Plaines rivers, indicating potential movement from the Mississippi Basin. Flathead catfish have been recorded in a total 21 rivers: 6 in Lake Erie, 10 in Lake Michigan, 1 in Lake Superior, 3 in Lake Huron, 1 in Lake St. Clair; and in lakes Erie, St. Clair, Huron, and Michigan (Figure S7). There is evidence for 9 or 10 unauthorized angler stockings in this decade. Details are as follows:

### **Lake St. Clair**

Four more fish were collected from Lake St. Clair: two from the Canadian side - in 2001 (ROM 75465) and 2003 (ROM 75466) (Figure S7-a), and two from the US side (2005, and 2008) (MDNR 2015) (Figure S7-b). In 2008, a fish was also collected from the St. Clair River on the Lake St. Clair side of the river (Figure S7-c) and another from near the mouth of Black River, a Lake St. Clair tributary (Figure S7-d) (USEPA 2008).

### **Clinton River, Michigan**

In 2001, a fish was collected from Crooked Lake which is in the Clinton River watershed which drains to Lake St. Clair (Figure S7-e) (MDNR 2015). Because of the isolated nature of this headwater lake, this was likely an unauthorized introduction. None were found in Crooked Lake

during a 1990, night electrofishing survey or in a 2009 survey using fyke nets, trap-nets, net lifts (at night), and gill-nets (Phillips and Cwalinski 2010).

## **Lake Huron**

After the 1991 record, there were no more records from Lake Huron until 2003, when a single large fish was taken from Saginaw Bay, Huron County (Figure S7-f) and another was collected from in the same area in 2005 (Figure S7-g) (MDNR 2015). None were collected in trawl and gill net surveys of Saginaw Bay that were conducted from 1989 to 2004 (Fielder et al. 2000; Fielder and Thomas 2006).

### Saginaw River, Michigan

The first flathead catfish was recorded in the Saginaw drainage in Saginaw County, in 2000 (Figure S7-h) (MDNR 2004). Bailey et al. (2004) documented this record on their published map and indicated it had no voucher specimen.

In 2005, there were records from the Saginaw and Shiawassee rivers (Figure S7-i, j) (MDNR 2015; National Fish Habitat Partnership 2016). Their presence in the rivers indicates they had likely moved into the Saginaw River from Saginaw Bay in Lake Huron.

In 2004 and 2005, flathead catfish were also caught upriver in three lakes in the Saginaw drainage: Sanford Lake and Pratt Lake (Tittabawassee River watershed), and Tipsico Lake (Shiawassee River system) (Figure S7-k, l, m) (MDNR 2015). These were likely all unauthorized stockings, as MDNR did not stock these drainages (MDNR unpublished fish stocking records).

Both Pratt Lake and Lake Tipsico are at the headwaters of their respective drainages, are isolated by dams from the rest of the watershed, and have no upstream river connection. Sanford Lake is

a mainstem impoundment, formed by Sanford Dam, on the Tittabawassee River, is approximately 54 miles upriver from Lake Huron (as measured on Google Maps), and there is no fish passage at Sanford Dam. It is possible that these fish moved downriver from Sanford Lake into the stretch of the Tittabawassee River above Dow Dam in Midland where they were found in a creel survey in 2005 (Figure S7-n). By 2009, they were present in the entire stretch of the Tittabawassee River, from Sanford Lake to the Saginaw River (Figure S7-o) (Schrouder et al. 2009), and had spread to the Flint River, a tributary of the Saginaw River (Figure S7-p).

The number of records of fish in the Lake Huron drainage submitted to MDNR Master Angler Program increased quickly after 2005 (USGS 2017 - see animated map:

<https://nas.er.usgs.gov/queries/SpeciesAnimatedMap.aspx?speciesID=750>). During this time, flathead catfish continued moving north in Lake Huron and ascending coastal rivers, with the Saginaw River being the locus of the Lake Huron distribution.

#### AuSable River, Michigan

Flathead catfish were not found in a 2001 assessment of the AuSable River (Zorn and Sendek 2001). In 2005, flathead catfish were collected from VanEtten Lake, Iosco County, in the AuSable River drainage in northern Michigan (Figure S7-q) (MDNR 2015). This lake is approximately 8 km from Lake Huron and has a water control structure on the AuSable River with limited fish passage. This introduction could be attributable to either an unauthorized introduction or the movement of the fish from Lake Huron to the VanEtten Lake via the AuSable River. This location was not mapped by Bailey et al. (2004).

#### Thunder Bay River, Michigan

A 2006 survey of the Thunder Bay River did not find any flathead catfish (Cwalinski et al.

2006). However, another unauthorized introduction was discovered in 2008 in Ess Lake, Montmorency County (Figure S7-r) which is an isolated lake in the Thunder Bay River watershed with no direct river connections. A second fish was taken that same year from the Thunder Bay River (MDNR 2015).

## **Lake Erie**

The third fish from the Canadian side of Lake Erie was reported in 2005 (ROM 79185), in the same area as the previous two, west of Point Pelee (Figure S7-s). Coker et al. (2001) list flathead catfish as introduced into the province of Ontario.

### Cuyahoga River, Ohio

Two flathead catfish were collected from the Cuyahoga River in 2006 (OSUM 104678; OSUMU 552027) (Figure S7-t). This is the first time they were collected from this river since 1938. Poor water quality likely prevented habitation in the intervening years. Only a few others were collected by the end of the decade.

### Portage River, Ohio

Two more fish were collected from the lower Portage River in 2008 (Figure S7-u) (Ohio EPA 2017).

### Sandusky River, Ohio

The first collections of flathead catfish in the Sandusky River were made in 2009 (Figure S7-v). Five collections, totaling six fish were made in in July and August of that year (Ohio EPA 2017).

### Maumee River, Ohio

Flathead catfish remained confined to the mainstem of the Maumee River and the lower Auglaize River up to the split with the Powell Creek (Ohio EPA 2017) (Figure S7-w).

## **Lake Michigan**

### St. Joseph River, Michigan

By 2005, the population of flathead catfish was estimated to be 4,000 to 7,000 fish in the lower reach of the St. Joseph River, up to Berrien Dam, and ranged from 1 to 17 years old (Daugherty and Sutton 2005). The population was substantially skewed towards smaller fish, with 89% of the population less than 400 mm.

An unauthorized introduction likely occurred in Long Lake, Hillsdale County, prior to 2000 (Figure S7-x), the earliest year a fish was submitted to the Master Angler Program (MDNR 2016). This is an isolated lake without river access and is not close to any known population. Bailey et al. (2004) did not map any locations in the St. Joseph River. We did not find more collections from above Berrien Dam since the one in 1993.

### Fox River, Wisconsin

After 2000, the number of reports in the Fox River drainage increased (Figure S7-y) (WDNR 2017). Flathead catfish were not present in the catch during the 2009 comprehensive survey of Swan Lake, on the upper Fox River (N. Nye, WDNR, personal communication, 2017).

### Muskegon River, Michigan

In 2002, a fish was taken from Pleasant Lake (Figure S7-z) (MDNR 2016) in the very

headwaters of the Muskegon River drainage. This is undoubtedly an unauthorized introduction. The lake is small, has no apparent connection to the river, and is more than 160 km from the Hardy Dam Pond collection. None of these locations was mapped by Bailey et al. (2004).

#### Milwaukee River, Wisconsin

Flathead catfish was documented in the Milwaukee River, a tributary of Lake Michigan, in 2003 (Figure S7-aa) (WDNR 2017). This is the second drainage in Wisconsin to be invaded.

#### Kalamazoo River, Michigan

Their presence upriver in Allegan Lake, above Allegan Dam (the lowest Kalamazoo River barrier dam from Lake Michigan) by 2004 (Figure S7-bb) (MDNR 2016), is attributed to an unauthorized stocking event. This was determined because Allegan Dam does not have any type of fish passage (GEW). No flathead catfish were caught in Kalamazoo Lake during 2009 to 2011 sampling with fyke nets (Janetski and Ruetz III 2015). They were still only found near the mouth in a 2005 assessment (Wesley 2005). The location at the river mouth was mapped by Bailey et al. (2004).

#### Grand River, Michigan

Bailey et al. (2004) depict the lower Grand River for most of its length and the Maple River as having flathead catfish (Figure S7-cc), but not the upper Grand River watershed above Lyons Dam as occupied by this species.

#### Macatawa River, Michigan

There have only been three Master Angler entries submitted for Lake Macatawa (Figure S7-dd) since 1973, single fish in 2008, 2009, and 2011, respectively. Flathead catfish have remained

confined to Lake Macatawa and have not spread upriver.

## **Northern Lake Michigan**

Flathead catfish began appearing in northern Lake Michigan in 2002, when fish were collected from both Little Bay de Noc and Big Bay de Noc (Figure S7-ee) (MDNR 2015).

### Boardman–Charlevoix drainage, Michigan

Flathead catfish were collected from Birch Lake, Antrim County, in the Boardman–Charlevoix drainage, in the northwest part of Michigan in 2006 and 2009 (Figure S7-ff) (MDNR 2015). This is the most northern record from the western side of Lake Michigan and is likely an unauthorized introduction. The lake is immediately adjacent to the East Arm of Grand Traverse Bay (Lake Michigan) and is connected via a very small outlet stream that flathead catfish are unlikely to use.

## **Other Areas of Northern Michigan**

Michigan DNR personnel have not collected any flathead catfish from Les Cheneaux Islands, in the Upper Peninsula, from 1969 to present, nor the St. Marys River (which connects Lake Huron to Lake Superior) in gillnets from 2006 – 2013 (David G. Fielder, personal communication, MDNR 2016). No fish have been reported in Lake Superior.

## **Southern Lake Michigan**

Although the southern end of Lake Michigan is hypothesized to be on the access routes to Lake Michigan through the Chicago Sanitary and Ship Canal, there are virtually no records from there. This lack of records is likely due to water quality issues in the canal. In 2003, two fish were

collected from the Kankakee River at the confluence with the Des Plaines River (FMNH 118356) (Figure S7-gg). This may indicate the species is using the cross-over point from the Mississippi drainage (Kankakee) to the Great Lakes drainage using the Des Plaines River connection with the Chicago Sanitary and Ship Canal system. Water quality probably prevented use of this river in the past. This is the same area of concern for bighead, silver, grass, and black carps as a connection to allow them access to the Great Lakes.

## 2010–2017

In the past eight years, flathead catfish were caught for the first time in northern Lake Michigan; invaded two new drainages (Kawkawlin and Black rivers); and four rivers connecting the Mississippi Basin to the Great Lakes Basin. In addition to these four trans-basin rivers, they have been recorded in a total 24 rivers: 7 in Lake Erie, 11 in Lake Michigan, 1 in Lake Superior, 4 in Lake Huron, 1 in Lake St. Clair; and in lakes Erie, St. Clair, Huron, and Michigan (Figure S8).

There is evidence for 6 new unauthorized angler stockings. Details are as follows:

### **Southern Lake Michigan**

Numerous flathead catfish were collected from the Des Plaines River, both above and below the Army Corps of Engineer's Electric Dispersal Barrier at Romeoville, Illinois; from the Little Calumet River; and from Calumet Lake (Figure S8-a). The Calumet River is a connection between the Mississippi and Great Lakes basins. This is the same area that is of great concern for Asian Carp gaining access to the Great Lakes. In fact, these fish were collected while biologists were monitoring for silver and bighead carps in channels connecting the Mississippi Basin to the Great Lakes Basin. More than 300 flathead catfish were also caught in the Dresden Island,

Marseille, and Starved Rock pools of the upper Illinois waterway (Mississippi Basin) in 2011 (Asian Carp Regional Coordinating Committee (ACRCC) 2012). These collections clearly show that flathead catfish use the Chicago Area Waterway to move between the Mississippi Basin and Lake Michigan. No doubt they have been using this connection for some time, once water quality improved after the late 1970s.

No flathead catfish were collected from the East Branch Little Calumet River in electrofishing surveys conducted in 1990, 2011, and 2015 (Linville and Simon 2015).

## **Lake St. Clair**

One more fish was collected from Lake St. Clair in 2011 (Figure S8-b) (A. Cooke, Ontario Ministry of Natural Resources and Forestry, personal communication, 2016). In 2012, a fish was collected from the middle of the St. Clair River near St. Clair (Figure S8-c) (MDNR 2015). These collections provide evidence that the fish potentially are using this connection to move between the Great Lakes.

## **Lake Huron**

### AuSable River, Michigan

Flathead catfish were apparently introduced by an angler above the dam on the AuSable River into Mio Pond by 2011 (Figure S8-d) (MDNR 2015).

### Saginaw River, Michigan

In 2012, flathead catfish were collected in the Cass River (Figure S8-e), a tributary of the Saginaw River. One was also collected at Murphy Lake in the Cass watershed (Figure S8-f) that

same year. These are apparently both unauthorized introductions as the Cass River did not have fish passage past Frankenmuth Dam until 2017 (Saginaw Bay Watershed Initiative Network, personal communication, 2017). A specimen captured in July 2017 by MDNR biologists was believed to have been the first flathead catfish above Frankenmuth Dam fishway.

No flathead catfish have been collected in MDNR gill net sampling of Saginaw Bay since sampling began in 1989 (D. Fielder, MDNR, personal communication, 2016).

### Kawkawlin River, Michigan

In 2014, an angler caught a flathead catfish in the Saginaw River and released it in the Kawkawlin River (Clark 2014) (Figure S8-g).

## **Lake Erie**

ODNR reports that field trawl and gill net sampling by staff since 1967 on Lake Erie has not yielded any flathead catfish, nor has more recent electrofishing sampling (M. Faust, ODNR, personal communication, 2017).

The flathead catfish population is now considered abundant in the Huron, Sandusky and Maumee rivers (Figure S8-h, i, j) (C. Vandergoot, ODNR, personal communication, 2016). Because flathead catfish were not mentioned by Trautman (1975, 1981) as occurring in the Maumee, Cuyahoga, Sandusky, and Black rivers; and because they were not found in a 1975–1977 survey of limnetic fish larvae in the Maumee and Sandusky river estuaries (Cooper et al. 1981), we presume they invaded these rivers after 1980. The first flathead catfish collected by Ohio Environmental Protection Agency (OEPA) in a tributary of Lake Erie was in 2012 (S. Winkler, OEPA, personal communication, 2017).

### Black River, Ohio

The first-year flathead catfish were recorded from the Black River was in 2012. Twelve were collected that year (Ohio EPA 2017), and two more in 2013 (OSUM 113963; 113964) (Figure S-8k). A single fish was captured from Lake Erie in 2012 during agency sampling for smallmouth bass *Micropterus dolomieu* (M. Faust, ODNR, personal communication, 2017) (Figure S8-l).

### Maumee

In 2012, flathead catfish began invading two Maumee River tributaries, the Tiffin and Auglaize rivers (Ohio EPA 2017) (Figure S8-m, n). In 2013, they were recorded for the first time in the St. Marys River, another tributary farther upriver (Figure S8-o). (Ohio EPA 2017). There was single collection in 2014 from the St. Marys River and many were captured in 2015 (Ohio EPA 2017). Presumably, these fish migrated up the Maumee River to into the St. Marys River, however, because these locations were collected by Ohio EPA, their sampling stops at the Indiana state line, leaving a gap in the distribution between the two known occupancy areas of the rivers in the Fort Wayne, Indiana area.

### Rocky River, Ohio

The first flathead catfish (~3 lbs) was collected from the Rocky River in 2012 (S8-p) by the Cleveland Metroparks Department of Natural Resources (CPDNR). A second, much larger one, was collected from Wallace Lake just off the Rocky River in 2014 (S8-q) (M. Durkalec, CMDNR, personal communication, 2018).

## **Lake Michigan**

The National Oceanic and Atmospheric Administration (NOAA) has never caught a flathead catfish in Lake Michigan in bottom trawls, gill nets, or seines in sampling since 1998. Most of their sampling is done off Muskegon, but there is some sampling as far south as St. Joseph and as far north as Pentwater, Michigan (S. Pothoven, NOAA, personal communication, 2017). No flathead catfish were caught in Pentwater Lake, Pigeon Lake, or Lincoln Lake during 2009 to 2011 sampling with fyke nets (Janetski and Ruetz III 2015).

## **Muskegon River, Michigan**

Although O’Neal (1997) only documented flathead catfish in Muskegon Lake, by 2016, flathead catfish were found upriver to at least to Mecosta County based on information from the MDNR Master Angler Program (Figure S8-r) (MDNR 2016). Fish can only freely move up to Croton Dam (Newaygo County) on the Muskegon River. This was enabled by the removal of the Newaygo Dam in 1969 that opened the river up to Croton Dam and no fish passage is available at this dam. The occurrence of flathead catfish from Mecosta County indicates that an angler moved these fish beyond at least two (Croton and Hardy), if not three (Croton, Hardy and Rogers), dams (depending on where in the county it was caught), between 1997 (O’Neal’s report) and 2016.

Flathead catfish were also collected during lake sturgeon *Acipenser fulvescens* sampling in Muskegon Lake between 2008 and 2013 using small-mesh gillnets, fyke nets, and boat electrofishing (Harris et al. 2017; Janetski and Ruetz III 2015).

### White River, Michigan

There were no flathead catfish occurrences indicated in this area by Bailey et al. (2004). No flathead catfish were caught in White Lake during 2009 to 2011 sampling with fyke nets (Janetski and Ruetz III 2015). The only other flathead catfish from this coastal area is one fish caught in Hamlin Lake, Mason County, at the outlet of Big Sable River (Figure S8-s), was entered into the Master Anglers Program in 2012. This fish is likely from an angler stocking into Hamlin Lake because Hamlin Lake has an impassible terminal barrier dam that controls its water surface elevation.

### St. Joseph River, Michigan

An unauthorized introduction likely occurred in Barron Lake, Cass County, sometime prior to 2014 (Figure S8-t) when a fish was submitted to the Master Anglers Program (MDNR 2016). This is an isolated lake without river access and is not close to known flathead catfish populations.

### Grand River, Michigan

The 2017 Grand River Assessment shows flathead catfish distribution as the entire length of the Maple River and the Grand River up to the confluence with the Maple River. Since Lyons Dam was removed in 2016 near the Maple River confluence, it is likely that flathead catfish are now found up to Webber Dam where the existing fishway, designed for salmonids, is unlikely to pass flatfish catfish. Myers and Cowden lakes are also depicted as having flathead catfish (Figure S8-u) (Hanshue and Harrington 2017).

## Fox River, Wisconsin

Flathead catfish have been documented in Puckaway Lake in Green Lake County (Figure S8-v). Wisconsin DNR have received angler reports from farther upriver, but have not verified those with sampling (D. Bartz, WDNR, personal communication, 2017). Wisconsin DNR staff are not aware of any reports from the upper Fox River in Columbia County. Furthermore, a DNR boat electrofishing survey on the Fox River between Buffalo Lake and Swan Lake (Governors Bend Park) in 2013 caught no flathead catfish. There were no flathead catfish collected in a wadeable stream survey of the Fox River between Spring Lake and Park Lake in 2013. A search of recent fishery survey records for Park Lake also found no records of flatheads. Upstream of Park Lake is a relatively small stream, and two wadeable electrofishing surveys in that segment from 2013 did not collect any flatheads (N. Nye, WDNR, personal communication, 2017).

No flathead catfish were caught in the southwest portion of Green Bay in fyke net sampling in May 2016 (Smith and Simpkins 2017).

## **Northern Lake Michigan**

Two more fish were caught from Lake Michigan in Little Bay de Noc in 2014 (Figure S8-w) (G. Sanville, personal communication; MDNR, 2015). Little Bay de Noc is the farthest north this species has been recorded anywhere in its range (USGS 2017).

## **Northern Lake Huron**

No flathead catfish have been collected from the St. Mary's River in gill net sampling from 2006 to 2013, nor in the Les Cheneaux Islands in gill nets from 1969 to present (D. Fielder, MDNR, personal communication, 2016).

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Supplemental Table:

Table S1. Significant new collections with discussion in the text and labeled on maps (Figures - S8).

List of Supplement Figures:

Figure S1. Flathead catfish distribution records in the Great Lakes Basin 1890 - 1949. Letters correspond to descriptions in the text. Flathead catfish may not still be present in all locations.

Figure S2. Flathead catfish distribution records in the Great Lakes Basin until 1959. New locations (1950 – 1959) are marked by triangles; locations prior to (1950) are marked by circles. Letters correspond to descriptions in the text. Flathead catfish may not still be present in all locations.

Figure S3. Flathead catfish distribution records in the Great Lakes Basin until 1969. New locations (1960 – 1969) are marked by triangles; locations prior to (1960) are marked by circles. Letters correspond to descriptions in the text. Flathead catfish may not still be present in all locations.

Figure S4. Flathead catfish distribution records in the Great Lakes Basin until 1979. New locations (1970 – 1979) are marked by triangles; locations prior to (1970) are marked by circles. Letters correspond to descriptions in the text. Flathead catfish may not still be present in all locations.

Figure S5. Flathead catfish distribution records in the Great Lakes Basin until 1989. New locations (1980 – 1989) are marked by triangles; locations prior to (1980) are marked by circles. Letters correspond to descriptions in the text. Flathead catfish may not still be present in all locations.

Figure S6. Flathead catfish distribution records in the Great Lakes Basin until 1999. New locations (1990 – 1999) are marked by triangles; locations prior to (1990) are marked by circles. Letters correspond to descriptions in the text. Flathead catfish may not still be present in all locations.

Figure S7. Flathead catfish distribution records in the Great Lakes Basin until 2009. New locations (2000 – 2009) are marked by triangles; locations prior to (2000) are marked by circles. Letters correspond to descriptions in the text. Flathead catfish may not still be present in all locations.

Figure S8. Flathead catfish distribution records in the Great Lakes Basin until 2017. New locations (2010 – 2017) are marked by triangles; locations prior to (2010) are marked by circles. Letters correspond to descriptions in the text. Flathead catfish may not still be present in all locations.

Table S-1. Significant new collections discussion in the text and labeled on maps.					
Great Lake	Drainage	Waterbody	Map label	Year	Notes
<b>1890-1940s</b>					
Erie		Huron River, OH	1-a	1890	earliest Great Lake record; a few fish annually
		Lake Erie at mouth of Cuyahoga	1-f	1938	speciman is missing
		Lake Erie	1-b	1940	OSUM 1866
		Lake Erie	1-c	1942	OSUM 6664
		Lake Erie	1-d	1948	OSUM 8471
		Huron River	1-e	1948	OSUM 8467
		Huron River	1-g	1947	
Michigan	Kalamazoo	Kalamazoo River	1-h	1922	first Lake Michigan drainage record; UMMZ 51272
	Grand	Grand R.	1-i	between 1904 1928	
	Macatawa	Lake Macatawa	1-j	1942	UMMZ 196980
	Fox	Fox River	not mapped	1927	questionable
<b>1950s</b>					
Lake Erie	Huron	Huron River, OH	2-a	1951	
Michigan	Fox	Lake Poygan	2-b	1953	first GL record for Wisconsin; angler introduction
	Fox	Lakes Poygan and Winnebago	2-b	1958-1961	24 fish collected
<b>1960s</b>					
Erie	Huron	Huron River, OH	3-a	1968	ODNR stocked 5,200; only GL stocking
Michigan	White	White Lake, MI	3-b	1965	8 fish collected
	Grand	Grand		1967-1989	commonly collected in surveys
	Grand	Maple	3-c	1967	UMMZ 186652
<b>1970s</b>					
Erie	Lake Erie	Lake Erie, Canada	4-a	1978	first collection from Canadian side of Lake Erie
Michigan	Kalamazoo	Kalamazoo		1922-1971	None collected in surveys
	Muskegon	Muskegon Lake	4-b	1973	first record for Muskegon River
	Macatawa	Lake Macatawa	4-c	1973	first collection since 1942
	Fox	lower Fox	4-d	1975	
	Fox	Embarrass River	4-e	1979	
	Manistee	Manistee Lake	4-f	1979	
<b>1980s</b>					
Michigan	White	White River	5-a	1981	second collection from here
	Kalamazoo	Kalamazoo	5-b	1982	first collection since 1922
	St. Joseph	St. Joseph River	5-c	1982	first record for this river
	Fox	upper Fox River	5-d	1983	
	Lake Michigan	Green Bay, Lake Michigan	5-e	late 1980s	
Erie	Lake Erie	Lake Erie, Canada	5-f	1986	second fish from Canadian side
Lake St. Clair	Lake St. Clair	Lake St. Clair, Canada	5-g	1989	first record for Lake
<b>1990s</b>					
Huron	Lake Huron	Saginaw Bay, Lake Huron, MI	6-a	1991	first records for Lake Huron
	Thunder Bay	Thunder Bay River, MI	6-b	1991	first records for Lake Huron
Erie	Maumee	Maumee River, OH	6-c	1992	first record for river
	Chagrin	Chagrin River, OH	6-d	1994	first record for river
	Portage	Portage River	6-e	1995	first record for river
Lake St. Clair	Lake St. Clair	Lake St. Clair, MI	6-f	1996	first record for US side
Michigan	Muskegon	Muskegon River, MI		1973-1990s	common
	Muskegon	Baptist Lake, MI	6-g	1990	stocked by MDNR; isolated lake
	Muskegon	Sand Lake, MI	6-h	1990	stocked by MDNR; isolated lake
	St. Joseph	St. Joseph River above Berrien Springs Dam, MI	6-i	1993	angler introduction
	St. Joseph	Sand Lake, MI	6-j	1997	stocked by MDNR; isolated lake
	Grand	Myers Lake, MI	6-k	1994	stocked by MDNR; isolated lake
	Grand	Cowden Lake, MI	6-l	1996	stocked by MDNR; isolated lake
	Manistee	Manistee Lake, MI	6-m	1995	stocked by MDNR; already present
	Pere Marquette-White River	Brush Lake, MI	6-n	1996	stocked by MDNR; isolated lake
	Kalamazoo	Hall, MI	6-o	1999	stocked by MDNR; isolated lake
Superior	AuTrain	Cole Creek, MI	6-p	1994	angler introduction
<b>2000s</b>					
Lake St. Clair	Lake St. Clair	Lake St. Clair, Canada	7-a	2001, 2003	
		Lake St. Clair, MI	7-b	2005, 2008	
		St. Clair River	7-c	2008	



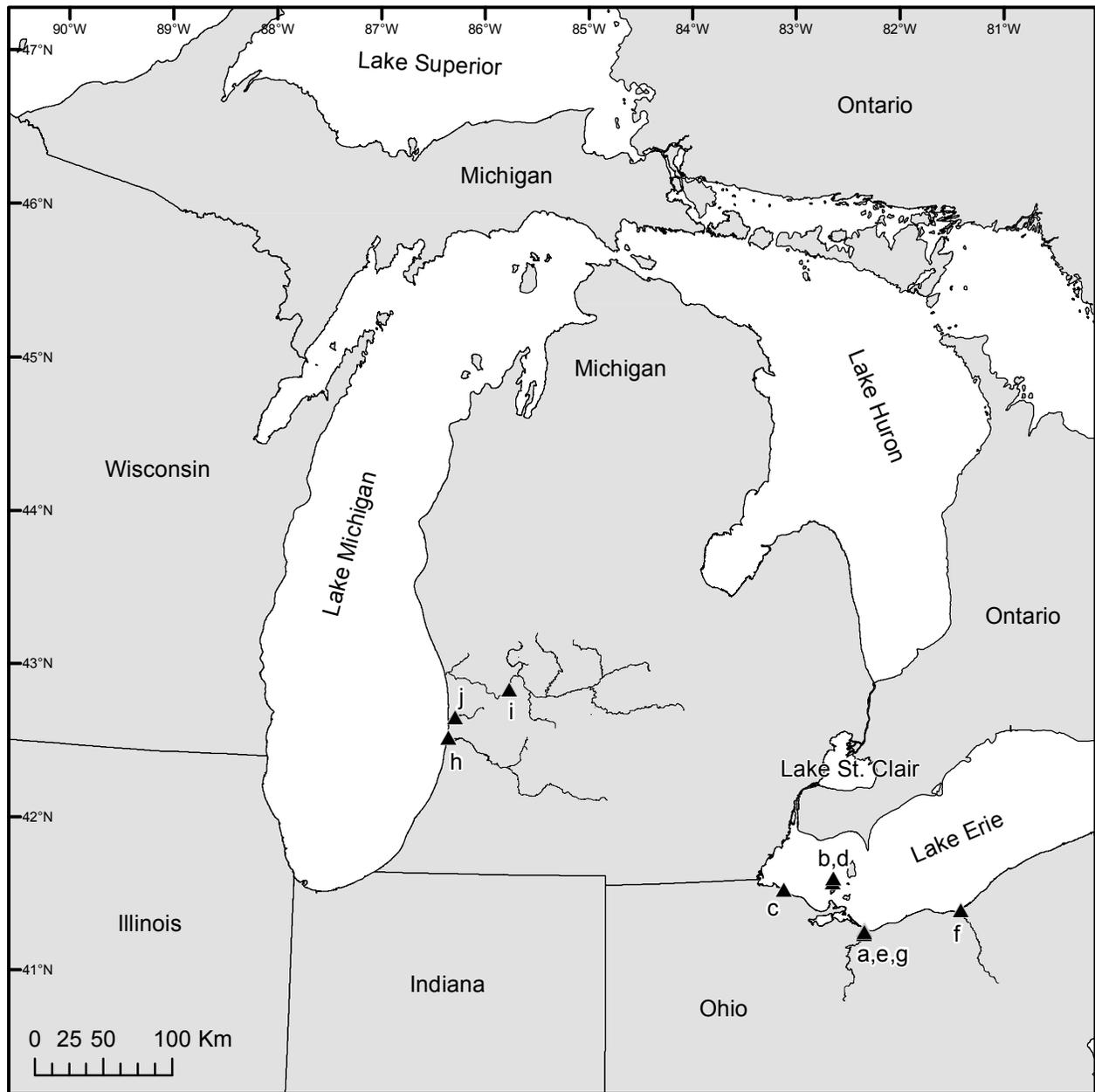


Figure S1



Figure S2



Figure S3

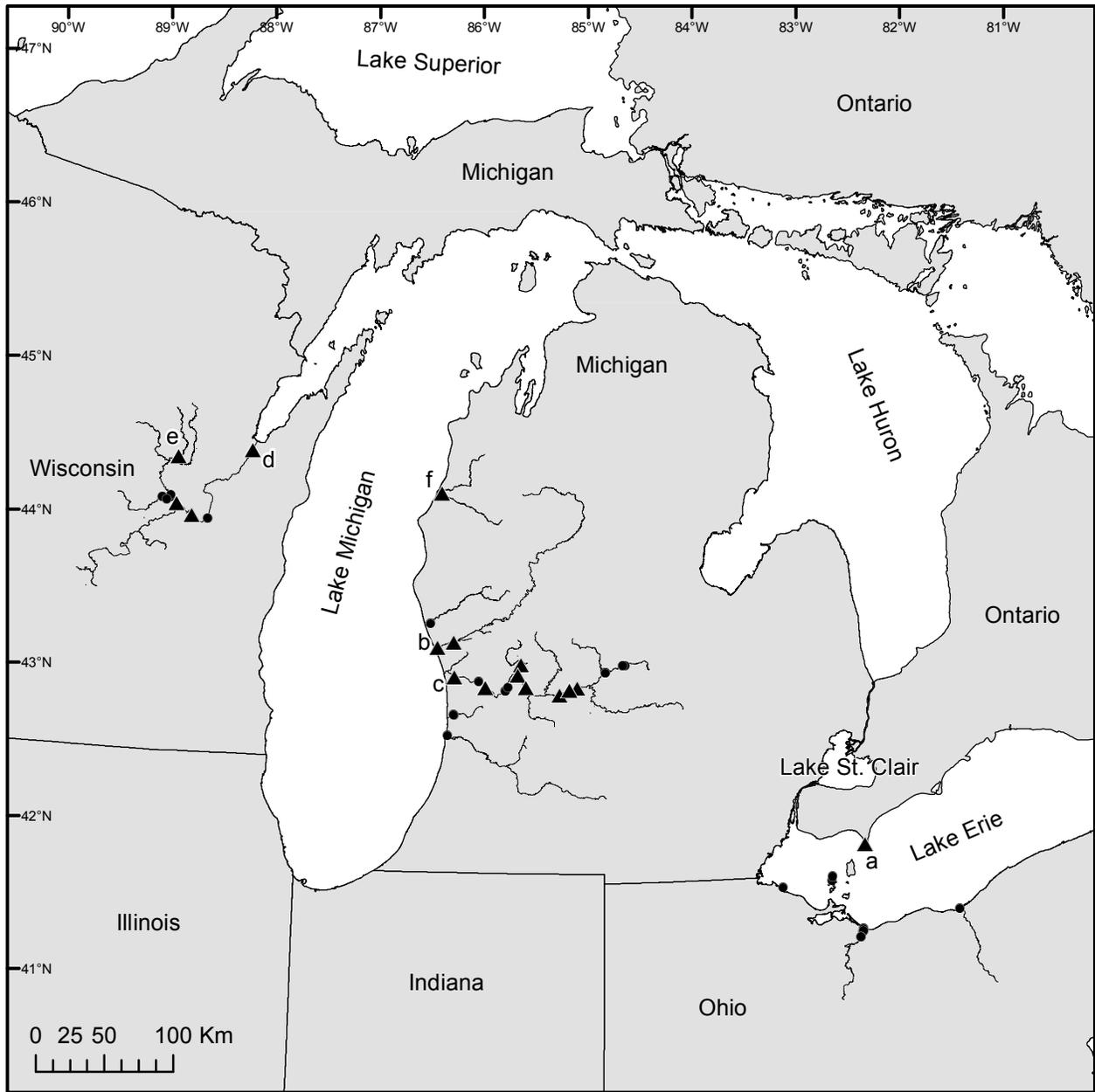


Figure S4



Figure S5

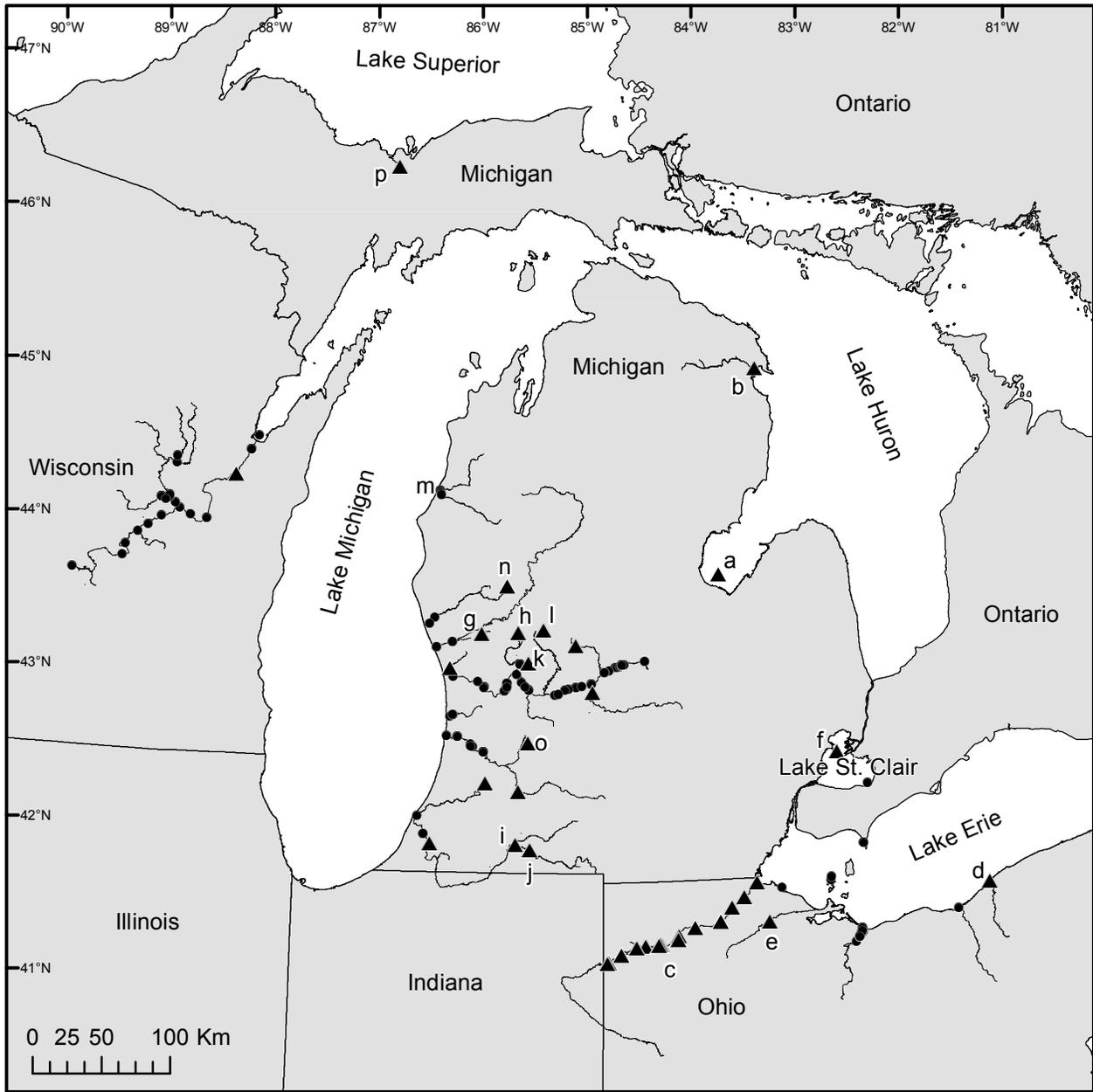


Figure S6

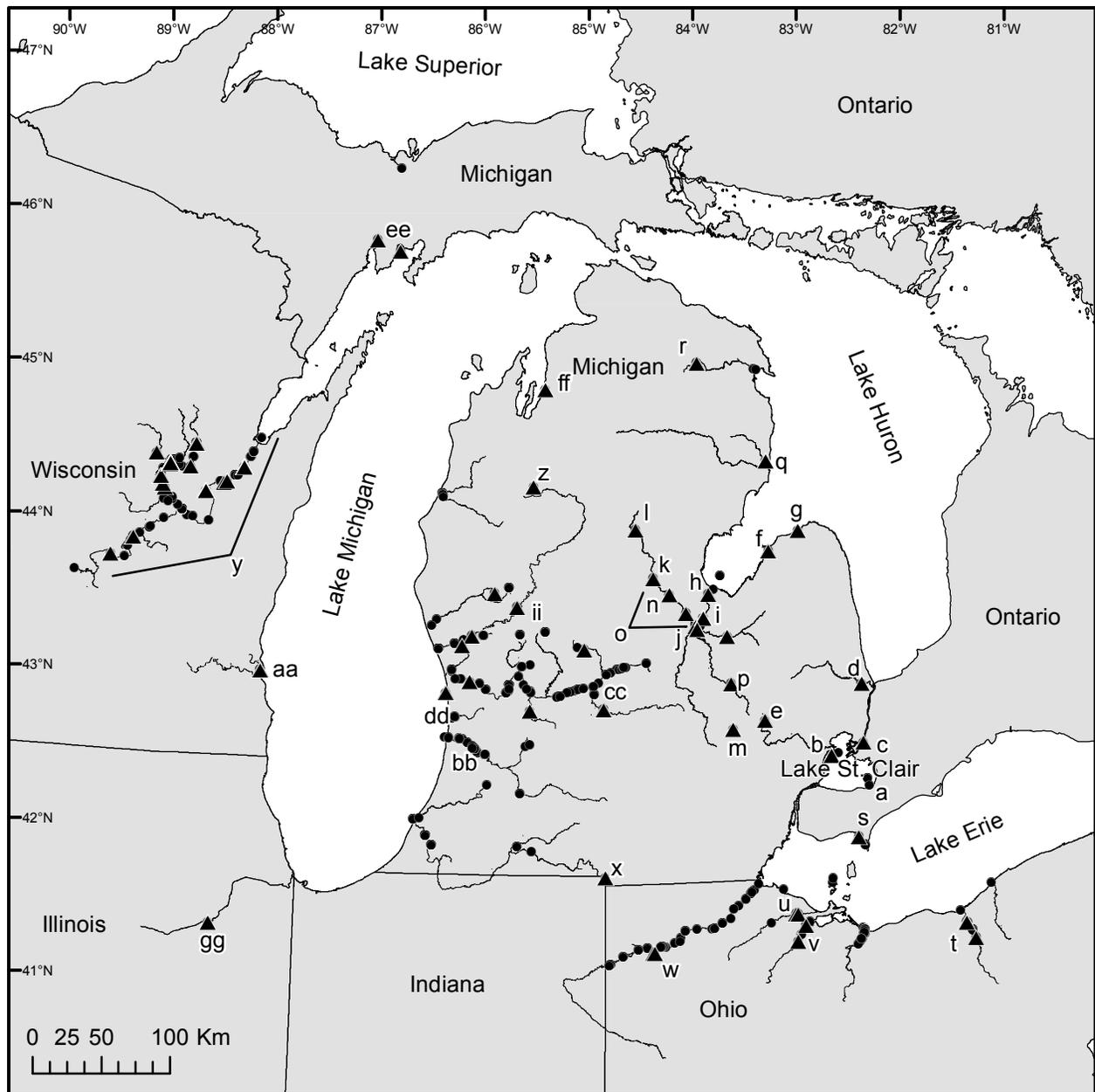


Figure S7

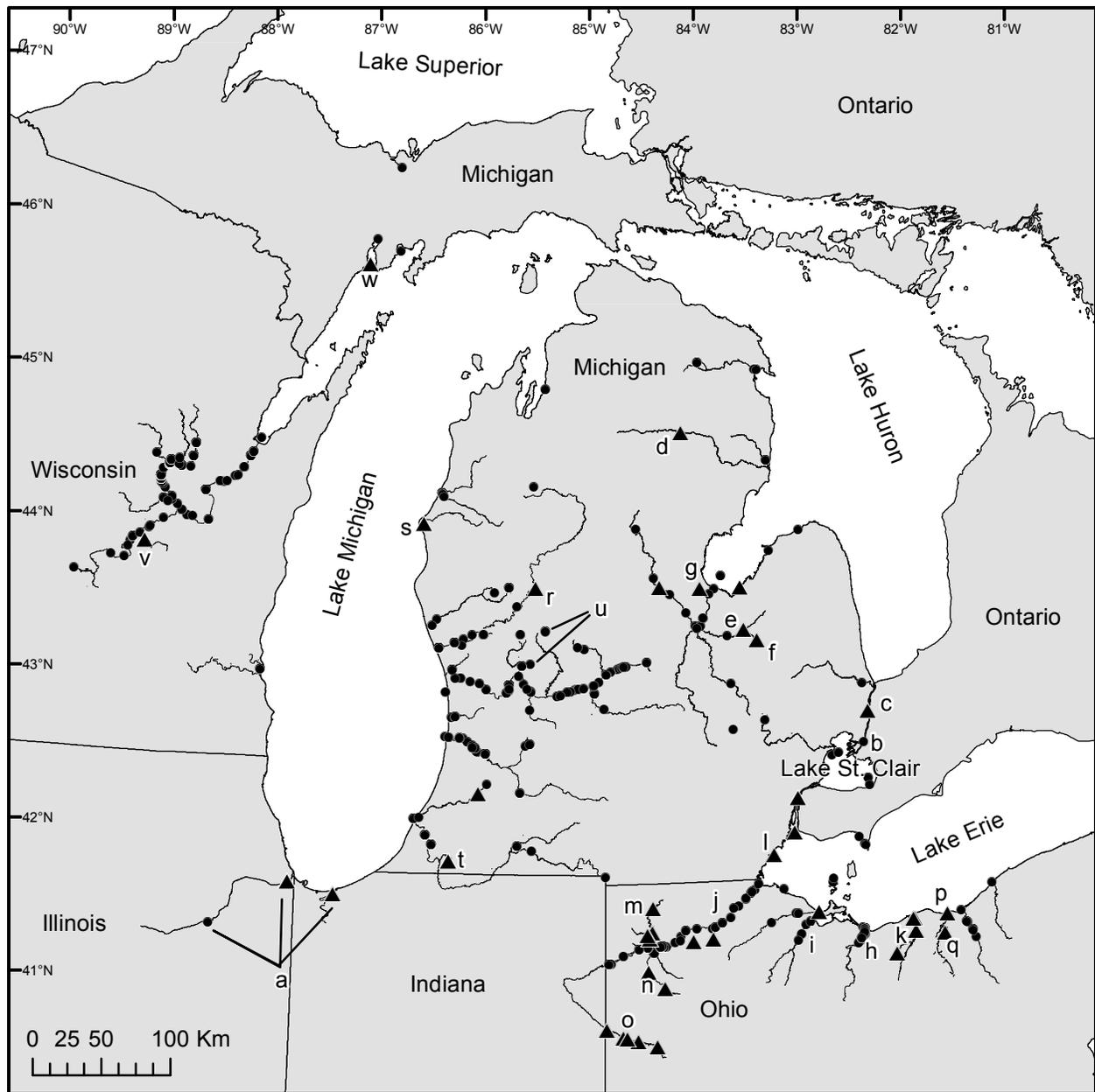


Figure S8