Freshwater Mussel Surveys of Great Lakes Tributary Rivers in Michigan

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Background photo: The Cass River one mile southwest of Cass City. Photo by Peter Badra **Left inset photo:** *Lampsilis ventricosa* (pocketbook) from the Cass River. Photo by Peter Badra. **Right inset photo:** An MNFI biologist searches for mussels along a transect in White Lake. Photo by Colleen McClean. **Photos in report body** by Peter Badra except for Figure 23., by Colleen McLean.

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Introduction

This project is part of an ongoing effort by Michigan Natural Features Inventory (MNFI) to assess Michigan's native freshwater biodiversity and investigate ecological factors affecting aquatic species and communities. The results of freshwater mussel (Unionidae) surveys conducted in 2003 and 2004 are presented in this report. Prior studies were conducted in 2001 and 2002 (Badra and Goforth 2002, Badra and Goforth 2003), and the surveys will continue through 2005. This information is being incorporated into decision making tools (such as the MNFI and NatureServe databases) to assist in the management of aquatic ecosystems and provide information needed to evaluate the State of Michigan and global status and distribution of native freshwater species and communities. Survey results from the White, Pere Marquette, Rifle, and Cass Rivers are included in this report.

There are four families of freshwater mussel occurring in Michigan. The Unionidae ("clams" or "mussels") and the Sphaeriidae (pea clams or fingernail clams) are native to North America, while the Corbiculidae (Asian clams) and Dreissenidae (zebra and quagga mussels) are exotic to this continent. The zebra mussel family is represented by two species, *Dreissena polymorpha* (zebra mussel) and *Dreissena bugensis* (quagga mussel) (Figure 1). *Corbicula fluminea* (Asian clam) is the only species of its family in North America (Figure 2). This species was introduced to North America in 1938 for food and has spread throughout the U.S. *D. polymorpha* and *D. bugensis* were accidentally introduced to North America in the 1980s by being transported in the ballast water of shipping vessels. *D. polymorpha* are having a dramatic ecological impact on Michigan's lakes and rivers due to their consumption of plankton and ability to colonize native freshwater mussels. The Sphaeriidae are native to North America and are fairly widespread in Michigan (Figure 3). The unionids are characterized by their relatively large size (3-25cm) and reliance on fish hosts in order to complete their life cycle.

Unionids are an important component of Michigan's aquatic ecosystems. They play a significant role in freshwater ecosystems, are useful indicators of water quality, and have historically been economically valuable. They also serve as umbrella taxa for the conservation of aquatic ecosystems because they are relatively sensitive to habitat degradation and pollution, and are dependent on fish hosts to complete their life cycle. Although unionids inhabit streams and lakes in Central America, North America, Eurasia, and Africa (Bogan 1993), eastern North America is the region of highest diversity with 292 described species (Williams et al. 1993). Forty-five unionid species have been documented in Michigan's rivers and lakes.

Mussel communities in southern Michigan were once economically valuable. In the early 1900s, live unionids were harvested from these and other large rivers to support the button industry. In 1938, Henry van der Schalie, a noted malacologist, documented a rapid decline of unionid mussels during the 1930s due to harvest pressure. In response, The Michigan Department of Natural Resources, then known as the Michigan Conservation Commission, closed the harvest for a period of five years beginning in 1944 to allow the resource to recover. By the end of the 1940s, much of the demand for unionid shell had subsided due to increased use of plastics to manufacture buttons. Surveys of the Grand River later revealed that at least some of the mussel beds had recovered (van der Schalie 1948). Although unionid shells are now collected in some parts of the country for the cultured pearl industry, Michigan's unionid communities are not considered stable enough to allow a harvest, and it is illegal to possess or collect them without a permit.

Unionids are now recognized as useful water quality indicators and for their ecological value. Most species are long-lived, some with life spans up to 50 years and more (Badra and Goforth 2001). They are generally sessile, spending most of their lives within a particular stream reach. Unionids are sensitive to, and tend to accumulate contaminants because they are filter feeders. Empty unionid shells can reveal historic community composition because they remain intact for many years *post mortem*. These characteristics make unionid mussels valuable indicators of water quality (Strayer 1999a). Chemical analysis of shell material can also reveal environmental information from years past (Mutvei and Westermark 2001).

Unionids also play significant ecological roles in rivers. The action of filter feeding can change the particle content of river water (Pusch et al. 2001). Both live individuals and empty shell provide habitat for aquatic insects, and empty shell also provides habitat for crayfish. Unionids play a substantial role in the flow of energy in stream ecosystems, often comprising the highest percentage of biomass relative to other benthic stream organisms (Strayer et al. 1994). They are, therefore, a key link in the food chain from aquatic microorganisms to crayfish, muskrats, and other large predators. Habitat requirements for pearly mussels vary among species, but the most species rich mussel beds are usually found in areas with the following characteristics: a mixture of pebble, gravel, and sand substrates with relatively little silt; clear water without excessive suspended particles; and good stream current (riffles or runs). Because they are sensitive to changes in habitat quality, the status of unionids can be indicative of the biological integrity of river ecosystems as a whole.

The Unionidae rely upon fish hosts to complete their life cycle. Larvae called glochidia (Figure 4) develop from fertilized eggs and live within the females' mantle tissues (i.e., marsupia). Glochidia are released into the water column and must attach to the gills or fins of a suitable fish host in order to survive. These parasitic glochidia transform into juvenile versions of the adult form and drop off the host after a 6-160 day period depending on the mussel species (Kat 1984). Some unionids are known to have only a few suitable host species, while others are generalists and utilize several species. The females of some taxa display mantle flaps or conglutinates that function as lures to fish hosts, thereby increasing the chances that larvae will successfully attach to an appropriate host (Kraemer 1970). Since adult mussels are relatively sessile (Amyot and Downing 1997), the transportation of glochidia by fish hosts is the primary mode of dispersal for the Unionidae (Kat 1984; Watters 1992). Gene flow, the exchange of genetic material among unionid populations, is facilitated by fish hosts, thus allowing genetic diversity to be maintained.

Over the past century, many factors have negatively impacted Michigan's river ecosystems. Increasing land use intensity within watersheds, point source pollution, direct habitat alteration (e.g., drain clean-outs and dredging), and non-native species introductions have impacted native mussel and fish communities (Bogan 1993; Fuller 1974; Strayer 1999b). Without the appropriate host species present in sufficient densities, the unionid life cycle cannot be completed. Therefore, threats to native fish communities can undermine the stability of unionid populations. Barriers to fish migration, such as dams and degraded habitat, are also barriers to the successful reproduction and dispersal of unionids (Watters 1995a). They can inhibit the re-colonization of suitable habitat, threaten genetic diversity through lack of gene flow, and prevent the recovery of unionid populations. The non-native *D. polymorpha* has had drastic effects on unionid communities (Schloesser et al. 1998) and is continuing to spread throughout the surface waters of Michigan.

Over one-third (19) of Michigan's 45 unionids are state-listed as special concern, threatened, or endangered. A review of the status of U.S. and Canadian unionids by the American Fisheries Society found that 97 of the 292 species that occur in the U.S. are considered endangered (Williams et al. 1993). The decline of freshwater bivalves is occurring in other parts of the world as well (Bogan 1993). Goals for conserving unionid diversity in Michigan parallel those that exist on the national level. These include: prevent or minimize the continued degradation of high quality habitat; increase our fundamental knowledge of basic biology and habitat requirements; increase our knowledge of the current distribution and health of unionid populations; and understand how anthropogenic factors such as habitat alteration and water quality degradation impact unionids (National Native Mussel Conservation Committee 1998).
A more complete understanding of the status, distribution, and ecology of the Uniondae in Michigan is needed to effectively manage this endangered group and can assist in the management of aquatic ecosystems.

Figure 1. *Dreissena polymorpha* (Zebra mussel, left) and *Dreissena bugensis* (quagga mussel, right). Length approximately 25mm.

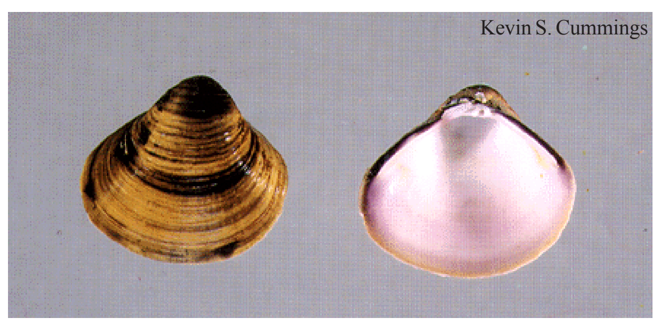


Figure 2. *Corbicula fluminea* (Asian clam). Length 35mm.

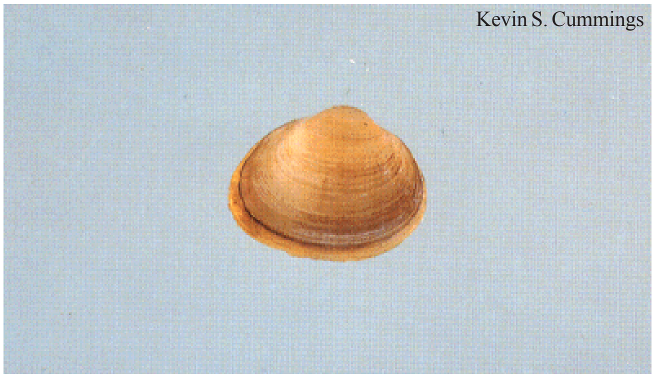


Figure 3. Sphaeriidae (Pea clam). Length 12mm.

Figure 4. Unionidae larvae (glochidia). The larger ones are *Lampsilis siliquoidea* (fatmuckets, length 0.25mm) and the smaller ones are *Cumberlandia monodonta* (spectaclecase).

Methods

Sites were surveyed in the White, Pere Marquette, Rifle, and Cass Rivers during the summer and fall of 2003 and 2004. These rivers were chosen due to the lack of information on unionids in these systems. Survey sites on White Lake and Pere Marquette Lake were deep enough to require the use of SCUBA. Several sites on the White River and Pere Marquette River were also deep and required SCUBA. All other sites were in shallow enough water to allow wading with glass bottomed buckets.

In reaches where a boat and SCUBA were used, the nearest boat ramp to the reach was identified and used as an access point. The use of a jet drive outboard motor made navigating in shallow areas more time-efficient, and mechanical failure was far less likely than with a traditional propeller drive outboard motor (Figure 5). Mussel habitat and signs of mussel beds, such as shells in muskrat middens, were identified from a boat within these reaches and were used as a basis for selecting survey sites. A section of the Pere Marquette River was accessed by canoe. All areas within the canoed section that appeared to have suitable substrate (i.e. not pure, unstable sand) for unionids were surveyed. In addition, the Pere Marquette River was assessed for unionid habitat at Gleason's Landing, Bowman Bridge at Carrs Rd., Rainbow Rapids, and Upper Branch Bridge at South Branch Rd.. Handheld GPS units (Garmin 12XL) and USGS topographic maps were used to document the position of sites where a boat or canoe was used to access the area. Latitude and longitude were recorded at a point in the approximate center of the site.

The field crew typically consisted of two divers and a third person who recorded data, assisted divers with gear, and tended the boat while divers were in the water. Once signs of a mussel bed were identified, the boat was anchored and transects were set. In some cases, sites were surveyed without prior evidence of shell or live individuals other than apparently suitable habitat. Transects were set side by side approximately 3 to 8m apart, parallel to river flow. Transects were delineated using 10m lengths of 2.54cm nylon webbing with 4.5kg anchors fastened to each end. An arms-width (approx. 0.8m) on each side of each transect was searched by passing the hands over and through the substrate to a depth of approximately 5cm of substrate. A buoy was tied to one or both anchors to mark the endpoints of each transect. Divers started working each pair of transects at the same time, moving in an upstream direction. Searching in an upstream direction prevented a decrease in visibility due to disturbance of fine sediments during surveys. Divers searched a total of eight transects at each site (four transects per diver). Subsequent pairs of transects were placed directly upstream from the previous pair. Transects that were in water shallow enough to wade (approx. <70cm) allowed surveyors to kneel on the bottom and perform tactile searches without the use of SCUBA. Glass bottom buckets were also used at these sites to help detect mussels visually (Figure 6). When stream width was less than approximately 6m, the entire width of the stream was surveyed without transect lines for a reach length that would allow an area of 128m^2 to be covered.

Unionids buried up to approximately 5cm below the substrate surface and located within 0.8m on either side of transect lines were detectable. At sites with low underwater visibility, mussels were located primarily by feel as divers passed their hands through the substrate adjacent to the transect lines. Relatively clear water at a few of the sites made visual detection of mussels possible in addition to locating by hand.

Live unionids were placed in mesh bags, brought to the surface, and identified after completing each transect. Length measurements of all individuals were taken (Figure 7). The presence of *D. polymorpha* within transects was recorded, and the number of *D. polymorpha* attached to each live unionid was determined. The presence of shell or live *C. fluminea* was recorded when detected. Although *Neogobius melansostomus* was not a target of these surveys, their presence was recorded when they were observed. Empty unionid shell found during transect searches was either identified underwater or brought to the surface for identification. Additional species represented only by empty shell were noted. After processing, live unionids were planted in the substrate, anterior end down, along transect lines in approximately the same density as they were found. Most empty shells were returned to the river. Approximately 50 shells were collected. The boat and outboard motor were either dried for several days or washed with a bleach solution to prevent the transportation of live *D. polymorpha* and other exotics between different river reaches. The substrate within each transect was characterized by estimating the percent composition by volume 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 (<0.0625) (Hynes 1970).

To maximize diver safety three factors had to be addressed; water quality, current, and visibility. Bacteria counts in Lower Michigan rivers are often high enough that contact with river water should be avoided. Sediments in river substrates can also contain potentially hazardous substances. Reports of discharges into the river were monitored and no diving occurred downstream from points of discharge for at least a week after the event. Drysuits (D.U.I. ™) and full facemasks (Scubapro™) were used to minimize direct contact with river water and sediments. Current speeds at most of the sites made it necessary for divers to wear a much heavier weight belt than usual. Transect lines not only delineated the area to be searched, but were also used as a hand line to help divers stabilize themselves in the current. Broken glass, scrap metal, zebra mussel shell, and other sharp debris was frequently encountered during tactile searches. Neoprene gloves (3mm) with kevlar reinforcement were worn to minimize the chance of injury. Visibility typically ranged from a few cm to greater than 3m in the rivers surveyed. Transect lines were essential for keeping divers oriented to sampling areas during surveys (Figure 8). The person on the boat also spotted divers to help them avoid hazards.

Figure 5. Boat used for surveying large river habitats.

Figure 6. Locating unionids with a glass bottom bucket in the Cass River.

Figure 7. Measuring the length of a *Lasmigona costata* (fluted-shell) from the Cass River.

Results

A total of 58 sites were surveyed in four rivers. Latitude and longitude of survey site locations are given in Table 1. Surveys sites are mapped in Figures 9-20. The following sites required the use of SCUBA; PM1-PM7 on the Pere Marquette River. The entire reach of the Pere Marquette between the Lower Branch Bridge at Landon Rd. and Custer Bridge at Custer Rd. was surveyed by canoe to identify suitable unionid habitat. Sites PM8-PM17 were located within this reach. In addition, the Pere Marquette River was assessed for unionid habitat at Gleason's Landing; Bowman Bridge at Carrs Rd.; Rainbow Rapids; and Upper Branch Bridge at South Branch Rd..

A total of 20 unionid species were found during the surveys (Table 2). Density and relative abundance measures for each species at each site are

Figure 8. Transect line anchored to the stream bottom and ready for survey.

given in Table 3. The highest density and species richness measures were recorded in the Cass River at sites CS1, CS2 (Figure 21), and CS5. Very low density and species richness were recorded at sites PM8-PM26 in the upper Pere Marquette River (three live individuals and an empty shell representing four species). No live individuals or shells were found during brief qualitative surveys of the Pere Marquette River at Gleason's Landing, Bowman Bridge at Carrs Rd., Rainbow Rapids, or Upper Branch Bridge at South Branch Rd. Sites in the Rifle River also had very low density and species richness. The highest density and species richness in the White River drainage was found at W10, the most upstream site surveyed in this system. No live unionids were found in White Lake. Though few very young unionids were found during the surveys, the possibility of recent reproduction cannot be ruled out. Specific methods targeting young unionids are needed to consistently detect individuals less than approximately 2cm in length. The use of such methods was beyond the scope of this study.

A potential occurrence for the state-listed as threatened *Lampsilis fasciola* (wavy-rayed lampmussel) was found in White Creek, a tributary of the Cass River at sites C7 and C8. One broken and worn half shell was collected. This shell was compared to specimens at the University of Michigan Museum of Zoology mollusk collection, but a definite identification could not be made due to its poor condition. The shell may be *Lampsilis ventricosa* (pocketbook). Updates of historic occurrences for several species of special concern were documented, including *Alasmidonta marginata* (elktoe) in the Cass River (C2); *Alasmidonta viridis* (slippershell) in the Cass River (C1), White Creek (C7 and C8), and Rifle River (Ri9 and Ri10); *Pleurobema sintoxia* (round pigtoe) in the Cass River (C3 and C4); *Venustaconcha ellipsiformis* (ellipse) in the Cass River (C1, C2, C4, and C5) and White Creek (C7 and C8); and *Villosa iris* (rainbow) in the Cass River (C1, C3, and C4) and White Creek (C8). *Actinonaias ligamentina* (mucket), a species that may be declining in Michigan, was found in the Cass River at sites C1 and C2. This species was particularly abundant at site C2 (Figure 22).

The exotic *D. polymorpha* (zebra mussel) and *Neogobius melanostomus* (round goby) were found in Pere Marquette Lake and White Lake. *Corbicula fluminea* (Asian clam) was found in White Lake only (Table 4). Bysal threads from *D. polymorpha* were found attached to empty unionid shell (*Lampsilis siliquoidea*, fatmucket) at two sites in Pere Marquette Lake (PM1 and PM2). Three live *D. polymorpha* were found attached to a live *L. siliquoidea* at site PM4. Dozens of clumps of live *D. polymorpha* were observed in Pere Marquette Lake. These were attached to woody debris that had settled on the lake bottom (Figure 23). Live *D. polymorpha* were seen attached to empty unionid shell (*Lampsilis siliquoidea*, fatmucket) in White Lake at sites W3 and W4. Empty *D. polymorpha* shells were found scattered throughout Pere Marquette and White Lakes.

The substrate at survey sites in the Cass River was typically composed of a mixture of different particle size classes including silt, sand, gravel, pebble, and cobble (Figure 24). The exception was site C6 which was dominated by silt with some sand. Sites in Pere Marquette Lake were also dominated by silt with some sand, while the Pere Marquette River contained a wider variety of substrate types. Sites PM5-PM7 were characterized by sandy substrate with some woody debris and other organic materials. The reach between the Lower Branch Bridge at Landon Rd. and Custer Bridge at Custer Rd. (sites PM8-PM26) had a 100% sand substrate with patches of a clean sand, gravel, pebble mixture. The sand was not stable and seemed to be flowing downstream due to stream current. This unstable substrate is not suitable habitat for unionids. Within this reach, sites were chosen based on the presence of sand, gravel, and pebble substrates that appeared to have enough stability to support unionids. Brief qualitative surveys of the Pere Marquette River at Gleason's Landing, Bowman Bridge at Carrs Rd., Rainbow Rapids, and Upper Branch Bridge at South Branch Rd. revealed that the substrate at these sites was 100% loose sand and appeared to be unsuitable for unionids. All but a few sites in the Rifle River had a mixture of silt, sand, gravel, and pebble substrates which appeared suitable for unionids. The exceptions were site Ri2, which was mostly bedrock with some patches of gravel and pebble, and site Ri5, which was silt with some sand. The substrate in White Lake (sites W1-W5) was dominated by sand with a small percentage of silt and/or gravel. Sites W6-W9 ranged from equal parts silt and sand, to 100% sand. Site W10 was sand with some gravel.

Table 1. Latitude and longitude for sites surveyed in the summers of 2003 and 2004.

Site	Latitude	Longitude	Site	Latitude	Longitude
C1	43.35167	-83.58500	PM21	43.87056	-86.07917
C2	43.41083	-83.48833	PM22	43.84472	-86.07583
C3	43.50149	-83.36077	PM23	43.81556	-86.08472
C4	43.50832	-83.35193	PM24	43.74222	-85.95972
C5	43.58444	-83.18111	PM25	43.85750	-85.85222
C6	43.64111	-83.07750	PM26	43.81667	-85.80000
C7	43.51889	-83.28694	Ri1	44.02639	-83.83194
C8	43.51917	-83.28250	Ri2	44.04611	-83.85667
C9	43.65583	-83.02194	Ri3	44.07944	-84.03500
PM1	43.93254	-86.44635	Ri4	44.14139	-84.04389
PM2	43.93221	-86.44255	Ri5	44.18000	-84.07361
PM3	43.93617	-86.43469	Ri6	44.21028	-84.07361
PM4	43.93339	-86.43258	Ri7	44.25028	-84.06917
PM5	43.93209	-86.41438	Ri8	44.31278	-84.07000
PM6	43.92537	-86.39842	Ri9	44.33417	-84.06444
PM7	43.92675	-86.39241	Ri10	44.34972	-84.05222
PM8	43.93479	-86.19181	Ri11	44.36333	-84.04889
PM9	43.93349	-86.13351	Ri12	44.37667	-84.04556
PM10	43.93613	-86.12199	Ril3	44.39778	-84.03611
PM11	43.93545	-86.12176	W1	43.37842	-86.40395
PM12	43.93493	-86.12079	W2	43.37828	-86.40038
PM13	43.93357	-86.11775	W3	43.38570	-86.38055
PM14	43.93096	-86.07950	W4	43.38637	-86.35788
PM15	43.93575	-86.07708	W5	43.39833	-86.35650
PM16	43.93704	-86.06211	W6	43.42251	-86.33450
PM17	43.93569	-86.05201	W7	43.42445	-86.32107
PM18	43.87167	-85.76250	W8	43.42396	-86.31240
PM19	43.91833	-86.17889	W9	43.42753	-86.31050
PM20	43.87583	-86.11361	W10	43.43222	-86.31361

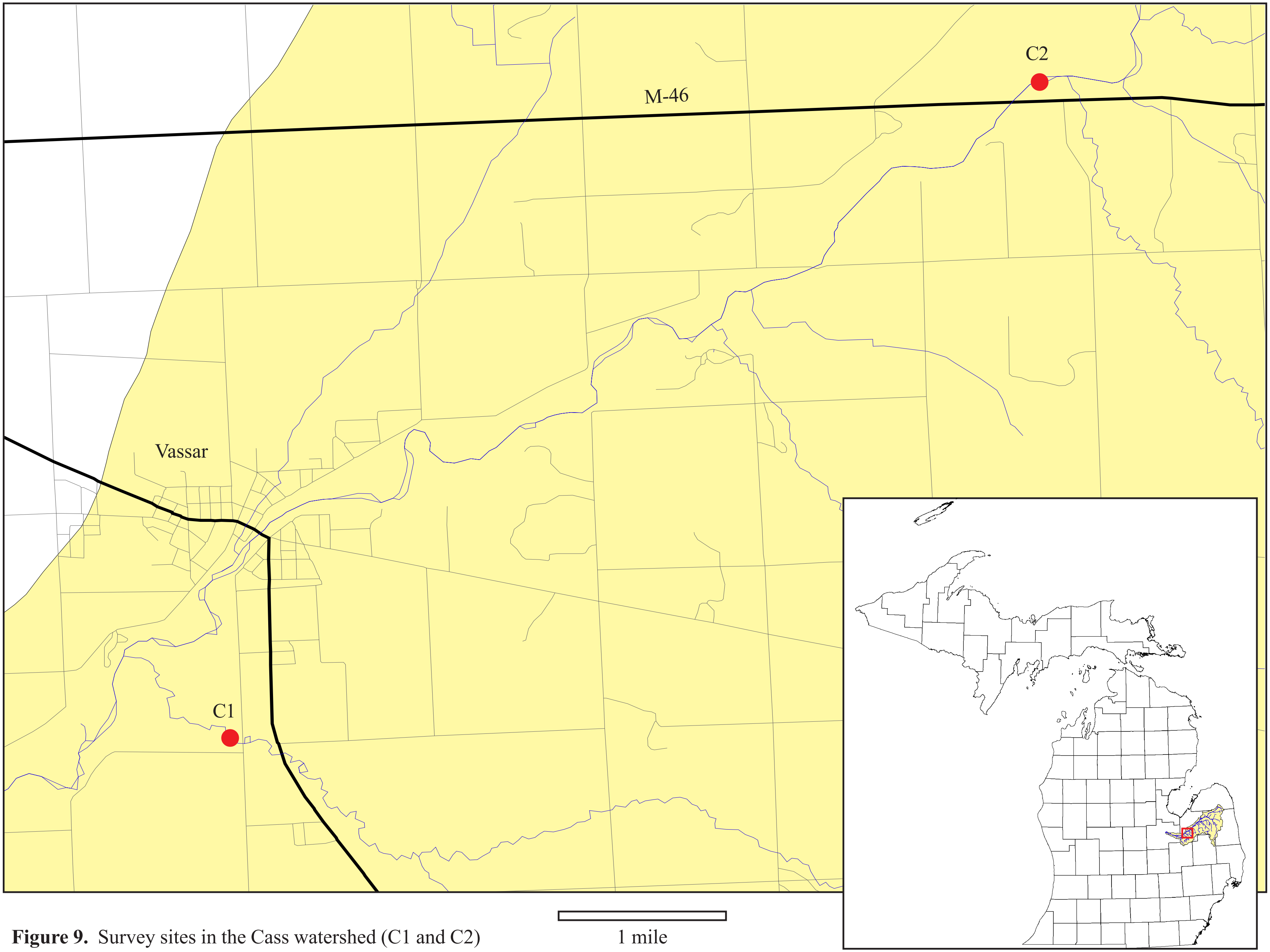


Figure 9. Survey sites in the Cass watershed (C1 and C2)

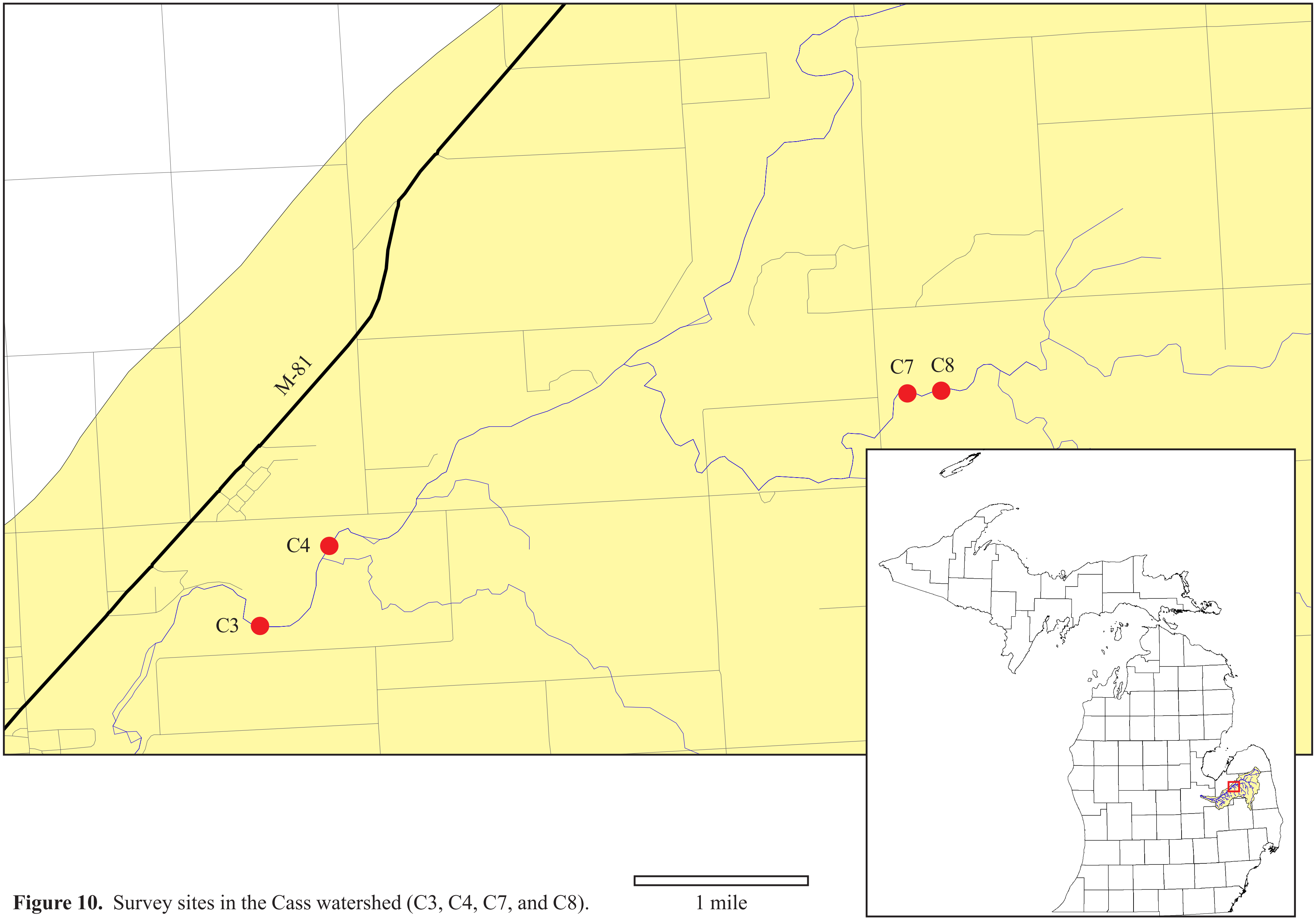


Figure 10. Survey sites in the Cass watershed (C3, C4, C7, and C8).

1 mile

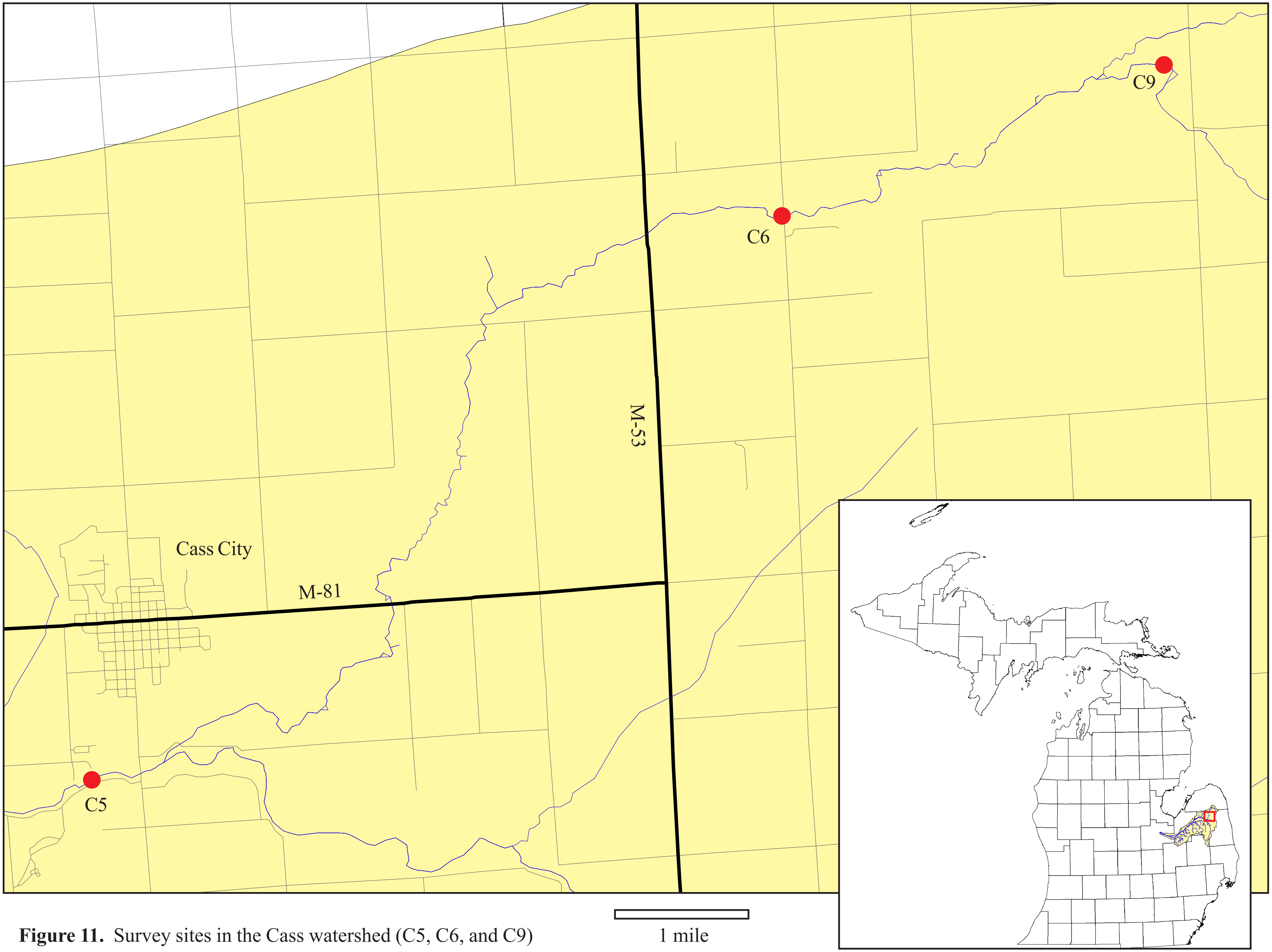


Figure 11. Survey sites in the Cass watershed (C5, C6, and C9)

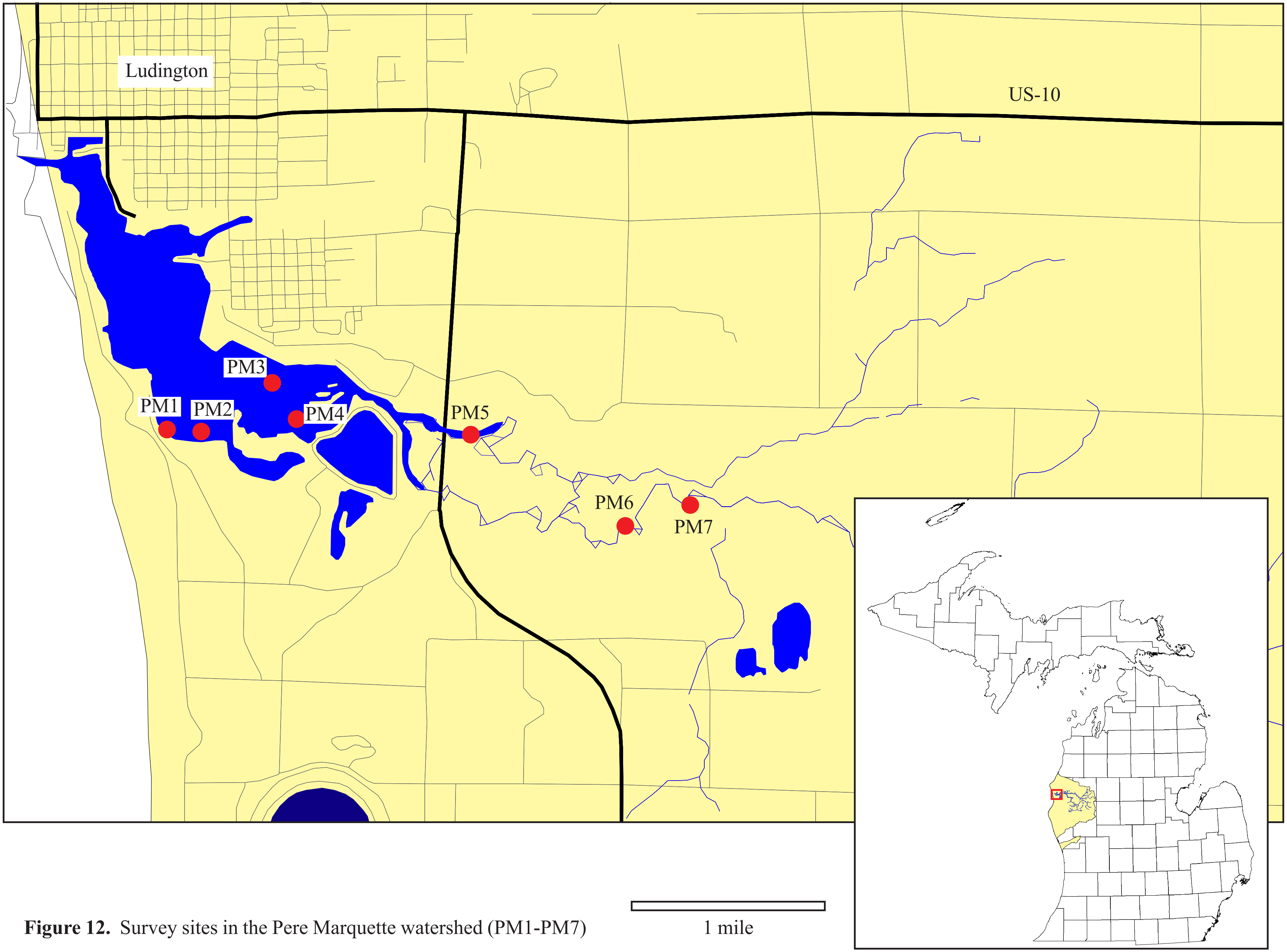


Figure 12. Survey sites in the Pere Marquette watershed (PM1-PM7)

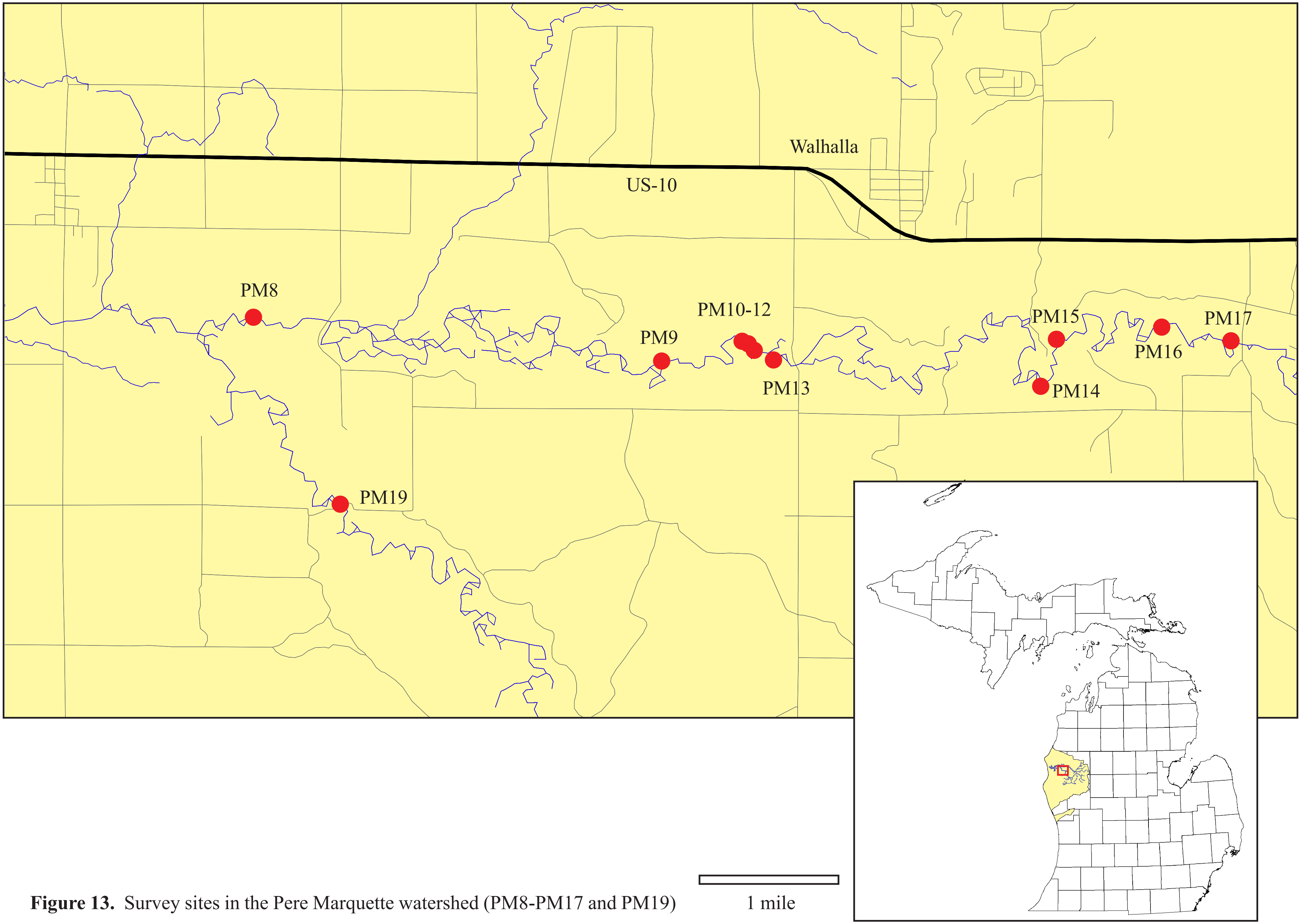


Figure 13. Survey sites in the Pere Marquette watershed (PM8-PM17 and PM19)

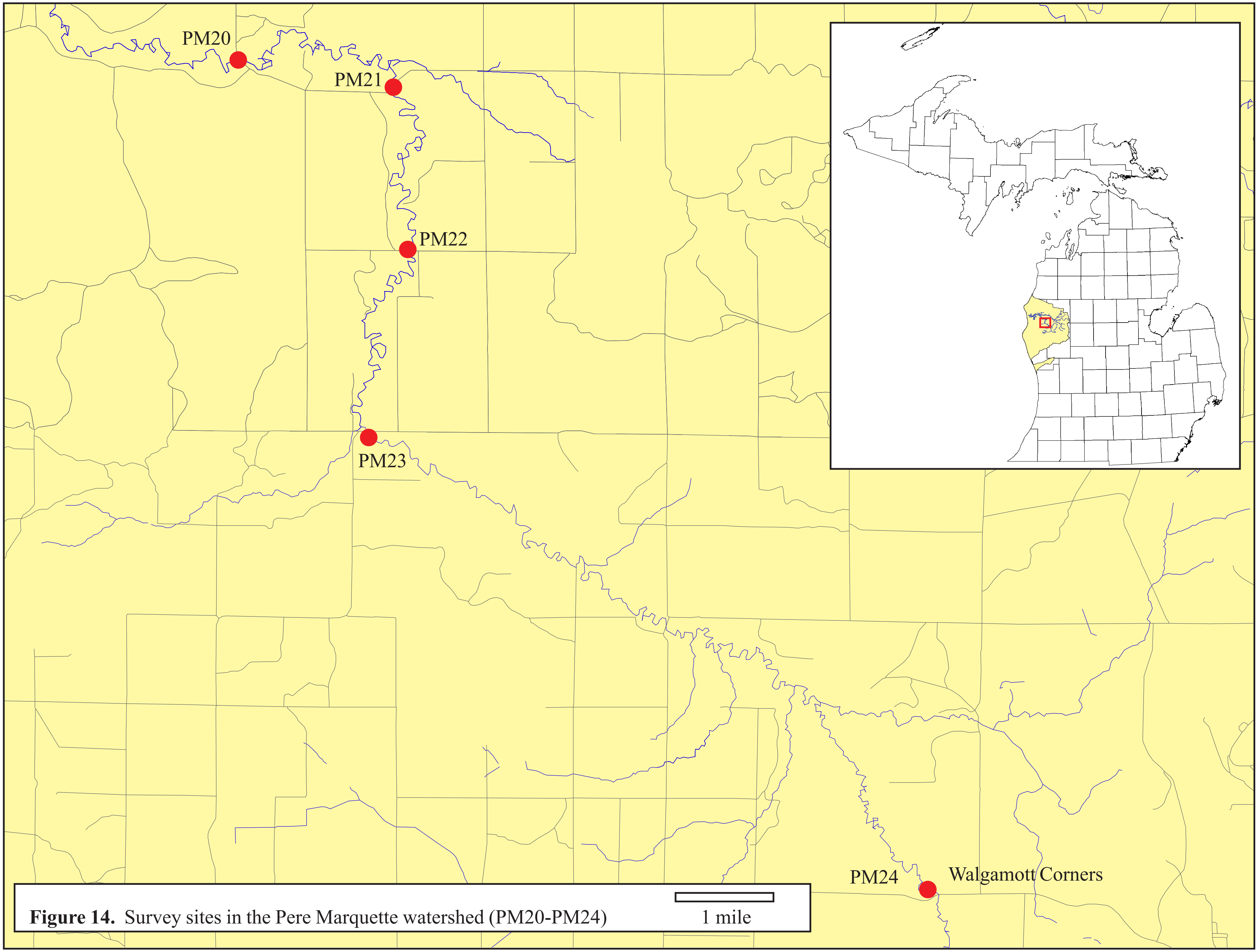


Figure 14. Survey sites in the Pere Marquette watershed (PM20-PM24)

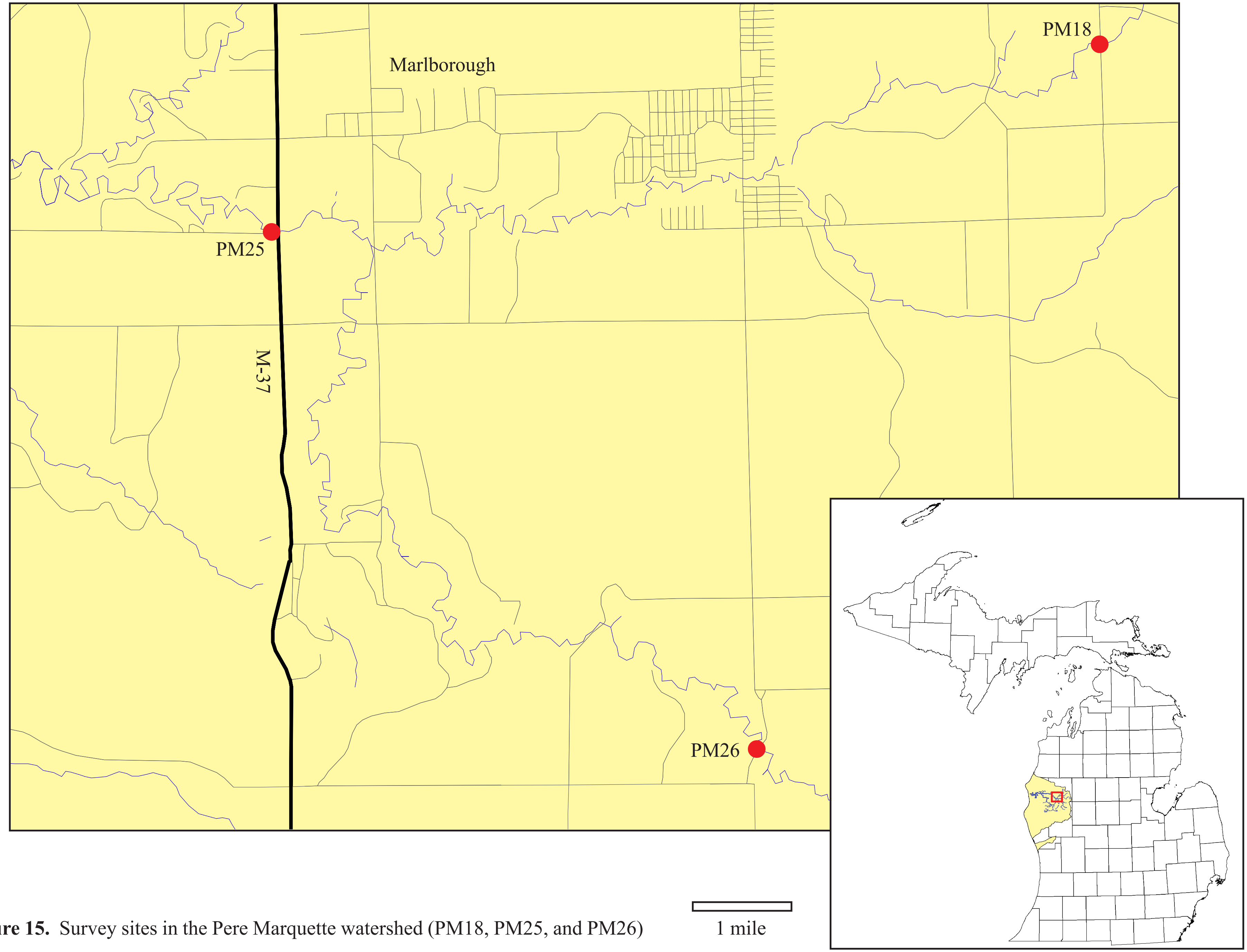


Figure 15. Survey sites in the Pere Marquette watershed (PM18, PM25, and PM26)

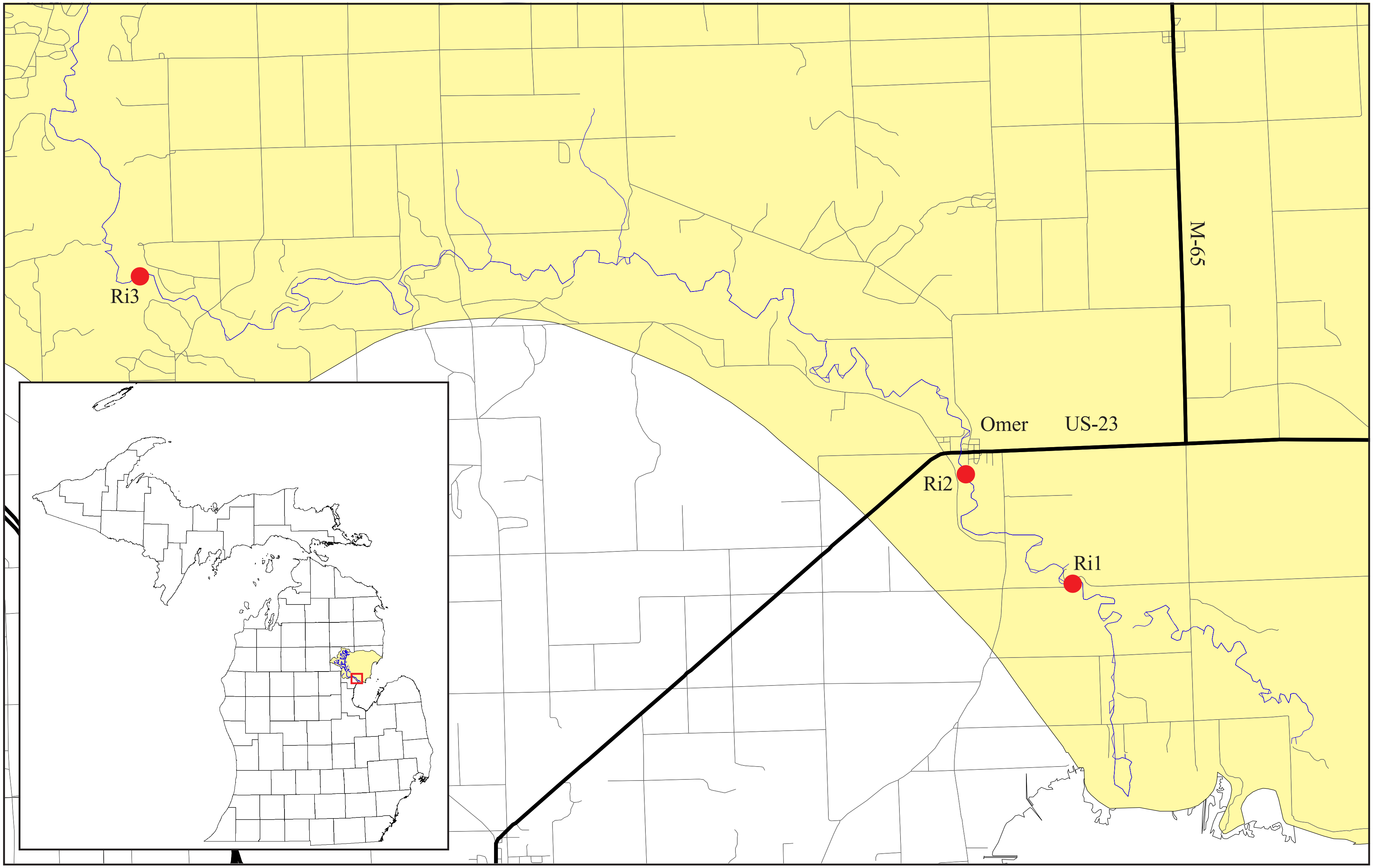


Figure 16. Survey sites in the Rifle River (Ri1-Ri3).

1 mile

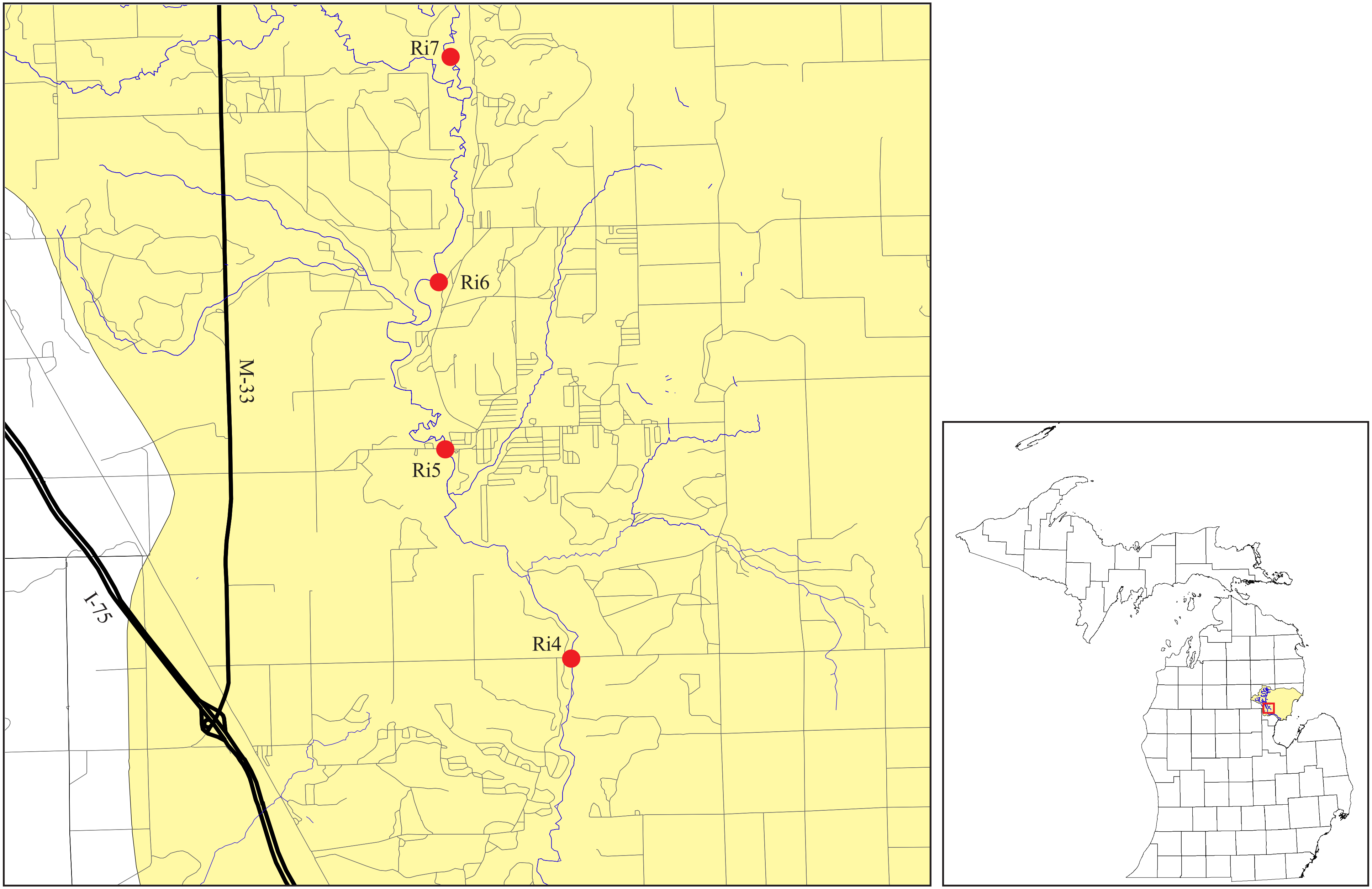


Figure 17. Survey sites in the Rifle River (Ri4-Ri7).

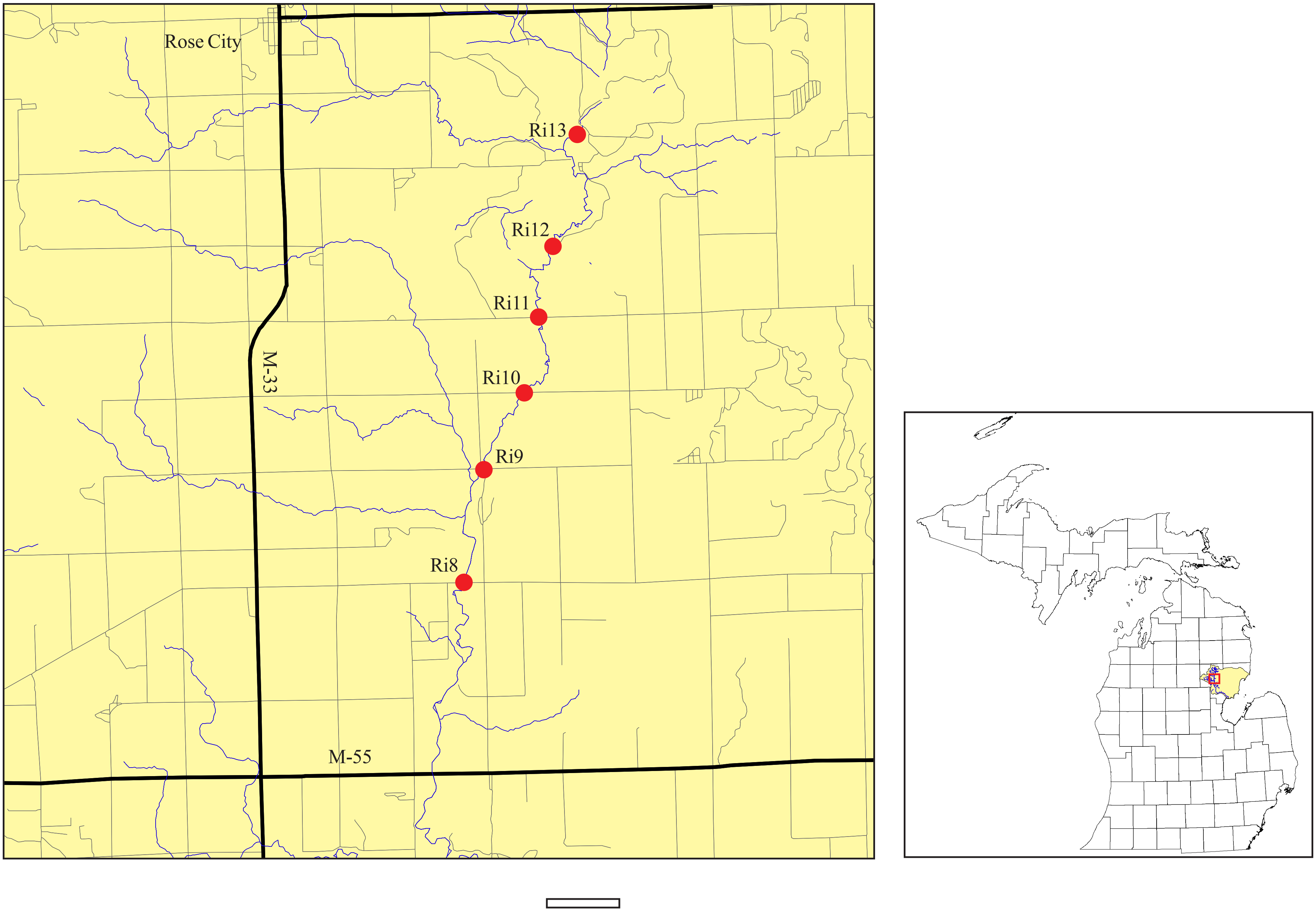
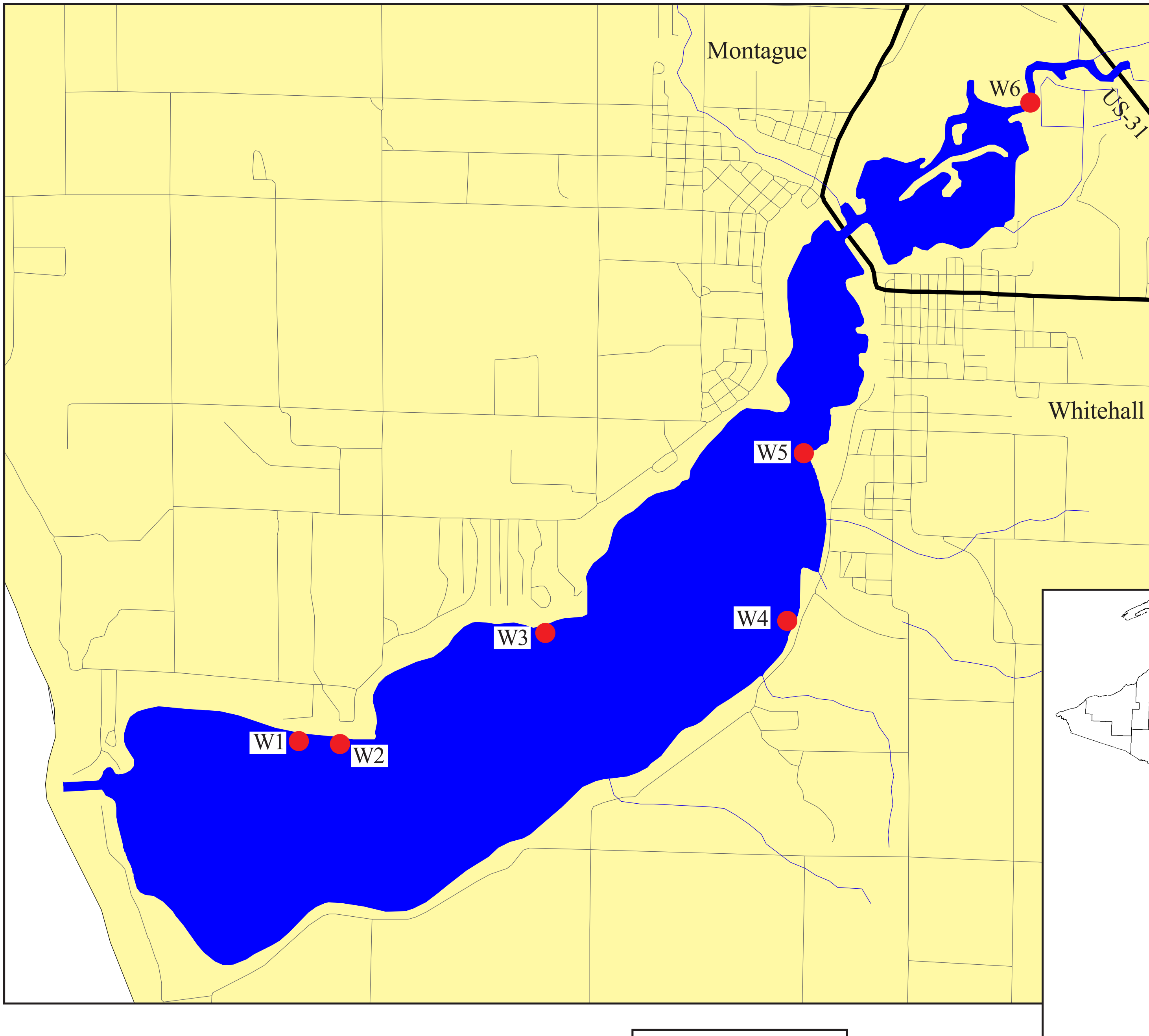


Figure 18. Survey sites in the Rifle River (Ri8-Ri13).



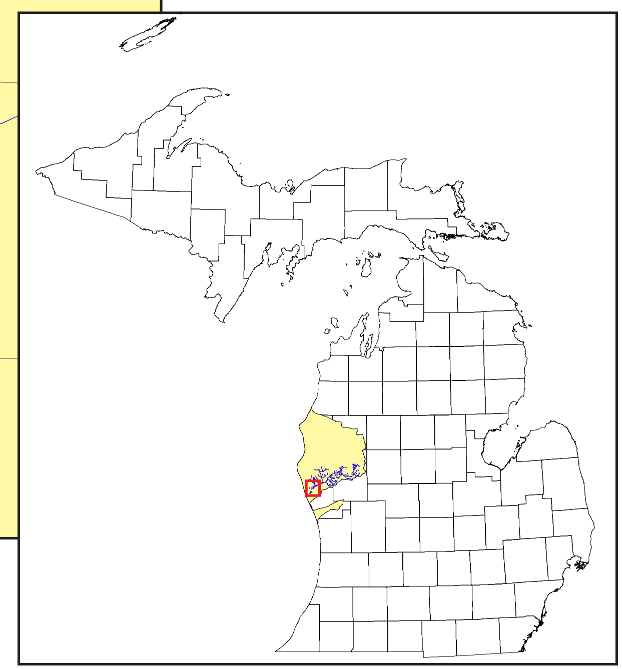


Figure 19. Survey sites in White Lake (W1-W6).

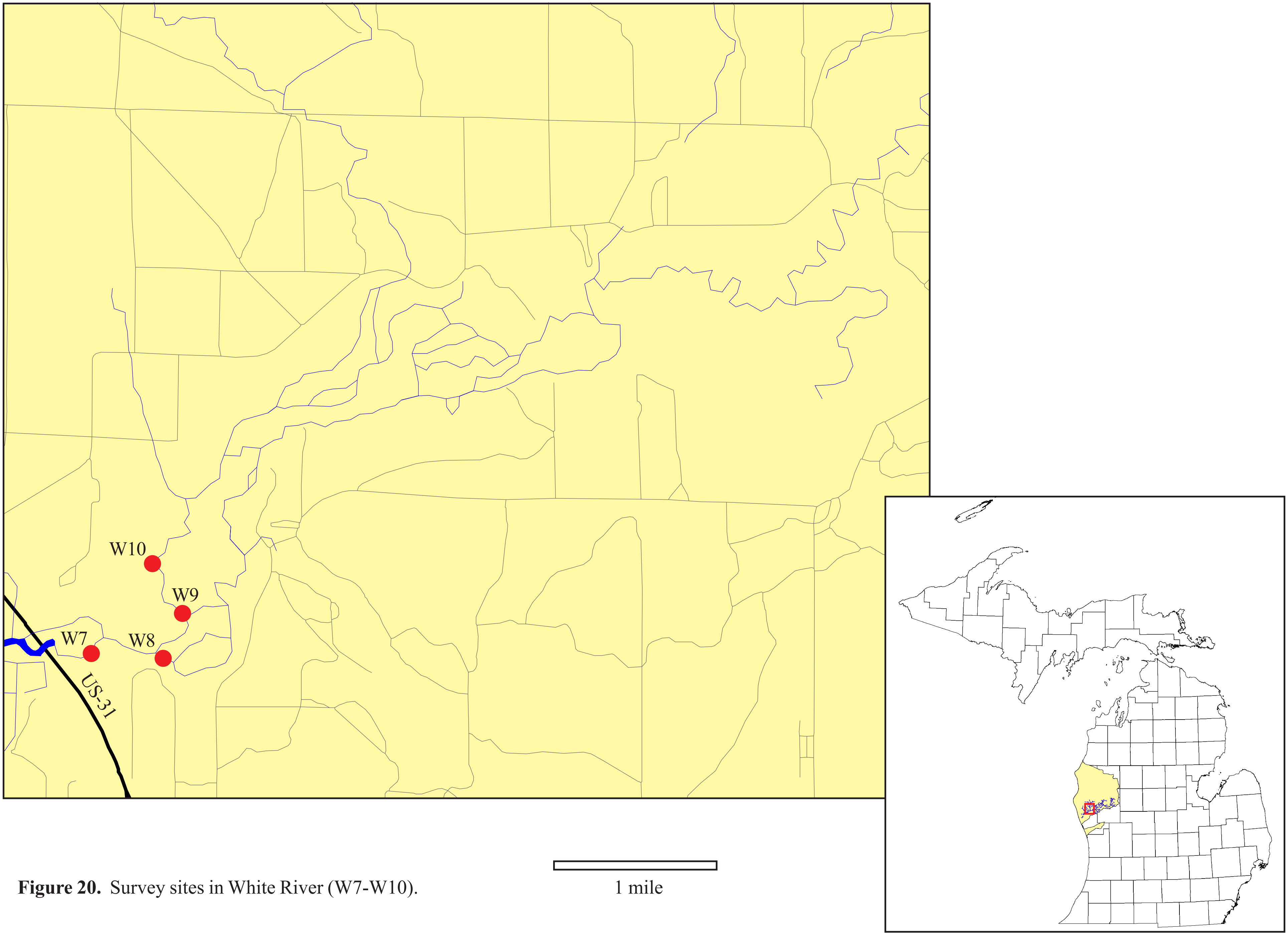


Figure 20. Survey sites in White River (W7-W10).

See Addendum for updated listed status of unionid mussel species

Table 2. Scientific and common names of unionids found during surveys. (L=species represented by live individuals; S=species represented by shell only; SpC=state listed as special concern)

Species	Common Name	Cass River	Pere Marquette Lake	Pere Marquette River	Rifle River	White Lake	White River
Actinonaias ligamentina	Mucket	L					
Alasmidonta marginata (SpC)	Elktoe	S					
Alasmidonta viridis (SpC)	Slippershell	L			S		
Amblema plicata	Threeridge	L					
Anodonta imbecillis	Paper pondshell						L
Anodontoides ferussacianus	Cylindrical papershell	S				S	
Elliptio dilatata	Spike	L	S	S	L		
Fusconaia flava	Wabash pigtoe	L	L				L
Lampsilis siliquoidea	Fatmucket	L	L	L		S	L
Lampsilis ventricosa	Pocketbook	L				L	L
Lasmigona complanata	White heelsplitter	L				S	L
Lasmigona compressa	Creek heelsplitter			L			
Lasmigona costata	Fluted-shell	L					
Leptodea fragilis	Fragile papershell					S	L
Ligumia recta	Black sandshell					L	
Pleurobema sintoxia (SpC)	Round pigtoe	S					
Ptychobranchus fasciolaris	Kidneyshell	S					
Pyganodon grandis	Giant floater	L	L				L
Strophitus undulatus	Strange floater			L			
Truncilla truncata	Deertoe					S	
Venustaconcha ellipsiformis (SpC)	Ellipse	L					
Villosa iris (SpC)	Rainbow	L			S		
# species live		12	3	3	1	2	7
# species live or shell		16	4	4	3	7	7
# sites surveyed		9	4	22	13	6	4
Corbicula fluminea (Exotic)	Asian clam					L	
Dreissena polymorpha (Exotic)	Zebra mussel		L			L	
Neogobius melanostomus (Exotic)	Round goby		L			L	

See Addendum for updated listed status of unionid mussel species

Table 3. Numbers of unionids (#), relative abundance (RA), and density (D, individuals/m2) recorded at each site surveyed. (C=Cass Watershed; PM=Pere Marquette Lake and River; Ri=Rifle River; W=White Lake and River; S=species represented by shell only; L=live individuals found; S-mdr=shell found outside of transect; L-mdr=live individuals found outside of transect)

	C1			C2			C3			C4			C5		
Species	#	RA	D	#	RA	D	#	RA	D	#	RA	D	#	RA	D
Actinonaias ligamentina	3	0.03	0.02	21	0.26	0.16									
Alasmidonta marginata (SpC)				S											
Alasmidonta viridis (SpC)	2	0.02	0.02												
Amblema plicata	S			1	0.01	0.01	S			1	0.17	0.01	5	0.23	0.04
Anodonta imbecillis															
Anodontoides ferussacianus	S														
Elliptio dilatata										1	0.17	0.01			
Fusconaia flava	S			S			S			S			1	0.05	0.01
Lampsilis siliquoidea				1	0.01	0.01							8	0.36	0.06
Lampsilis ventricosa	3	0.03	0.02	5	0.06	0.04				S			1	0.05	0.01
Lasmigona complanata				2	0.02	0.02	S								
Lasmigona compressa															
Lasmigona costata	S			49	0.60	0.38	2	1.00	0.02	2	0.33	0.02	3	0.14	0.02
Leptodea fragilis															
Ligumia recta															
Pleurobema sintoxia (SpC)							S			S					
Pyganodon grandis	1	0.01	0.01							S			1	0.05	0.01
Ptychobranchus fasciolaris										S					
Strophitus undulatus							S			1	0.17	0.01			
Truncilla truncata															
Venustaconcha ellipsiformis (SpC)	79	0.83	0.62	2	0.02	0.02				1	0.17	0.01	3	0.14	0.02
Villosa iris (SpC)	7	0.07	0.05				S			S					
Total # individuals and density	95		0.74	81		0.63	2		0.02	6		0.05	22		0.17
# species live	6			7			1			5			7		
# species live or shell	10			9			7			11			7		
Area searched (m^2)	128			128			128			128			128		

See Addendum for updated listed status of unionid mussel species

Table 3. (cont.)

	C6			C7			C8			C9			PM1	PM2
Species	#	RA	D	#	RA	D	#	RA	D	#	RA	D		
Actinonaias ligamentina														
Alasmidonta marginata (SpC)														
Alasmidonta viridis (SpC)				S			S							
Amblema plicata														
Anodonta imbecillis														
Anodontoides ferussacianus														
Elliptio dilatata							1	0.10	0.01					
Fusconaia flava				2	1.00	0.01	S							
Lampsilis siliquoidea										S			S	S
Lampsilis ventricosa														
Lasmigona complanata														
Lasmigona compressa														
Lasmigona costata							5	0.50	0.04					
Leptodea fragilis														
Ligumia recta														
Pleurobema sintoxia (SpC)														
Pyganodon grandis	1	1.00	0.01				S			2	1.00	0.02		
Ptychobranchus fasciolaris														
Strophitus undulatus														
Truncilla truncata														
Venustaconcha ellipsiformis (SpC)				S			S							
Villosa iris (SpC)							4	0.40	0.03					
Total # individuals and density	1		0.01	2		0.01	10		0.08	2		0.02	0	0
# species live	1			1			3			1			0	0
# species live or shell	1			3			7			2			1	1
Area searched (m^2)	140			140			128			132			128	128

See Addendum for updated listed status of unionid mussel species

Table 3. (cont.)

	PM3			PM4			PM5	PM6	PM7	PM8	PM9	PM10	PM11	PM12
Species	#	RA	D	#	RA	D								
Actinonaias ligamentina														
Alasmidonta marginata (SpC)														
Alasmidonta viridis (SpC)														
Amblema plicata														
Anodonta imbecillis														
Anodontoides ferussacianus														
Elliptio dilatata				S										
Fusconaia flava				1	0.50	0.01								
Lampsilis siliquoidea				1	0.50	0.01								
Lampsilis ventricosa														
Lasmigona complanata														
Lasmigona compressa														
Lasmigona costata														
Leptodea fragilis														
Ligumia recta														
Pleurobema sintoxia (SpC)														
Pyganodon grandis	1	1.00	0.01											
Ptychobranchus fasciolaris														
Strophitus undulatus														
Truncilla truncata														
Venustaconcha ellipsiformis (SpC)														
Villosa iris (SpC)														
Total # individuals and density	1		0.01	2		0.02	0	0	0	0	0	0	0	0
# species live	1			2			0	0	0	0	0	0	0	0
# species live or shell	1			3			0	0	0	0	0	0	0	0
Area searched (m^2)	128			128			128	128	128	59	40	50	77	19

See Addendum for updated listed status of unionid mussel species

Table 3. (cont.)

	PM13	PM14	PM15	PM16	PM17	PM18	PM19	PM20			PM21		
Species								#	RA	D	#	RA	D
Actinonaias ligamentina													
Alasmidonta marginata (SpC)													
Alasmidonta viridis (SpC)													
Amblema plicata													
Anodonta imbecillis													
Anodontoides ferussacianus													
Elliptio dilatata								S					
Fusconaia flava													
Lampsilis siliquoidea											1	1.00	<0.01
Lampsilis ventricosa													
Lasmigona complanata													
Lasmigona compressa								1	0.50	0.01			
Lasmigona costata													
Leptodea fragilis													
Ligumia recta													
Pleurobema sintoxia (SpC)													
Pyganodon grandis													
Ptychobranchus fasciolaris													
Strophitus undulatus								1	0.50	0.01			
Truncilla truncata													
Venustaconcha ellipsiformis (SpC)													
Villosa iris (SpC)													
Total # individuals and density	0	0	0	0	0	0	0	2		0.01	1		<0.01
# species live	0	0	0	0	0	0	0	2			1		
# species live or shell	0	0	0	0	0	0	0	3			1		
Area searched (m^2)	30	73	46	150	58	78	23	166			398		

See Addendum for updated listed status of unionid mussel species

Table 3. (cont.)

Species	PM22	PM23	PM24	PM25	PM26	Ri1	Ri2	Ri3	Ri4	Ri5	Ri6	Ri7
Actinonaias ligamentina												
Alasmidonta marginata (SpC)												
Alasmidonta viridis (SpC)												
Amblema plicata												
Anodonta imbecillis												
Anodontoides ferussacianus												
Elliptio dilatata								S				
Fusconaia flava												
Lampsilis siliquoidea												
Lampsilis ventricosa												
Lasmigona complanata												
Lasmigona compressa												
Lasmigona costata												
Leptodea fragilis												
Ligumia recta												
Pleurobema sintoxia (SpC)												
Pyganodon grandis												
Ptychobranchus fasciolaris												
Strophitus undulatus												
Truncilla truncata												
Venustaconcha ellipsiformis (SpC)												
Villosa iris (SpC)												
Total # individuals and density	0	0	0	0	0	0	0	0	0	0	0	0
# species live	0	0	0	0	0	0	0	0	0	0	0	0
# species live or shell	0	0	0	0	0	0	0	1	0	0	0	0
Area searched (m^2)	427	557	581	128	158	128	128	128	128	128	128	128

See Addendum for updated listed status of unionid mussel species

Table 3. (cont.)

	Ri8			Ri9			Ri10	Ri11			Ri12	Ri13	W1	W2	W3	W4
Species	#	RA	D	#	RA	D		#	RA	D						
Actinonaias ligamentina																
Alasmidonta marginata (SpC)																
Alasmidonta viridis (SpC)				S			S									
Amblema plicata																
Anodonta imbecillis																
Anodontoides ferussacianus													S-mdr			
Elliptio dilatata	1	1.00	0.01	1	1.00	0.01		3	1.00	0.02	S					
Fusconaia flava																
Lampsilis siliquoidea													S	S	S	S
Lampsilis ventricosa																
Lasmigona complanata																S
Lasmigona compressa																
Lasmigona costata																
Leptodea fragilis																
Ligumia recta																
Pleurobema sintoxia (SpC)																
Pyganodon grandis																
Ptychobranchus fasciolaris																
Strophitus undulatus																
Truncilla truncata													S-mdr			
Venustaconcha ellipsiformis (SpC)																
Villosa iris (SpC)								S								
Total # individuals and density	1		0.01	1		0.01	0	3		0.02	0	0	0	0	0	0
# species live	1			1			0	1			0	0	0	0	0	0
# species live or shell	1			2			1	1			1	0	3	1	1	2
Area searched (m^2)	128			128			128	128			128	128	128	128	128	128

See Addendum for updated listed status of unionid mussel species

Table 3. (cont.)

	W5	W6			W7			W8			W9	W10		
Species		#	RA	D	#	RA	D	#	RA	D		#	RA	D
Actinonaias ligamentina														
Alasmidonta marginata (SpC)														
Alasmidonta viridis (SpC)														
Amblema plicata														
Anodonta imbecillis								1	0.17	0.01				
Anodontoides ferussacianus														
Elliptio dilatata														
Fusconaia flava								2	0.33	0.02		7	0.64	0.05
Lampsilis siliquoidea	S											1	0.09	0.01
Lampsilis ventricosa		2	0.67	0.02	2	1.00	0.02	1	0.17	0.01		2	0.18	0.02
Lasmigona complanata												L-mdr		
Lasmigona compressa														
Lasmigona costata														
Leptodea fragilis		S						2	0.33	0.02				
Ligumia recta		1	0.33	0.01										
Pleurobema sintoxia (SpC)														
Pyganodon grandis												1	0.09	0.01
Ptychobranchus fasciolaris														
Strophitus undulatus														
Truncilla truncata														
Venustaconcha ellipsiformis (SpC)														
Villosa iris (SpC)														
Total # individuals and density	0	3		0.02	2		0.02	6		0.05	0	11		0.09
# species live	0	2			1			4			0	5		
# species live or shell	1	3			1			4			0	5		
Area searched (m^2)	128	128			128			128			128	128		

Figure 21. Flags marking live unionids in the Cass River at site C2.

Figure 22. *Actinonaias ligamentina* from the Cass River, site C2.

Table 4. Occurrence of *Corbicula fluminea* (Asian clam), *Dreissena polymorpha* (zebra mussel), and *Neogobius melanostomus* (round goby) by site. (L=species represented by live individuals; LA=*D. polymorpha* found attached to unionids; S=species represented by shell only)

Exotic species	PM1	PM2	PM3	PM4	W1	W2	W3	W4	W5
Corbicula fluminea (Asian clam)					L	L	L	L	
Dreissena polymorpha (zebra mussel)	L	L	S	LA	L	L	LA	LA	L
Neogobius melanostomus (round goby)	L	L	L						L

Figure 23. *Dreissena polymorpha* attached to woody debris and an empty *Lampsilis siliquoidea* shell from Pere Marquette Lake.

Figure 24. Two unionids in silt, gravel, pebble, and cobble substrate in the Cass River.

Discussion

Unionid density and species richness varied considerably between watersheds. The Cass River had the highest species richness and density of the four watersheds surveyed, with a total of 16 unionid species found in nine sites, and a maximum unionid density of 0.74 live individuals per m^2. Compared to other Lower Peninsula rivers surveyed by MNFI in previous years, the Cass River had close to an average unionid species richness and density. For example in 2002, 27 species were found in 11 sites surveyed in the Belle River (one of the most species-rich rivers in Michigan), and six species were found in 12 sites in the Galien River (Badra and Goforth 2003).

The Pere Marquette watershed and the Rifle River had very few unionids. This was somewhat unexpected because adjacent watersheds are known to have at least average unionid abundance and species richness. The Manistee River to the north of the Pere Marquette watershed, and the Muskegon River to the south, both support relatively rich unionid communities (at least 10 and 18 species respectively)(Badra and Goforth 2003, Carman and Goforth 2003). Similarly, the Rifle River is bordered by the Au Sable to the north and the Tittabawassee River to the south which also support rich unionid communities (at least 11 and 18 species respectively)(Badra and Goforth 2003). Although the Rifle River had little unionid species richness or abundance, there were two occurrences of the special concern *Alasmidonta viridis*. These were at the two most upstream sites surveyed in the watershed (Ri9 and Ri10). Since *A. viridis* is known to prefer headwater habitats, surveys further upstream may reveal live individuals.

The White watershed had a moderate number of species represented (10). There was a dramatic difference between the unionid communities in White Lake and White River. The lack of live unionids in White Lake combined with the presence of live *D. polymorpha* attached to empty unionid shell strongly suggests that this exotic has negatively impacted the unionid community there. No *D. polymorpha* were seen in the White River, where there were eight unionid species, all represented by live individuals. There are likely populations of additional species further upstream due to the lack of *D. polymorpha* in the river.

The largest population of the *Venustachonca ellipsiformis* on record at MNFI was found in the Cass River at site C1. This species of special concern was found in higher density at C1 than any species at any site during these surveys. This population is most likely well protected from *D. polymorpha* colonization because the stream's small size excludes any recreational boats that could be inadvertently transporting *D. polymorpha*. The site is located within a public roadside park. One of the streambanks is a lawn that is mowed to within 10 meters of the waters edge. An increased vegetated buffer between the lawn and the stream may reduce possible impacts to the population from erosion of the bank, change in water temperature due to reduced shade, or input of fertilizer or other lawn chemicals. The minimum width of riparian buffers to maintain all riparian processes has been estimated at 100-300 feet (Knutson and Naef 1997, May and Horner 2000, Martin et al. 2000, and others cited in NC Wildlife Resources Commission 2002). Minimum riparian buffer widths to retain certain riparian habitat functions, such as filtering nitrogen, erosion control, and water temperature control, have been estimated by various researchers and are also summarized by the NC Wildlife Resource Commission (2002).

Venustachonca ellipsiformis was also found at sites C2, C4, C5, C7, and C8. The high density and frequency of occurrence of this species makes the Cass watershed one of the top priorities for the conservation of *V. ellipsiformis* in Michigan. Density is an especially important factor for the persistence of unionid populations because they rely on an interactive mode of reproduction (i.e. require fish hosts). Conserving this high density population will help ensure the species remains at an ecologically effective density allowing it to persist through time (Soule et al. 2003). The Cass watershed is important for other special concern species as well. Sites C1, C4, and C8 each had occurrences of three special concern species.

The potential occurrences of the state threatened *Lampsilis fasciola* at sites C7 and C8 in the Cass River would be the first records of this species from the Lake Huron drainage. The range of *L. fasciola* is thought to be restricted to the Lake Erie and Lake St. Clair drainages (R. Sherman Mulcrone pers. com.). Additional surveys in White Creek need to be performed to determine with certainty if *L. fasciola* occurs in this watershed, or if the shells were from a population of *Lampsilis ventricosa*. These sites are located on private land. The landowner has a strong interest in wildlife conservation so the unionid populations most likely have protection from any local threats such as removal of the forested riparian zone or channelization.

There is historic record for the state listed as endangered, *Toxolasma lividus* (purple lilliput) at the city of Vassar in Cass River. One old shell was collected pre-1930 by C. Davis (MNFI database). The site was resurveyed in 1984 but the species was not found. No live individuals or empty shells were found in surveys performed by MNFI. *T. lividus* may have been extirpated from the watershed sometime in the last 70+ years.

The Cass River and its tributaries are in a region of relatively high intensity agricultural land use. Riparian zones in the Cass watershed ranged from of few meters of low vegetation bordered on each side by agricultural field, to hundreds of meters of forest on both sides of the stream. A few sites had some forested riparian zone on one or both sides. The Cass River flows through several lands managed by the State of Michigan, including Vassar, Tuscola, Deford, Cass City and Sanilac State Game Areas. Its tributaries run through Murphy Lake and Minden State Game Areas. Along with scattered private lands, these areas contain forested riparian zones and intact wetlands that are part of the Cass River ecosystem. In addition, site C9 is located at the Sanilac Petroglyphs Historic Site. Most of the Pere Marquette River and its tributaries fall within an expansive area of forested land that includes the Manistee National Forest, Pere Marquette State Forest, and private land. The Pere Marquette itself is designated a National Scenic River. The approximately 30 miles of river upstream of Pere Marquette Lake is bordered on both sides by wetlands that form an almost continuous riparian zone between the State and National Forests, and Pere Marquette Lake. Pere Marquette Lake is heavily developed along most of its shore. The Rifle River, which runs through the Au Sable State Forest and Rifle River State Recreation Area, has wide forested riparian zones along much of its length. The main-stem of the White River, flowing through Mainstee National Forest, has forested and non-forested wetland riparian zones along nearly all of its length. Some survey sites in this river (W7-W10) were bordered by non-forested wetlands on both sides. The shores of White Lake are partly forested and moderately developed.

Deforestation of riparian zones is known to impact the species composition and abundance of aquatic taxa. For example, fish abundance in southern Appalachian streams has been found to decrease with an increasing length of non-forested riparian patch (Jones et al. 1999). Comparing the results of surveys in the Cass watershed with that of the Pere Marquette and Rifle watersheds may appear to contradict this. However, the suitability of rivers for supporting unionid communities is determined by many other factors as well, including biogeography, water chemistry, geology, fish host populations, and chance events. This may explain why relatively high species richness and abundance was found in the Cass watershed as compared to the Pere Marquette and Rifle watersheds, which have much more intact riparian zones. Surveyed by MNFI in 2002, the Galien River was found to have unstable pure sand substrate that was unsuitable for unionids. This is likely due to the surface geology present in the watershed (Albert 1995). The surface geology of all but the three most upstream sites in the Pere Marquette is sand lake plain and end moraine, which has a large component of sand (Albert 1995). Similarly the unstable substrates of the Pere Marquette River may be the result of surface geology rather than impacts from human activities. If this is true, the Pere Marquette and Rifle watersheds should have a lower priority for unionid conservation than other watersheds.

The discovery of live *D. polymorpha* attached to empty unionid shell and live individuals in Pere Marquette and White Lake indicate that *D. polymorpha* has negatively impacted unionid communities in these waterbodies. This exotic, rather than degraded habitat, lack of fish host, or poor water quality is likely the limiting factor for unionids in the two lakes. However, these other factors have contributed negative impacts as well. Judging by the high colonization rate of hard substrate by *D. polymorpha* and the scarcity of hard substrate in both lakes, *D. polymorpha* appears to be limited to some degree by the amount of stable hard substrates to attach to.

A common cause of *D. polymorpha* introduction is incidental transportation by boat. It is not surprising then, that this species was found in Pere Marquette Lake and White Lake. Both are used heavily for recreational boating. *D. polymorpha* have free-swimming larvae that can be displaced by water currents. The current in rivers tends to make *D. polymorpha* populations less likely to persist unless there is reoccurring introduction of them to an upstream site. Free flowing rivers can act as natural refugia that protect unionids from *D. polymorpha* impacts (Sickel et al. 1997)(Harman et al. 1998 and Clarke 1992 cited in Nichols et al. 2000). The highest density and species richness in the White River drainage was found at W10, the most upstream site surveyed in this system. The upstream reaches may be a refugium for unionids from *D. polymorpha*. This type of natural refugia may be present in other coastal lake-river systems. Watersheds similar to the White and Pere Marquette should be surveyed to see if this model for unionid refugia applys broadly to other systems. These could include Betsy Lake and the Betsy River, Manistee Lake and the Manistee River, Hamlin Lake and the Big Sable River, Pentwater Lake and the Pentwater River, and others.

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ADDENDUM - Updated status of unionid mussel species recorded in Michigan as of April 9, 2009.
Villosa fabalis and *Epioblasma triquetra* were federally listed as endangered on March 15, 2012.

Species	Common name	MI status	U.S. status	Global rank
Actinonaias ligamentina	Mucket			G5
Alasmidonta marginata	Elktoe	SC		G4
Alasmidonta viridis	Slippershell	T		G4G5
Amblema plicata	Threeridge			G5
Anodontoides ferussacianus	Cylindrical papershell			G5
Cyclonaias tuberculata	Purple wartyback	T		G5
Elliptio complanata	Eastern elliptio			G5
Elliptio crassidens	Elephant-ear			G5
Elliptio dilatata	Spike			G5
Epioblasma obliquata perobliqua	White catspaw	E	E	G1T1
Epioblasma torulosa rangiana	Northern riffleshell	E	E	G2T2
Epioblasma triquetra	Snuffbox	E	E	G3
Fusconaia flava	Wabash pigtoe			G5
Lampsilis fasciola	Wavy-rayed lampmussel	T		G5
Lampsilis siliquoidea	Fatmucket			G5
Lampsilis ventricosa	Pocketbook			G5
Lasmigona complanata	White heelsplitter			G5
Lasmigona compressa	Creek heelsplitter			G5
Lasmigona costata	Fluted-shell			G5
Leptodea fragilis	Fragile papershell			G5
Leptodea leptodon	Scaleshell	SC	E	G1G2
Ligumia nasuta	Eastern pondmussel	E		G4
Ligumia recta	Black sandshell	E		G5
Obliquaria reflexa	Three-horned wartyback	E		G5
Obovaria olivaria	Hickorynut	E		G4
Obovaria subrotunda	Round hickorynut	E		G4
Pleurobema clava	Clubshell	E	E	G2
Pleurobema sintoxia	Round pigtoe	SC		G4G5
Potamilus alatus	Pink heelsplitter			G5
Potamilus ohiensis	Pink papershell	T		G5
Ptychobranchus fasciolaris	Kidney-shell	SC		G4G5
Pyganodon grandis	Giant floater			G5
Pyganodon lacustris	Lake floater	SC		GU
Pyganodon subgibbosa	Lake floater	T		G?
Quadrula pustulosa	Pimpleback			G5
Quadrula quadrula	Mapleleaf			G5
Simpsonaias ambigua	Salamander mussel	E	Candidate	G3
Strophitus undulatus	Strange floater			G5
Toxolasma lividus	Purple lilliput	E		G2
Toxolasma parvus	Lilliput	E		G5
Truncilla donaciformis	Fawnsfoot	T		G5
Truncilla truncata	Deertoe	SC		G5
Utterbackia imbecillis	Paper pondshell	SC		G5
Venustaconcha ellipsiformis	Ellipse	SC		G4
Villosa fabalis	Rayed bean	E	E	G2
Villosa iris	Rainbow	SC		G5Q