Surveys of Native Freshwater Mussels in the Lower Reaches of Great Lakes Tributary Rivers in Michigan

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Left inset photo - An empty *Leptodea fragilis* (fragile papershell) shell with numerous empty *Dreissena polymorpha* (zebra mussel) shells attached (Tittabawassee River, site T3).

Right inset photo - *Truncilla truncata* (deertoe) (St. Joseph River, site J6).

Background photo - St. Joseph River near Berrien Springs.

Cover photos by Reuben Goforth and Peter Badra. All other photos by Peter Badra unless noted otherwise.

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Introduction

Native freshwater mussels (Unionidae) are an important component of Michigan's wildlife. 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 comparatively very sensitive to habitat degradation and pollution and are dependent on fish hosts to complete their life cycle. Unionids inhabit streams and lakes in Central America, North America, Eurasia, and Africa (Bogan 1993), although 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.

The Tittabawassee, Kalamazoo, Grand and St. Joseph Rivers (Lake Michigan drainage) have provided habitat for diverse and abundant unionid communities. Over 50% of the unionid species recorded in Michigan have been reported from these four rivers. Mussel communities in southern Michigan were once economically valuable. In the early 1900's, live unionids were collected 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 1930's due to harvest pressure. In response, 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 1940's, 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, with life spans up to 50 years and more. They are generally sessile, spending most of their lives within a particular stream reach. Unionids are sensitive to, and 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 1999). Chemical analysis of shell material can 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). Unionids play a substantial role in the flow of energy in stream ecosystems. They often comprise the highest percentage of biomass relative to other benthic stream organisms (Strayer et al. 1994), and are therefore a key link in the food chain from aquatic microorganisms to crayfish, muskrats, and other large predators. Thus, the status of unionids is 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 hatch from fertilized eggs and develop within the females' mantle tissues (i.e., marsupia). Glochidia are then released into the water column and must attach to a suitable fish host in order to survive. 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).

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 such as drain clean-outs and dredging, and non-native species have impacted native mussel and fish communities. Without the appropriate host species present in sufficient densities, the unionid life cycle cannot be completed. 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 1995). They can inhibit the re-colonization of suitable habitat and prevent the recovery of unionid populations. The non-native *Dreissena polymorpha* (zebra mussel) can have devastating effects on unionid communities (Schloesser et al. 1998) and are continuing to spread throughout the surface waters of Michigan.

Over one-third (17) 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). Current knowledge of the status and distribution of the Uniondae in Michigan is incomplete. The lower reaches of larger rivers have not been adequately surveyed in part due to the difficulty in accessing and surveying these habitats. The purpose of this project was to increase our knowledge of the status and distribution of unionids in the lower Tittabawassee, Kalamazoo, Grand, and St. Joseph Rivers, and to collect ecological data relevant to the conservation of unionids such as the distribution and density of the exotic *D. polymorpha*. These surveys are part of an ongoing effort to build an up-to-date knowledge base that is used to promote the conservation of Michigan's unionids and associated communities.

Methods

River reaches were selected for field visits based on availability of suitable unionid habitat and potential for occurrences of listed unionids. Surveys focused on the lower Tittabawassee, Kalamazoo, Grand, and St. Joseph Rivers, habitats that have not been systematically surveyed in recent years and would otherwise be inaccessible without the use of a boat and/or SCUBA. The nearest boat ramp to the reach was identified and used as an access point. Mussel habitat and signs of mussel beds such as shells in muskrat middens (Figure 1) were identified from a boat within these reaches and were used as a basis for survey site selection. Handheld GPS units (Garmin 12XL) and topographic maps were used to document the position of each site. Latitude and longitude were recorded at a point in the approximate center of the site. Some sections of the St. Joseph River and most sections of the Grand River that were surveyed had occasional shallow (0.2-0.5m) gravel bars. The use of a jet drive outboard motor made navigating over these bars much more time efficient and mechanical failure was far less likely than with a traditional propeller drive outboard motor (Figure 2).

The field crew typically consisted of two divers and a third person who transcribed data, assisted divers with gear, and tended the boat while divers were in the water (Figure 3). Transects were delineated using 10m lengths of 2.54cm nylon webbing with 4.5kg anchors fastened to each end. A buoy was tied to each anchor to mark the endpoints of each transect. Once signs of a mussel bed were identified, the boat was anchored and transects were set. Two transects were set side by side approximately 3 to 8m apart parallel to river flow. Divers started working each pair of transects at the same time, moving in an upstream direction. Searching in an upstream direction minimized increased turbidity due to disturbance of fine substrate particles during surveys. A few transects were set in

Figure 1. A midden of *Truncilla truncata* (deertoe) shell on the St. Joseph River (J5). These shells were recently emptied and arranged as shown by a predator such as a muskrat.

Figure 2. Boat and jet drive motor used during surveys.

Figure 3. Divers preparing for transect searches on the Grand River. Photo by Dave Kenyon, MI DNR.

water that was shallow enough to allow surveyors to kneel on the bottom and perform tactile searches without the use of SCUBA.

Unionids buried up to approximately 5cm below the substrate surface and located within 0.8m on either side of transect lines were detectable. Due to low underwater visibility at most sites, mussels were located tactually by divers passing their hands through the substrate adjacent to the transect lines. Relatively clear water and rocky substrate at a few of the sites made visual searches of transects a more reliable and time efficient method for detecting mussels. Rocks and live mussels were more easily distinguished visually than tactually at these sites. Live unionids were placed in mesh bags, brought to the surface, and identified after completing each transect.

When possible, external annular rings were counted to provide age estimates. Individuals with rings that were largely obscured were not aged. In some cases, annular rings were distinct up to the shell margin, at which point they became too crowded to effectively count as separate rings. A minimum number of annular rings was recorded in these cases. The number of *D. polymorpha* attached to each live unionid was recorded when present. The exotic *Corbicula fluminea* (Asian clam) was generally too small to be detected reliably using the methods described above. Presence/absence of shell or live Asian clams was recorded. 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. Empty shells were returned to the river. Divers spent approximately the same length of time searching transects and 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. 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.

A number of factors were addressed to ensure diver safety. Bacteria counts in the Tittabawassee, Kalamazoo, Grand, and St. Joseph 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 (DUI ™) 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. Over 14kg was often needed in order to keep divers from drifting downstream. Transect lines not only delineated the area to be searched, but were also used as a hand line to help divers remain stable in the current. Broken glass, zebra mussel shell, and other sharp debris was frequently encountered during tactile searches. Neoprene gloves (3mm) were worn to minimize the chance of injury. Visibility ranged from a few centimeters to greater than 3 meters, but was usually between 0.3 and 0.6 meters. Transect lines were essential for keeping divers oriented to sampling areas during surveys.

Results

Surveys were conducted at 25 sites for a total of 126 transect searches. Five sites were in the Tittabawassee River between the cities of Midland and Saginaw (Figure 4), four sites in the Kalamazoo River between Allegan and Saugatuck/Douglas (Figure 5), six sites in the Grand River between Portland and Ionia (Figure 6), eight in the St. Joseph River between Berrien Springs and St. Joseph, MI (Figures 7 and 8), and two in the St. Joseph River near Mendon, MI (Figure 9). In addition, qualitative meander searches were conducted at four sites on the Kalamazoo River (Figure 5). Sites are numbered in order from downstream to upstream. Survey site locations are provided in Table 1.

Several live occurrences of rare unionids were documented in the Grand River, including the state listed as endangered *Epioblasma triquetra* (snuffbox), and the state listed as special concern *Cyclonaias tuberculata* (purple wartyback), *Pleurobema sintoxia* (round pigtoe), and *Alasmidonta marginata* (elktoe). Empty shells of the state listed as special concern *Alasmidonta viridis* (slippershell) and *Venustaconcha ellipsiformis* (ellipse) were also found in the Grand River.

Live occurrences of rare unionids in the St. Joseph River included the state listed as special concern *C. tuberculata*, *P. sintoxia*, and *A. marginata*. In addition, empty shells of the state listed as endangered *E. triquetra* and state listed as special concern *A. viridis* were documented.

Two occurrences of special concern species, *A. marginata* shell and one empty valve of *Obovaria olivaria* (hickorynut), were recorded in the Tittabawassee River. Shell of the special concern *A. viridis*, *C. tuberculata*, and *P. sintoxia* were recorded from the Kalamazoo River. Scientific and common names of all unionid species found during the study are given in Table 2.

All but a few transects occurred in water deep enough to require the use of SCUBA. Mussels were easily detected, even while wearing neoprene gloves. Descriptions of habitats are provided in Table 3. Unionids as small as 3cm in length were commonly observed in sandy substrates. Sand and gravel were the most common substrate particle sizes encountered among sites (Figure 10). Detection of small mussels became more difficult as substrate particle size increased from pebble to cobble substrates. Results for sites with larger substrate particles may be skewed slightly towards larger individuals and larger species.

Relatively low densities of unionids were observed in Grand River in this study compared to surveys conducted in the Grand River in 1999 (Goforth et al. 2000). Densities of live unionids were very low in the Tittabawassee and Kalamazoo Rivers, although empty shells representing a relatively large number of

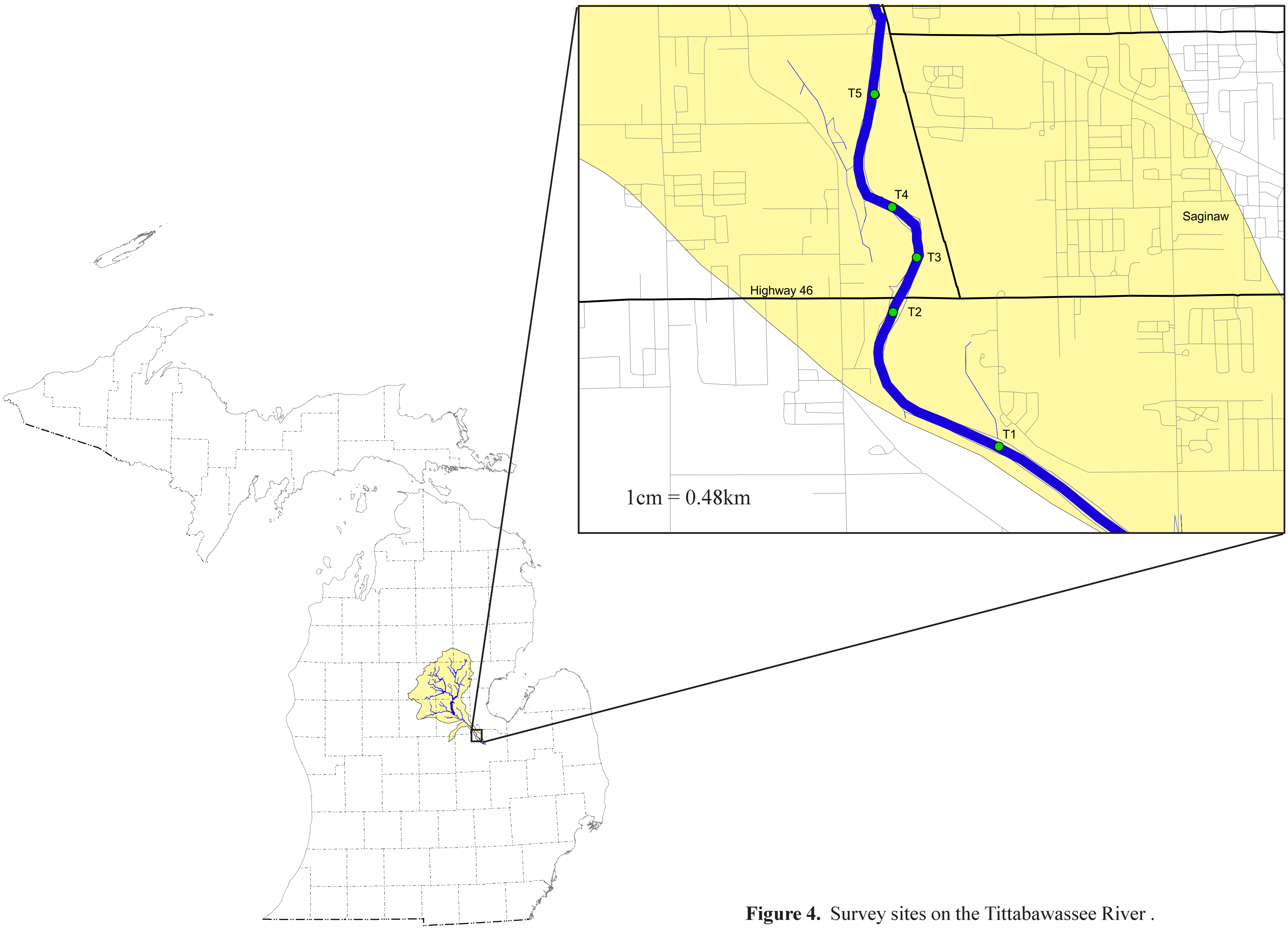

Figure 4. Survey sites on the Tittabawassee River .

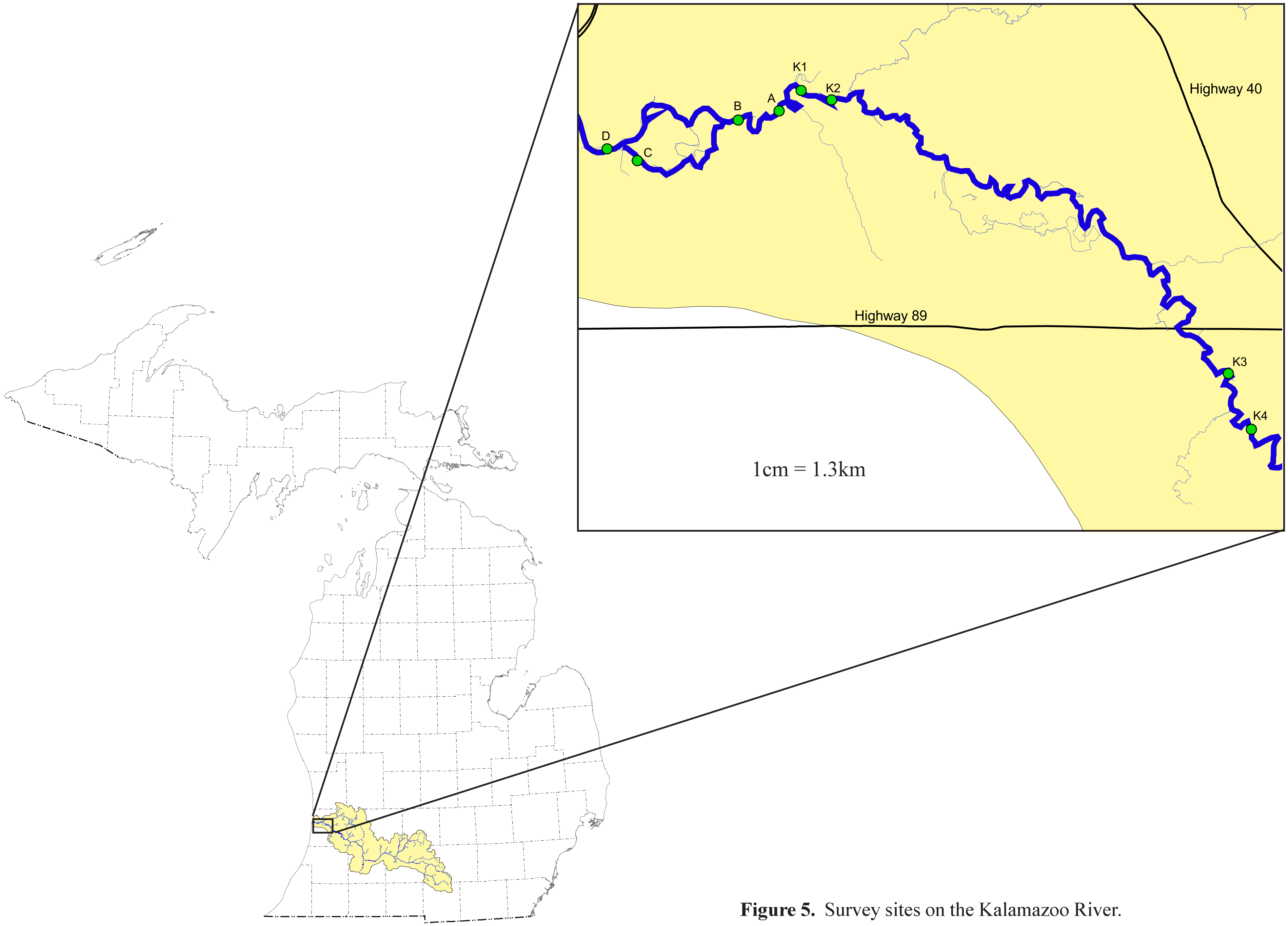

Figure 5. Survey sites on the Kalamazoo River.

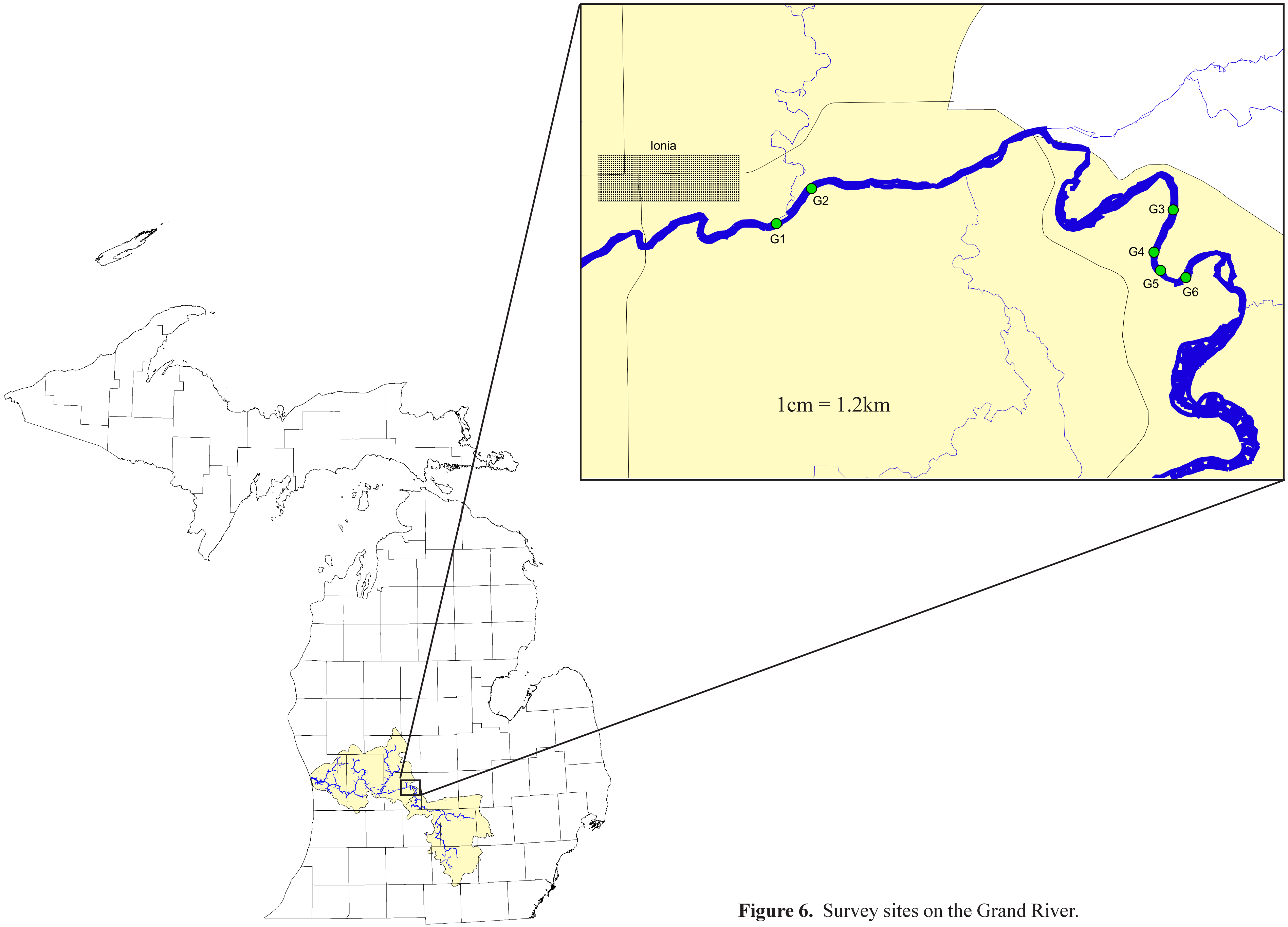

Figure 6. Survey sites on the Grand River.

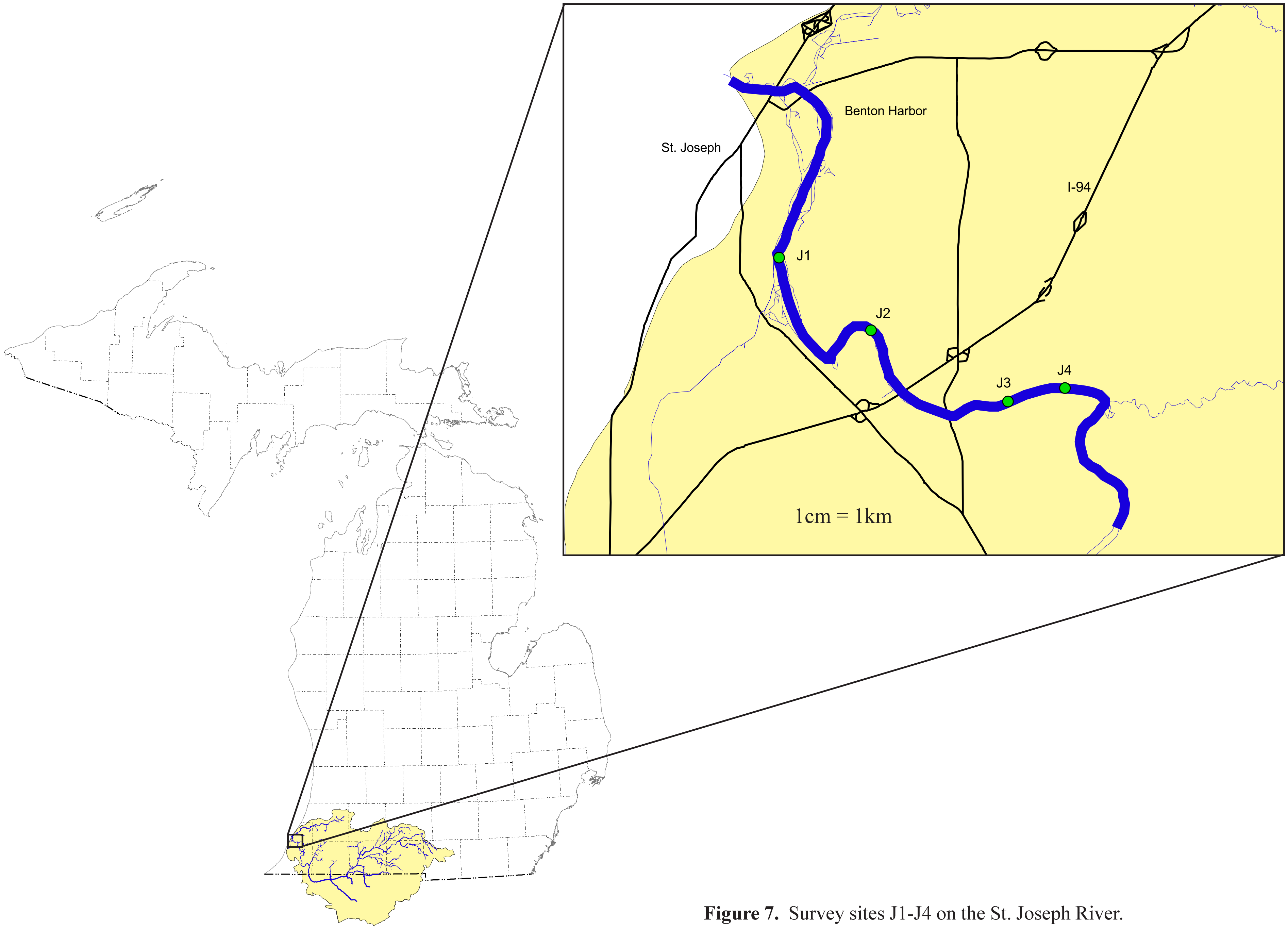

Figure 7. Survey sites J1-J4 on the St. Joseph River.

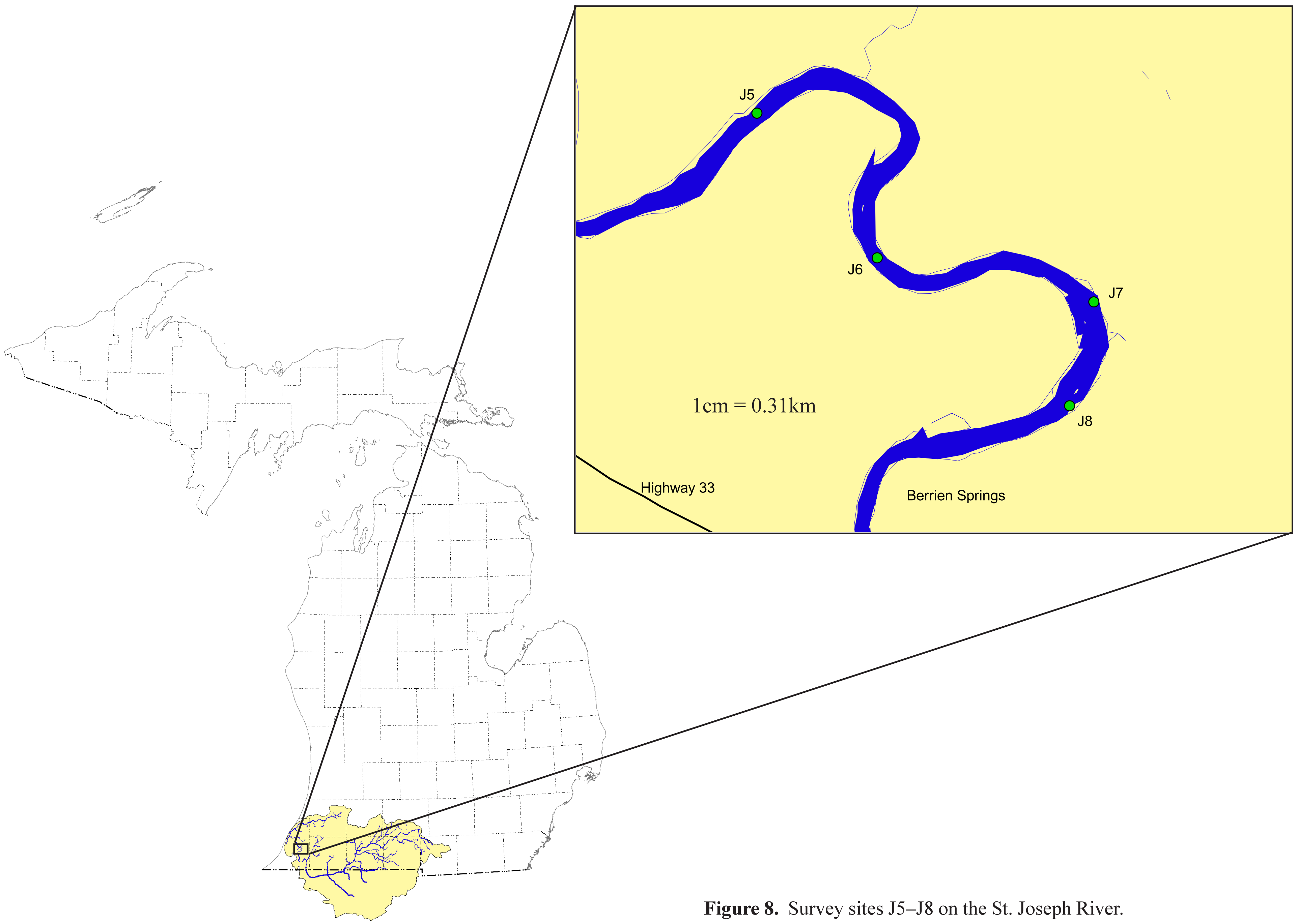

Figure 8. Survey sites J5–J8 on the St. Joseph River.

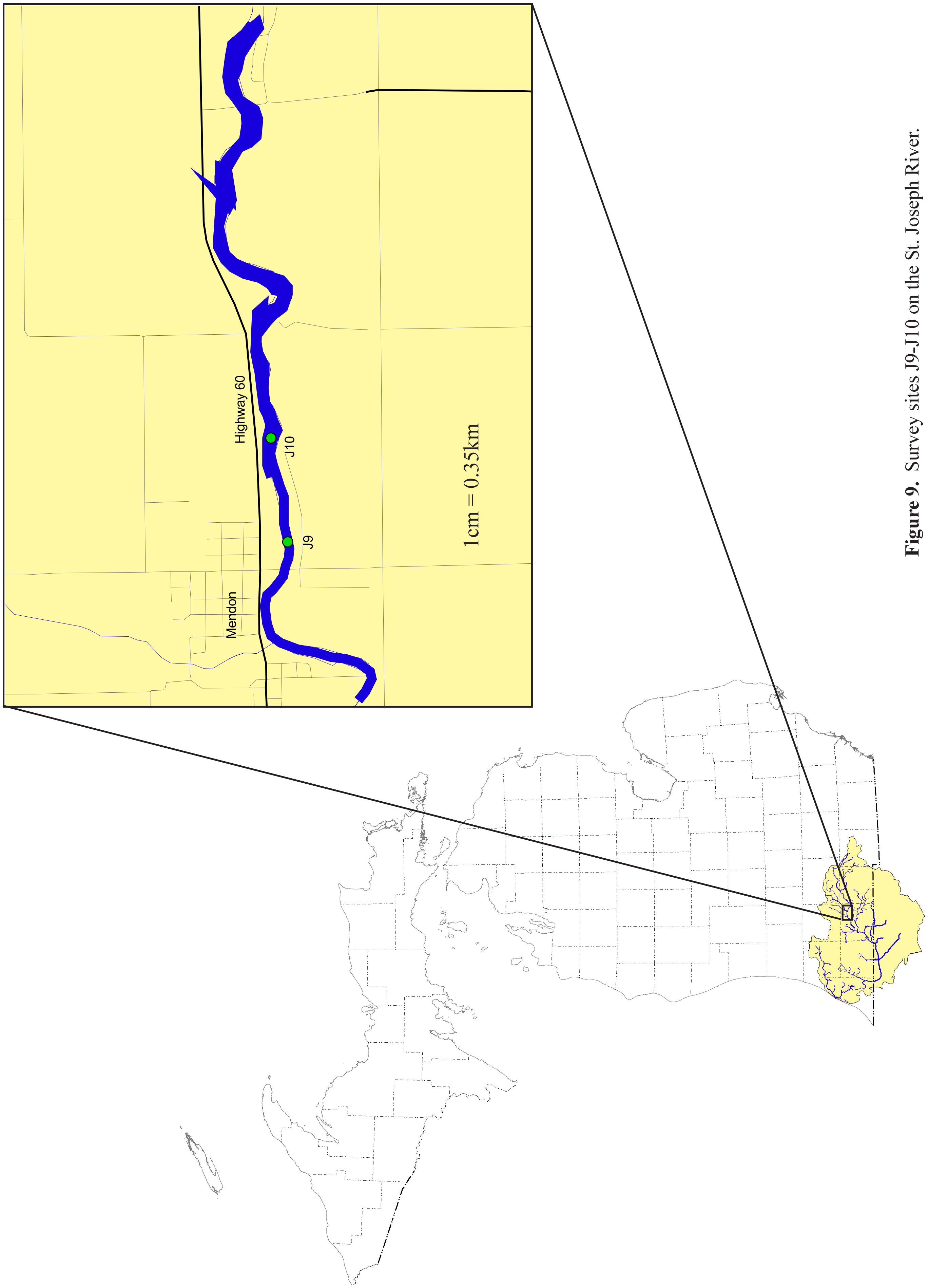

Figure 9. Survey sites J9-J10 on the St. Joseph River.

Table 1. Latitude, Longitude, and town-range-section of survey sites on the Tittabawassee (T1-T5), Kalamazoo (K1-K4, Ka-Kd), Grand (G1-G6), and St. Joseph (J1-J10) Rivers. Sites with listed unionids are marked.

Site	Latitude	Longitude	TRS	Listed Sp.
T1	N 43°24.159'	W 84°02.023'	12N 4E sec31 NE4	X
T2	N 43°24.800'	W 84°02.785'	12N 4E sec30 SW4	
T3	N 43°25.186'	W 84°02.608'	12N 4E sec30 N2	
T4	N 43°25.417'	W 84°02.821'	12N 4E sec19 SW4	
T5	N 43°25.978'	W 84°02.839'	12N 4E sec19 NW4	
K1	N 42°38.865'	W 86°05.773'	3N 15W sec17 NE4	
K2	N 42°38.887'	W 86°06.548'	3N 15W sec17 NE4	
K3	N 42°34.847'	W 85°58.133'	2N 14W sec4 S2	
K4	N 42°34.217'	W 85°58.667'	2N 14W sec9 SE4	X
Ka	N 42°38.827'	W 86°06.666'	3N 15W sec17 NW4	
Kb	N 42°38.655'	W 86°07.433'	3N 15W sec18 S2	
Kc	N 42°38.041'	W 86°09.361'	3N 16W sec14 SW4	
Kd	N 42°38.217'	W 86°09.950'	3N 16W sec23 NE4	
G1	N 42°58.610'	W 85°01.909'	7N 6W sec21 SW4	X
G2	N 42°58.870'	W 85°01.482'	7N 6W sec21 NE4	X
G3	N 42°58.978'	W 84°55.079'	7N 5W sec20 SE4	X
G4	N 42°58.500'	W 84°55.220'	7N 5W sec29 NE4	X
G5	N 42°58.548'	W 84°55.142'	7N 5W sec29 SE4	X
G6	N 42°57.805'	W 84°54.966'	7N 5W sec28 SW4	X
J1	N 42°05.020'	W 86°28.568'	4S 19W sec35 NE4	
J2	N 42°04.330'	W 86°27.300'	5S 18W sec6 NW4	
J3	N 42°03.804'	W 86°24.917'	5S 18W sec5 S2	X
J4	N 42°03.641'	W 86°24.220'	5S 18W sec4 SW4	
J5	N 41°58.566'	W 86°20.583'	6S 18W sec1 SE4	X
J6	N 41°58.050'	W 86°20.150'	6S 17W sec7 NW4	X
J7	N 41°57.564'	W 86°19.305'	6S 17W sec8 W2	
J8	N 41°57.457'	W 86°19.599'	6S 17W sec7 SE4	X
J9	N 42°00.321'	W 85°27.331'	5S 10Wsec26 SW4	X
J10	N 42°00.350'	W 85°26.383'	5S 10Wsec26 SE4	X

species were very abundant at several sites in the two rivers. Numbers of individuals found, relative abundance, and density at each site are given in Tables 4-7. Numbers of unionids found per transect are given in Appendices I-IV.

Only 6 of the 18 native species observed at Tittabawassee River sites were represented by live individuals. A similar situation was recorded in the Kalamazoo River with 9 of 19 species represented by live individuals. In the Grand River 9 of the 16 native species recorded were represented by live individuals, and in the St. Joseph 13 of 20.

Dreissena polymorpha were found attached to unionids at sites in the Tittabawassee, Kalamazoo, and St. Joseph Rivers (Tables 8 and 9, Figure 11). Byssal threads were occasionally found on live unionids and empty shell, indicating that the individual had been colonized by *D. polymorpha* in the past. Additional live *D. polymorpha* were found attached to rocks or substrate other than unionids at sites J1(n=1), J5(n=4), J9(n=10), and J10(n=4). Two unionids (4% of individuals processed) were found in the Tittabawassee River with live *D. polymorpha* attached. Six unionids (7% of individuals processed) were found in the Kalamazoo River with live *D. polymorpha* attached. A total of 65 unionids (17% of individuals processed) were found in the St. Joseph with live *D. polymorpha* attached. The mean number of *D. polymorpha* attached to unionids was 3.0 zebra mussels/unionid for Tittabawassee River sites, 1.0 *D. polymorpha*/unionid for Kalamazoo River sites, and 1.2 *D. polymorpha*/ unionid for St. Joseph River sites. Most *D. polymorpha* were relatively large, up to 4cm in length. No signs of *D. polymorpha* were found at Grand River survey sites. Live *C. fluminea* were found at three sites on the St. Joseph River. *C. fluminea* densities at these sites were fairly low and were restricted to a few individuals per transect. *C. fluminea* shells were found

Table 2. Scientific and common names of unionids found during transect searches in the Tittabawassee, Kalamazoo, Grand, and St. Joseph Rivers. (L = represented by live individuals, S = represented only by empty shell, SpC = State listed as special concern, End = State listed as endangered).

Species	Common name	Tittabawassee	Kalamazoo	Grand	St. Joseph
Actinonaias ligamentina	Mucket	L	S	L	L
Alasmidonta marginata (SpC)	Elktoe	S		S	L
Alasmidonta viridis (SpC)	Slippershell		S	S	S
Amblema plicata	Threeridge	S	S	L	S
Anodonta grandis	Giant floater	L	S	L	S
Anodonta imbecillis	Paper pondshell		L		S
Anodontoides ferussacianus	Cylindrical papershell				S
Cyclonaias tuberculata (SpC)	Purple wartyback		S	L	L
Elliptio dilatata	Spike	S	S	S	L
Epioblasma triquetra (End)	Snuffbox			L	S
Fusconaia flava	Wabash pigtoe	S	L	L	L
Lampsilis siliquoidea	Fatmucket	S	S		
Lampsilis ventricosa	Pocketbook	S	L	L	L
Lasmigona complanata	White heelsplitter	L	L		L
Lasmigona costata	Fluted-shell	S	S	S	L
Leptodea fragilis	Fragile papershell	L	L		L
Ligumia recta	Black sandshell	S	S	L	L
Obliquaria reflexa	Three-horned wartyback	S			
Obovaria olivaria (SpC)	Hickorynut	S			
Pleurobema sintoxia (SpC)	Round pigtoe		S		L
Ptychobranchus fasciolaris	Kidney-shell	S			
Quadrula pustulosa	Pimpleback	S	L	L	S
Quadrula quadrula	Mapleleaf	L	L	S	L
Strophitus undulatus	Strange floater		L	S	
Truncilla truncata	Deertoe	L	L		L
Venustaconcha ellipsiformis (SpC)	Ellipse			S	
Corbicula fluminea (Exotic)	Asian clam	S	S	S	L
Dreissena polymorpha (Exotic)	Zebra mussel	L	L		L
Total species live		7	10	9	15
Total species shell only		13	11	8	7
Total species live or shell		20	21	17	22

at sites in all four rivers.

Ease of distinguishing external annular rings varied among species and among individuals of the same species. Annular ring data was collected only from individuals from which relatively accurate counts could be made (Tables 10-13). Sample sizes for *Q. quadrula* in the Tittabawassee River, *A. plicata* in the Grand River, and *T. truncata* in the St. Joseph River were large enough to make comparisons of annular ring data among sites (Tables 14-16). Mean number of annuli for *Q. quadrula* varied significantly among Tittabawassee River sites (p=0.002). Individuals at site T5 had a significantly higher mean number of annuli than those at site T1 (p=0.047). There was no significant difference in mean number of annuli for *A. plicata* among sites in the Grand River (p=0.227). Mean number of annuli for *T. truncata* varied significantly among sites in the St. Joseph River (p<0.001). Mean number of annuli at site G6 was significantly higher than at sites G1, G3, G5, and G7 (p=0.003, 0.031, 0.006, and 0.004 respectively). Mean number of annuli at site G4 was significantly higher than at sites G1, G5, and G7 (p=0.014, 0.040, and 0.034 respectively)(Figures 12-14).

Table 3. Substrate, current (approximate), and visibility at survey sites in the Tittabawassee, Kalamazoo, Grand, and St. Joseph Rivers. (gravel = 4-30mm, pebble = 30-60mm, cobble > 60mm in diameter).

Site	Substrate	Current (approx.)	Visibility
T1	sand and gravel to silty sand	0.2m/sec.	0.3m
T2	sand and gravel	0.1m/sec	0.6m
T3	silty sand	0.1m/sec.	0.6m
T4	silty sand	0.1m/sec.	0.6m
T5	sand w/ some gravel	0.1m/sec.	0.6m
K1	sand	0.3m/sec.	0.1m
K2	sand covered by muck	0.1m/sec.	0 - 0.1m
K3	sand to gravel	0.1m/sec.	0.3m
K4	gravel	0.2m/sec.	0.3m
G1	gravel w/ some cobble	0.3m/sec.	0.6 - 1m
G2	gravel w/ some sand	0.3m/sec.	0.6 - 1m
G3	ranged from silty sand to gravel and pebble	0.4 - 0.6m/sec.	0.3m
G4	ranged from large gravel w/ some sand to cobble	0.4 - 0.6m/sec.	0.3m
G5	gravel and pebble	0.1m/sec.	0.3m
G6	large gravel and pebble	0.1 - 0.6m/sec.	0.3 - 0.6m
J1	sand	0.3m/sec.	1.5m
J2	sand	0.3m/sec.	1.5m
J3	gravel w/ some sand	0.3m/sec.	0.6m
J4	ranged from sand to sand w/ gravel	0.3m/sec.	0.6m
J5	sand and gravel	0.2 - 0.3m/sec.	0.6 - 0.8m
J6	silty sand and gravel	0 - 0.1m/sec.	< 0.1m
J7	gravel w/ some silt	0.1 - 0.3m/sec.	0.6m
J8	large gravel	0.3m/sec.	1m
J9	sand and gravel	0.1m/sec.	3.5m
J10	sand w/ some gravel and pebble	0.4m/sec.	3m

Figure 10. Sand and gravel substrate in the St. Joseph River (J9). Particles in photo range up to 2cm in diameter.

Table 4. Numbers of unionids, relative abundance, and density (indvs./m^2) recorded from Tittabawassee River sites. Occurrence of live *Corbicula fluminea* (Asian clam), *Dreissena polymorpha* (zebra mussel) or their empty shells is indicated. (SpC = State listed as special concern, End = State listed as endangered, shell = only empty shell was found at the site).

Species	T1			T2			T3			T4			T5		
		rel. ab.	density		rel. ab.	density		rel. ab.	density		rel. ab.	density		rel. ab.	density
Actinonaias ligamentina	shell						2	0.12	0.02				1	1	0.01
Alasmidonta marginata (SpC)	shell														
Amblema plicata	shell			shell			shell								
Anodonta grandis	shell			1	0.04	0.01	shell								
Elliptio dilatata	shell						shell								
Fusconaia flava				shell											
Lampsilis siliquoidea	shell			shell			shell								
Lampsilis ventricosa				shell											
Lasmigona complanata	shell			1	0.04	0.01	shell								
Lasmigona costata	shell														
Ligumia recta							shell								
Leptodea fragilis	shell			1	0.04	0.01	shell								
Obovaria olivaria (SpC)	1 valve														
Obliquaria reflexa	1 valve														
Ptychobranchus fasciolaris	shell						shell								
Truncilla truncata	2	0.40	0.02	17	0.68	0.13	2	0.12	0.02						
Quadrula pustulosa	shell														
Quadrula quadrula	3	0.60	0.02	5	0.2	0.04	13	0.76	0.10						
Total	5		0.04	25		0.20	17		0.13	0		0	1		0.01
Corbicula fluminea (Exotic)				shell											
Dreissena polymorpha (Exotic)	shell									Live					

Table 5. Numbers of unionids, relative abundance, and density (indvs./m^2) recorded from Kalamazoo River sites. Occurrence of live *Corbicula fluminea* (Asian clam), *Dreissena polymorpha* (zebra mussel) or their empty shells is indicated. (SpC = State listed as special concern, End = State listed as endangered, shell = only empty shell was found at the site).

	K1			K2			K3			K4		
Species		rel. ab.	density		rel. ab.	density		rel. ab.	density		rel. ab.	density
Actinonaias ligamentina										shell		
Alasmidonta viridis (SpC)										shell		
Amblema plicata										shell		
Anodonta grandis												
Anodonta imbecillis	1	0.20	0.01									
Cyclonaias tuberculata (SpC)												
Elliptio dilatata												
Fusconaia flava							1	0.07	0.01			
Lampsilis siliquoidea												
Lampsilis ventricosa	2	0.40	0.02	1	1.00	0.01				1	0.04	0.01
Lasmigona complanata							1	0.07	0.01	shell		
Lasmigona costata										shell		
Leptodea fragilis							3	0.20	0.02	1	0.04	0.01
Ligumia recta												
Pleurobema sintoxia (SpC)												
Strophitus undulatus							2	0.13	0.01	2	0.09	0.02
Truncilla truncata							3	0.20	0.02	5	0.22	0.04
Quadrula pustulosa	1	0.20	0.01							1	0.04	0.01
Quadrula quadrula	1	0.20	0.01				5	0.33	0.03	13	0.57	0.10
Total	5		0.04	1		0.01	15		0.09	23		0.18
Corbicula fluminea (Exotic)										shell		
Dreissena polymorpha (Exotic)												

Table 5. continued...

Species	Ka			Kb			Kc			Kd		
		rel. ab.	density		rel. ab.	density		rel. ab.	density		rel. ab.	density
Actinonaias ligamentina				shell			shell			shell		
Alasmidonta viridis (SpC)												
Amblema plicata				shell			shell			shell		
Anodonta grandis				shell			shell			shell		
Anodonta imbecillis							shell			shell		
Cyclonaias tuberculata (SpC)				shell								
Elliptio dilatata				shell			shell			shell		
Fusconaia flava	6	0.23	0.006	shell			shell			5	0.25	0.03
Lampsilis siliquoidea				shell			shell			shell		
Lampsilis ventricosa	1	0.04	0.001				shell			shell		
Lasmigona complanata							shell			shell		
Lasmigona costata							shell			shell		
Leptodea fragilis	5	0.19	0.005				1	1		4	0.20	0.02
Ligumia recta										shell		
Pleurobema sintoxia (SpC)				shell								
Strophitus undulatus							shell			shell		
Truncilla truncata	3	0.12	0.003	shell			shell			shell		
Quadrula pustulosa	7	0.27	0.007				shell			5	0.25	0.03
Quadrula quadrula	4	0.15	0.004				shell			6	0.30	0.03
Total	26		0.026				1			20		0.10
Corbicula fluminea (Exotic)												
Dreissena polymorpha (Exotic)	Live									shell		

Table 6. Numbers of unionids, relative abundance, and density (indvs./m^2) recorded from Grand River sites. Occurrence of live *Corbicula fluminea* (Asian clam), *Dreissena polymorpha* (zebra mussel) or their empty shells is indicated. (SpC = State listed as special concern, End = State listed as endangered, shell = only empty shell was found at the site).

	G1			G2			G3		
Species		rel. ab.	density		rel. ab.	density		rel. ab.	density
Actinonaias ligamentina				2	0.04	0.02			
Alasmidonta marginata (SpC)	shell			shell			shell		
Alasmidonta viridis (SpC)							shell		
Amblema plicata	12	0.63	0.09	34	0.61	0.27	14	0.56	0.11
Anodonta grandis				shell			1	0.04	0.01
Cyclonaias tuberculata (SpC)	shell			5	0.09	0.04	shell		
Elliptio dilatata				shell					
Epioblasma triquetra (End)	1	0.05	0.01	2	0.04	0.02			
Fusconaia flava	shell			3	0.05	0.02	5	0.20	0.04
Lampsilis ventricosa	6	0.32	0.05	5	0.09	0.04	5	0.20	0.04
Lasmigona costata							shell		
Ligumia recta	shell			1	0.02	0.01			
Pleurobema sintoxia (SpC)	shell								
Strophitus undulatus				shell			shell		
Quadrula pustulosa	shell			4	0.07	0.03	shell		
Quadrula quadrula							shell		
Venustacocha ellipsiformis (SpC)							shell		
Total	19		0.15	56		0.44	25		0.20
Corbicula fluminea (Exotic)				shell			shell		
Dreissena polymorpha (Exotic)									

Table 6 continued...

	G4			G5			G6		
Species		rel. ab.	density		rel. ab.	density		rel. ab.	density
Actinonaias ligamentina	1	0.06	0.01	1	0.1	0.0			
Alasmidonta marginata (SpC)	shell			shell			shell		
Alasmidonta viridis (SpC)									
Amblema plicata	13	0.76	0.10	2	0.25	0.02	1	0.33	0.01
Anodonta grandis	1	0.06	0.01				1	0.33	0.01
Cyclonaias tuberculata (SpC)									
Elliptio dilatata	shell						shell		
Epioblasma triquetra (End)				shell					
Fusconaia flava	shell						shell		
Lampsilis ventricosa	2	0.12	0.02	5	0.63	0.04	1	0.33	0.01
Lasmigona costata	shell								
Ligumia recta									
Pleurobema sintoxia (SpC)	shell								
Strophitus undulatus	shell								
Quadrula pustulosa									
Quadrula quadrula									
Venustacocha ellipsiformis (SpC)				shell					
Total	17		0.13	8		0.06	3		0.02
Corbicula fluminea (Exotic)	shell						shell		
Dreissena polymorpha (Exotic)									

Table 7. Numbers of unionids, relative abundance, and density (indvs./m^2) recorded from St. Joseph River sites. Occurrence of live *Corbicula fluminea* (Asian clam), *Dreissena polymorpha* (zebra mussel) or their empty shells is indicated. (SpC = State listed as special concern, End = State listed as endangered, shell = only empty shell was found at the site).

	J1			J2			J3			J4			J5		
Species		rel. ab.	density		rel. ab.	density		rel. ab.	density		rel. ab.	density		rel. ab.	density
Actinonaias ligamentina							shell			shell			shell		
Alasmidonta marginata (SpC)							4	0.12	0.03				3	0.12	0.02
Alasmidonta viridis (SpC)							shell						shell		
Amblema plicata							shell						shell		
Anodonta grandis										shell					
Anodonta imbecillis	shell	0	0												
Anodontoides ferussacianus										shell			shell		
Cyclonaias tuberculata (SpC)							shell						shell		
Elliptio dilatata							shell						1shell		
Epioblasma triquetra (End)							shell						shell		
Fusconaia flava	1	0.06	0.01				2	0.06	0.02	2	0.02	0.02	2	0.08	0.02
Lampsilis ventricosa							1	0.03	0.01	1	0.01	0.01			
Lasmigona complanata							1	0.03	0.01						
Lasmigona costata							shell						shell		
Ligumia recta							shell						shell		
Leptodea fragilis	1	0.06	0.01				1	0.03	0.01	2	0.02	0.02	1	0.04	0.01
Pleurobema sintoxia (SpC)													shell		
Quadrula pustulosa							shell								
Quadrula quadrula	1	0.06	0.01				3	0.09	0.02	1	0.01	0.01			
Strophitus undulatus															
Truncilla truncata	14	0.78	0.11	1	1	0.01	20	0.61	0.16	113	0.95	0.88	19	0.76	0.15
Venustaconcha ellipsiformis (SpC)															
Total	17		0.13	1		0.01	32		0.25	119		0.93	25		0.20
Corbicula fluminea (Exotic)	shell						Live			shell			shell		
Dreissena Polymorpha (Exotic)	Live						Live			Live			Live		

Table 7 continued...

Species	J6			J7			J8			J9			J10		
		rel. ab.	density		rel. ab.	density		rel. ab.	density		rel. ab.	density		rel. ab.	density
Actinonaias ligamentina							shell			8	0.14	0.06	6	0.35	0.05
Alasmidonta marginata (SpC)										shell			shell		
Alasmidonta viridis (SpC)										shell					
Amblema plicata				shell			shell								
Anodonta grandis															
Anodonta imbecillis															
Anodontoides ferussacianus															
Cyclonaias tuberculata (SpC)							shell			20	0.34	0.16	shell		
Elliptio dilatata				2	0.03	0.02				3	0.05	0.02			
Epioblasma triquetra (End)										shell	0.00	0.00	shell		
Fusconaia flava	24	0.17	0.19	12	0.16	0.09	4	0.17	0.03	7	0.12	0.05	1	0.06	0.01
Lampsilis ventricosa	1	0.01	0.01	9	0.12	0.07	1	0.04	0.01	2	0.03	0.02			
Lasmigona complanata				1	0.01	0.01	shell								
Lasmigona costata										5	0.08	0.04	1	0.06	0.01
Ligumia recta							shell						1	0.06	0.01
Leptodea fragilis	2	0.01	0.02	5	0.07	0.04	16	0.70	0.13						
Pleurobema sintoxia (SpC)	1	0.01	0.01				shell			1	0.02	0.01	shell		
Quadrula pustulosa															
Quadrula quadrula	1	0.01	0.01	1	0.01	0.01									
Strophitus undulatus															
Truncilla truncata	114	0.80	0.89	44	0.59	0.34	2	0.09	0.02						
Venustaconcha ellipsiformis (SpC)															
Total	143		1.12	74		0.58	23		0.18	46		0.36	9		0.07
Corbicula fluminea (Exotic)				shell						Live			Live		
Dreissena Polymorpha (Exotic)	Live			Live			Live			Live			Live		

Table 8. *Dreissena polymorpha* (zebra mussel) colonization data for Tittabawassee and Kalamazoo River sites. Colonization measures include the number of unionids colonized by zebra mussels (UCZ), mean number of zebra mussels per colonized unionid (ZM/U), and the percentage of individuals at a site colonized by zebra mussels (%CU).

	Site								
	T1			K3			K4		
Species	UCZ	ZM/U	%CU	UCZ	ZM/U	%CU	UCZ	ZM/U	%CU
F. flava				1	1	100			
S. undulatus				2	1	100	1	1	50
T. truncata	1	2	50	1	2	33			
Q. quadrula	1	4	33				1	1	7.7
Total	2	3	40	4	1	26.7	2	1	8.7

Table 9. *Dreissena polymorpha* (zebra mussel) colonization data for St. Joseph River sites. Colonization measures include the number of unionids colonized by zebra mussels (UCZ), mean number of zebra mussels per colonized unionid (ZM/U), and the percentage of individuals at a site colonized by zebra mussels (%CU).

	Site											
	J1			J3			J4			J5		
Species	UCZ	ZM/U	%CU	UCZ	ZM/U	%CU	UCZ	ZM/U	%CU	UCZ	ZM/U	%CU
A. ligamentina												
A. marginata										1	1	33.3
C. tuberculata												
F. flava				1	1	50						
L. ventricosa												
L. fragilis												
L. recta												
T. truncata	1	1	7.1	5	1.2	25.0	2	1	1.8	1	1	5.3
Total	1	1	5.9	6	1.1	18.8	2	1	1.7	2	1	8.0

Table 9. continued...

	Site											
	J6			J7			J8			J9		
Species	UCZ	ZM/U	%CU	UCZ	ZM/U	%CU	UCZ	ZM/U	%CU	UCZ	ZM/U	%CU
A. ligamentina							1 shell	2		1	1	11.0
A. marginata												
C. tuberculata							1 shell	1		1	1	5.0
F. flava	5	2	20.8	2	1	16.7	3	2.7	75.0			
L. ventricosa				6	1.8	66.6	1	1	100.0			
L. fragilis				1	1	33.3	9	2.1	56.3			
L. recta							1 shell	2				
T. truncata	14	1.1	12.3	11	1.3	25.6						
Total	19	1.6	13.3	20	1.3	27.0	13	1.9	56.5	2	1	4.3

Figure 11. *Dreissena polymorpha* (zebra mussel) attached to *Truncilla truncata* (deertoe) from the St. Joseph River (J6). *D. polymorpha* is approximately 3cm in length.

Table 10. Mean, range, and sample size of external annular rings for selected species in the Tittabawassee River.

	mean	range	sample size
Actinonaias ligamentina	8.0	8	2
Anodonta grandis	8		1
Lasmigona complanata	4		1
Leptodea fragilis	3		1
Quadrula quadrula	10.5 ± 0.6	5-14	21
Truncilla truncata	3.4 ± 0.2	1-6	20

Table 11. Mean, range, and sample size of external annular rings for selected species in the Kalamazoo River including sites K1-K4 and Ka-Kd.

	mean	range	sample size
Fusconaia flava	10.3 ± 1.1	6-14	6
Lampsilis ventricosa	6.7 ± 2.4	2-10	3
Quadrula pustulosa	11.3 ± 1.6	6-16	7
Quadrula quadrula	11.5 ± 0.5	5-16	29
Strophitus undulatus	6.0	6	3
Truncilla truncata	7.0 ± 1.9	3-17	7

Table 12. Mean, range, and sample size of external annular rings for selected species in the Grand River.

	mean	range	sample size
Actinonaias ligamentina	12.0 ± 2.1	9-16	3
Amblema plicata	12.2 ± 0.3	6-20	62
Cyclonaias tuberculata (SpC)	12.4 ± 1.2	9-15	5
Epioblasma triquetra (End)	6		1
Fusconaia flava	10.2 ± 1.6	4-15	6
Lampsilis ventricosa	9.2 ± 1.6	4-18	9
Ligumia recta	9		1
Quadrula pustulosa	11.0 ± 1.2	6-15	4

Table 13. Mean, range, and sample size of external annular rings for selected species in the St. Joseph River.

	mean	range	sample size
Actinonaias ligamentina	20.2 ± 1.1	15-23	6
Alasmidonta marginata (SpC)	6.7 ± 0.6	4-8	7
Cyclonaias tuberculata (SpC)	15.0 ± 1.0	4-21	20
Elliptio dilatata	15		1
Fusconaia flava	10.7 ± 0.5	3-15	39
Lampsilis ventricosa	9.3 ± 3.5	4-16	3
Lasmigona costata	16.7 ± 0.9	15-18	3
Leptodea fragilis	3.8 ± 1.2	1-7	4
Pleurobema sintoxia (SpC)	4		1
Quadrula quadrula	9.6 ± 1.5	4-16	7
Truncilla truncata	6.6 ± 0.2	2-14	296

Table 14. Mean, range, and sample size of external annular rings for *Quadrula quadrula* (mapleleaf) in the Tittabawassee River.

	mean	range	sample size
T1	8.3 ± 0.9	7-10	3
T2	7.6 ± 1.2	5-12	5
T5	12.1 ± 0.5	8-14	13

Table 15. Mean, range, and sample size of external annular rings for *Amblema plicata* (three-ridge) in the Grand River.

	mean	range	sample size
G1	11.3 ± 1.2	8-16	7
G2	12.5 ± 0.3	10-15	31
G3	12.2 ± 1.2	6-21	15
G4	14.1 ± 0.5	12-16	10
G5	11 ± 2.0	9-13	2
G6	12		1

Table 16. Mean, range, and sample size of external annular rings for *Truncilla truncata* (deertoe) at selected sites in the St. Joseph River.

	mean	range	sample size
J1	4.2 ± 0.4	2-6	10
J2	3		1
J3	5.4 ± 0.6	2-11	20
J4	7.0 ± 0.3	3-14	111
J5	5.1 ± 0.6	2-11	19
J6	7.3 ± 0.2	3-12	111
J7	5.2 ± 0.5	2-11	23
J8	3		1

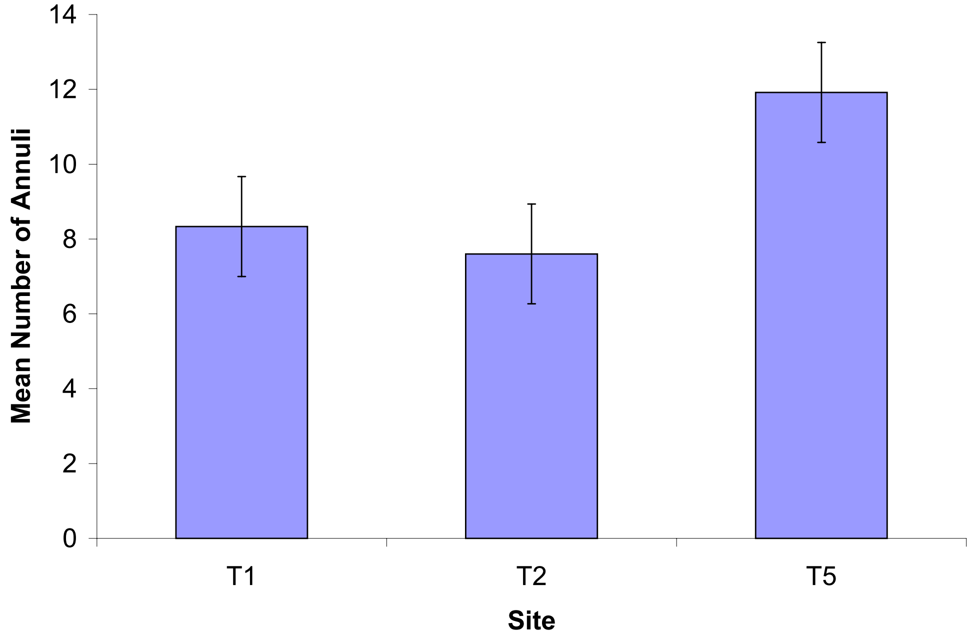

Figure 12. Mean number of annular rings for *Quadrula quadrula* at Tittabawassee River sites. Standard error bars are included.

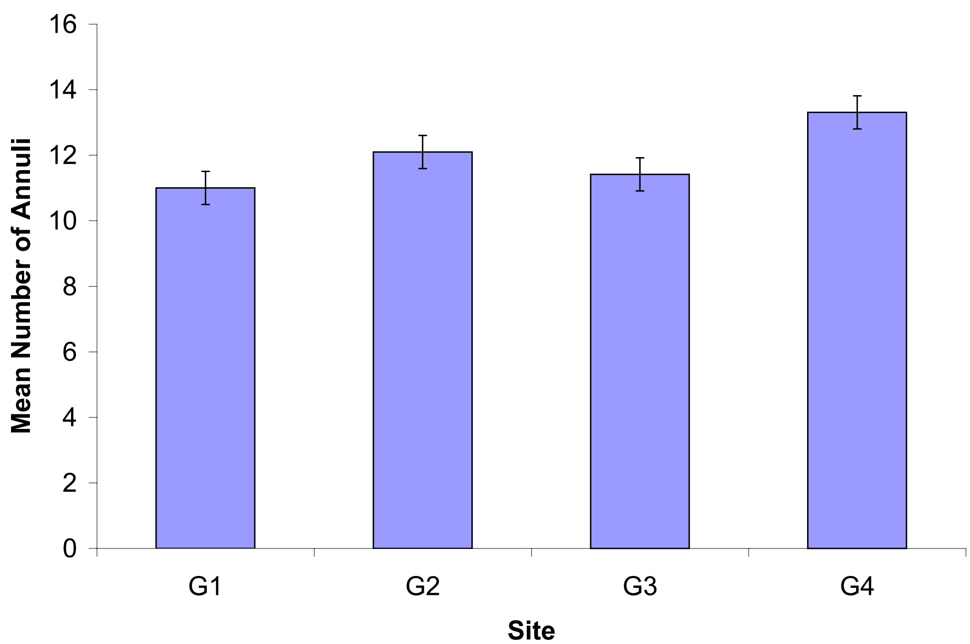

Figure 13. Mean number of annular rings for *Amblema plicata* at Grand River sites. Standard error bars are included.

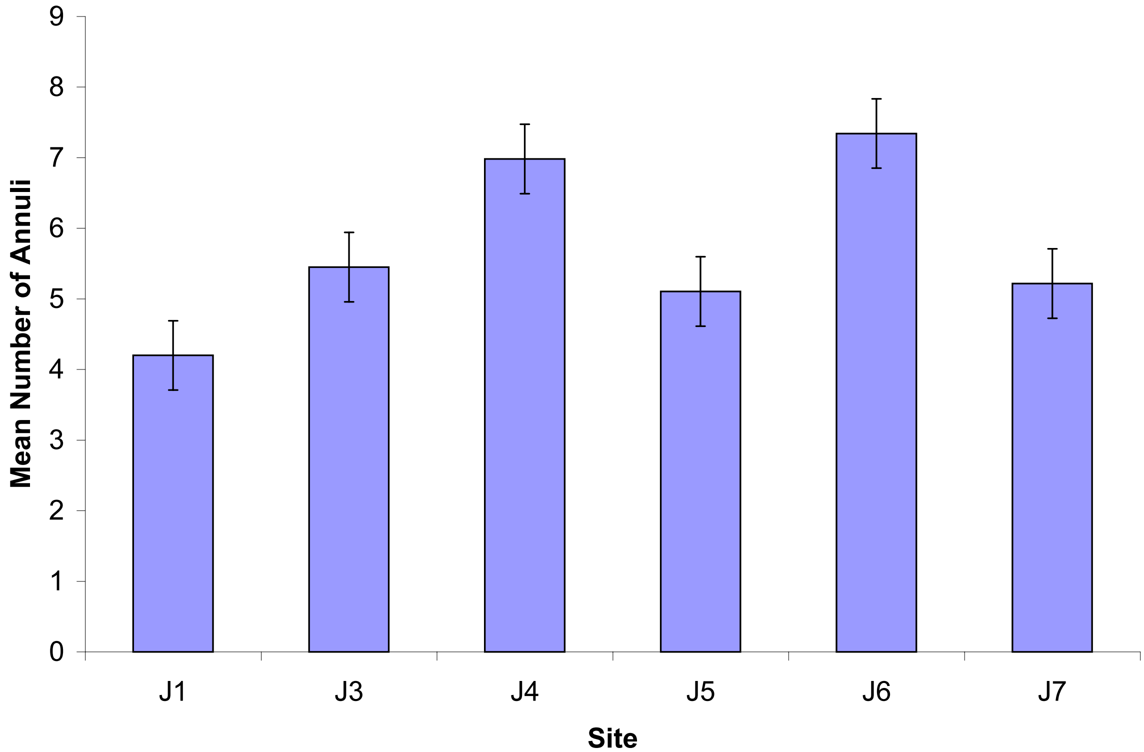

Figure 14. Mean number of annular rings for *Truncilla truncata* at St. Joseph River sites. Standard error bars are included.

Discussion

Shells provide a temporary record of the past composition of unionid communities. The rate at which empty shells show wear is highly variable depending on environmental conditions, but they can remain intact for many years. The low numbers of species represented by live individuals relative to the total number of species observed suggests the communities of the river reaches sampled were once much more species rich than they are currently. For example, *Elliptio dilatata*, a species that was once reported as common in the Grand River (van der Schalie 1948), was represented only by empty shell in this study. Another recent survey of Grand River unionids found no live *E. dilatata* (Goforth et al. 2000). It is possible that unionids are displaying an inherent boom and bust cycle driven by fluctuations in fish host densities or other factors (e.g., restricted fish movements due to dams). However, the decline is more likely indicative of impacts such as a loss of appropriate fish host populations, declining water quality, degraded habitat, and exotic species. The absence of *D. polymorpha* (zebra mussel) or live *C. fluminea* (Asian clam) in the Grand River indicates that the decline has not been driven by the presence of exotic species. Regardless, this documented decline is cause for concern, and the loss of species and individuals of species that currently persist in the Grand River will only be exacerbated if *D. polymorpha* are introduced into the system.

Live *D. polymorpha* were attached to unionids at several sites surveyed in the Tittabawassee River, however, these sites were characterized by a very low ratio of number of species represented by live individuals to species represented only by shell. In contrast, sites in the St. Joseph River with *D. polymorpha* had relatively higher ratios of species represented by live individuals to shells. One notable difference between the study sites in these two rivers was that the substrate in the Tittabawassee River was dominated by sand, while the substrate in the St. Joseph had a higher percentage of larger particles. One hypothesis is that the unionid community in the Tittabawassee was more heavily impacted by *D. polymorpha* than the St. Joseph unionid community due to differences in substrate. *D. polymorpha* requires a stable, hard surface to attach to in order to survive. In soft, unstable substrates (e.g., sand) unionids might provide the only suitable surfaces for colonization. Substrates with larger, more stable particles may lessen the impact of *D. polymorpha* by providing alternate attachment surfaces. Colonization of unionids in the Tittabawassee River was probably much higher in the past. As unionids suffered mortality due to fouling by *D. polymorpha*, the substrate suitable for attachment became more and more scarce so that a decline in *D. polymorpha* followed the decline of the unionid community. A finding that provides additional evidence for this hypothesis is the presence of empty unionid shell with empty *D. polymorpha* shell attached to only the posterior end of the unionid. In order for this to occur a live unionid must have been colonized with *D. polymorpha*, unionid mortality was caused by fouling, then *D. polymorpha* mortality was caused by loss of stability in its attachment point when the empty unionid shell began to drift.

A previous survey of the unionids in the Tittabawassee River watershed was conducted by Hoeh and Trdan from 1979-81. Some differences in species recorded between the two surveys are mostly due to the fact that the four sites surveyed in 2001 were in the lower reaches of the main stem of the Tittabawassee River and therefore include species that utilize large river habitat. Sites from the 1979-81 survey focus on tributaries and upstream sites on the Tittabawassee. Six species recorded in that survey were not found in 2001. Four of these species (*Alasmidonta viridis* (SpC), *Anodontoides ferussacianus, Lasmigona compressa,* and *Venustaconcha ellipsiformis*) are generally regarded as headwater species, one is often associated with impoundments (*Anodonta imbecilis*), and one is a habitat generalist (*Strophitus undulatus*). Twelve species recorded during the 2001 survey were not reported from the 1979-81 survey. These species are either generally associated with medium to large sized rivers (*Actinonaias ligamentina, Lasmigona costata, Ligumia recta, Obliquaria reflexa, Obovaria olivaria, Quadrula pustulosa, Quadrula quadrula, Truncilla truncata*), are found in wide range of habitats (*Amblema plicata, Leptodea fragilis*), or are exotics that had not been introduced until after 1981 (*C. fluminea, D. polymorpha*). Although no sign of *V. ellipsiformis* (SpC) was found in this survey, Hoeh and Trdan reported live individuals from sixteen sites including many "actively recruiting populations". The authors point out an apparent decline in *E. dilatata* and *Ptychobranchus fasciolaris*, and that the dams and impoundments present in the drainage would prevent reestablishment of populations by impeding the passage of fish carrying glochidia. Additional surveys are needed to assess the status of these two species and other unionids in the upper portion of the Tittabawassee River Drainage.

In addition to impacts typically associated with southern Michigan's Rivers, the Kalamazoo has a history of intense negative impacts from industry. The 35-mile stretch between Kalamazoo and Allegan Dam has been given EPA superfund status. Waste from paper mills in the watershed includes PCBs and a variety of heavy metals, some of which are known to cause mortality in unionids when in high enough concentrations (e.g., arsenic, cadmium, chlorine, copper, and mercury)(summarized in Fuller 1974). In one documented case, the unionid fauna was completely destroyed in a 15 mile stretch of river downstream of a paper mill on the Fenholloway River in Florida (Heard 1970). In addition to chemical pollution, unionids in the Kalamazoo could have been negatively impacted from the deposition of organic debris from paper mills. A thick organic substrate layer up to ½ meter thick was found at site K2. The fish community of the Kalamazoo River has also been influenced by changes in water and habitat quality. PCB concentrations found in Kalamazoo River fish are high enough to cause deformities, mortality, and interfere with reproduction (MDEQ 1998). Extirpation of fish hosts or reductions in fish host density can, in turn, prevent reproduction in unionids and undermine population stability.

A list of unionids known to occur in the St. Joseph River watershed (Lake Michigan drainage) was compiled from previous surveys by van der Schalie (1936)(Table 17). Twenty-three unionid species are reported as definitely established with an additional two species having inconclusive evidence. These two species (*L. complanata* and *Q. pustulosa*) were both found in 2001, although *Q. pustulosa* was represented by shell only. *A. imbecillis* and *Q. quadrula*, were found at St. Joseph River sites in 2001 but were not reported in 1936. The exotic *C. fluminea* and *D. polymorpha* did not make their appearance to North America until well after van der Schalie's surveys. Several species were reported in 1936 and not found in 2001, including *L. siliquoidea*, *P. alatus*, *S. undulatus*, *T. donaciformis*, *V. ellipsiformis* (SpC), and *V. iris* (SpC). The difference in findings of the two studies may be at least partially due to the fact that surveys were not performed at the same sites.

Although species richness in the St. Joseph River was high in relation to the three other rivers surveyed, most species were found in low densities compared to densities of these species that are typically observed in upstream tributaries of southern Michigan. The efficiency of methods used in this study is validated by the fact that numerous young, *T. truncata* were detected at several sites. Individuals of this species were typically smaller (2-6cm) in relation to other species. Behavioral or morphological characteristics of *T. truncata* may make it more resistant to negative impacts from zebra mussels, thus allowing it to remain in higher densities while other unionids decline. Although *T. truncata* was colonized by zebra mussels at six different sites, the rate of colonization may be lower than the colonization rates in other species. A larger sample size is needed to test this

Table 17. Comparison of unionids recorded from the St. Joseph River (Lake Michigan drainage) in this study (2001) to those compiled by van der Schalie (1936).

Species	Common name	2001	van der Schalie, 1936
Actinonaias ligamentina	Mucket	L	X
Alasmidonta marginata (SpC)	Elktoe	L	X
Alasmidonta viridis (SpC)	Slippershell	S	X
Amblema plicata	Threeridge	S	X
Anodonta grandis	Giant floater	S	X
Anodonta imbecillis	Paper pondshell	S	
Anodontoides ferussacianus	Cylindrical papershell	S	X
Cyclonaias tuberculata (SpC)	Purple wartyback	L	X
Elliptio dilatata	Spike	L	X
Epioblasma triquetra (End)	Snuffbox	S	X
Fusconaia flava	Wabash pigtoe	L	X
Lampsilis siliquoidea	Fatmucket		X
Lampsilis ventricosa	Pocketbook	L	X
Lasmigona complanata	White heelsplitter	L	
Lasmigona compressa	Creek heelsplitter		X
Lasmigona costata	Fluted-shell	L	X
Leptodea fragilis	Fragile papershell	L	X
Ligumia recta	Black sandshell	L	X
Pleurobema sintoxia (SpC)	Round pigtoe	L	X
Potamilus alatus	Pink heelsplitter		X
Quadrula pustulosa	Pimpleback	S	
Quadrula quadrula	Mapleleaf	L	
Strophitus undulatus	Strange floater		X
Truncilla donaciformis	Fawnsfoot		X
Truncilla truncata	Deertoe	L	X
Venustaconcha ellipsiformis (SpC)	Ellipse		X
Villosa iris (SpC)	Rainbow		X
Corbicula fluminea (Exotic)	Asian clam	L	
Dreissena polymorpha (Exotic)	Zebra mussel	L	
Total species live or shell		22	25

statistically. An alternate hypothesis is that *T. truncata*, which is a large river species, is better adapted to the habitats sampled at these downstream sites than the other species present and was therefore observed in greater abundance than other species during this survey.

Sites G1 and G2 correspond to locations of two sites surveyed by van der Schalie in 1945 east of Ionia, MI (sites 9 and 8 respectively). The unionid communities at these sites are somewhat similar but have shown a general decline in species richness and abundance with a few exceptions. The state endangered *E. triquetra* (End) was found at both sites in 2001 but was not observed at sites 8 or 9 in 1945. Shell of *A. grandis* and *S. undulatus* were found at G2 but were not reported from site 9 in 1945. *A. ligamentina*, *E. dilatata*, *L. cosatata*, and *V. ellipsiformis* were found at site 9 in 1945 but were not found at G1 in 2001. *L. cosatata*, *P. sintoxia* (SpC), and *V. ellipsiformis* (SpC) were found at site 8 in 1945 and not found at G2 in 2001. Three species found live in 1945 were represented by shell only in 2001.

Epioblasma triquetra (End) is a relatively small species, reaching a length of 8cm. Its small size makes it less likely to be collected by the brail bars (or crow-foot bars) that were used to survey unionids in 1945, and may have been overlooked for this reason. Locations of sites G1(2001) and 9(1945) are within 50m of each other, and G2(2001) and 8(1945) within 400m. It is possible that variations in habitat over these distances contributes to the differences observed between the two surveys.

Annular rings were generally more difficult to count on older individuals due close spacing of rings near the margin of the shell. Since a minimum number of rings was recorded in these cases, any error in the collection of annular ring data would most likely result in under-counting older individuals. Observed differences in mean number of annuli among sites are therefore conservative. Although there has been a long-standing opinion that age of unionids can be estimated with the number of annuli, in some cases "annular" rings do not directly correspond to years of age. Studies of both external and internal annular ring production provide evidence that actual ages of certain unionid species are higher than estimates made from annular ring counts (Downing et al. 1992, Kelser and Downing 1997). Annuli may at least provide a relative measure of age, if not actual years of age.

Individuals with more than 15 external annular rings were common in both the Grand and St. Joseph Rivers. Because they are long-lived, unionids generally outlive their host fish. The unionid community present at a particular site today utilized hosts from a fish community that was present up to 20 or more years ago. Changes in surrounding land use (Fongers and Fulcher 2001) and removal of riparian forests (Jones et al. 1999) impact river habitats and the aquatic communities they support. The fish communities of the Grand River have likely undergone changes in composition over the past few decades. In the summer of 1978, the DNR performed rotenone surveys of the Grand River (Nelson and Smith 1981). This study provides a snap shot of the fish community as it existed at the time that the unionids present today successfully parasitized fish hosts (Table 18). Updated fish surveys would provide valuable data for comparison with these historical data to evaluate the status of fish communities at mussel survey sites.

Live *D. polymorpha* and occurrences of state listed as special concern and/or endangered unionids were documented at several sites in the St. Joseph River (J3, J5, J6, J8, J9, and J10). A notable population of *C. tuberculata* (SpC) was found at one of these sites (J9). Live *C. fluminea* and *D. polymorpha* were present at this site, and two individuals of state listed species of special concern were colonized by *D. polymorpha*, one *C. tuberculata* (SpC) and one *A. marginata* (SpC). Most of the *D. polymorpha* observed were large (up to 4cm) with only a few repre-

Table 18. Fish collected in a rotenone survey of the Grand River by the Michigan DNR in 1978 (Nelson and Smith 1981). Sites 15 and 16 correspond to sites G1-G2 and G3-G6 respectively.

Species	Common name	Site 15 (G1-2)	Site 16 (G3-6)
Ichthyomyzon castaneus	Chestnut lamprey		X
Lepisosteus osseus	Longnose gar		X
Oncorhynchus tshawytscha	Chinook salmon		X
Esox lucius	Northern pike	X	X
Carpiodes cyprinus	Quillback	X	X
Moxostoma spp.	Redhorse spp.	X	X
Moxostoma erythrurum	Golden redhorse	X	X
Moxostoma macrolepidotum	Northern redhorse	X	
Hypentelium nigricans	Northern hogsucker	X	X
Cyprinus carpio	Carp	X	X
Carassius auratus	Goldfish	X	
Notropis atherinoides	Emerald shiner		X
Notropis cornutus	Common shiner		X
Notropis hudsonius	Spottail shiner		X
Notropis spilopterus	Spotfin shiner	X	X
Notropis stramineus	Sand shiner		X
Pimnephales notatus	Bluntnose minnow	X	X
Ictalurus spp.	Bullhead spp.	X	X
Ictalurus melas	Black bullhead		X
Ictalurus punctatus	Channel catfish	X	X
Pylodictis olivaris	Flathead catfish		X
Micropterus dolomieui	Smallmouth bass	X	X
Lepomis cyanellus	Green sunfish		X
Lepomis gibbosus	Pumpkinseed	X	X
Lepomis megalotis	Longear sunfish		X
Ambloplites rupestris	Rock bass	X	X
Pomoxis nigromaculatus	Black crappie	X	X
Stizostedion vitreum	Walleye		X
Percina maculata	Blackside darter	X	X
Percina caprodes	Logperch	X	X
Etheostoma nigrum	Johnny darter		X

senting young age classes. Reproductive success appears to be low in the St. Joseph River in the vicinity of the sites surveyed. This may indicate that *D. polymorpha* densities have stabilized at relatively low levels at these sites, in spite of an abundance of stable substrate that appears to be suitable for *D. polymorpha* colonization. The moderate current velocities observed at these sites is likely a significant limiting factors for *D. polymorpha* settling and colonization, keeping them at low densities.

Due to their dramatic impact on industry and recreation, *D. polymorpha* have developed an infamous reputation as an invasive species. Their ability to smother unionids by attaching to them in high densities is also well established. *D. polymorpha* densities observed at survey sites in the Tittabawasse, Kalamazoo, and St. Joseph River were low. However, the continued presence and spread of this species in Michigan's rivers and lakes jeopardizes communities of native unionids throughout the state. The Grand and St. Joseph Rivers are important resources for recreational boating, making them vulnerable to *D. polymorpha* introduction and/or spread.

Another exotic bivalve, *C. fluminea*, has been in the eastern U.S. since the late 1950's. Although it has successfully established itself across a wide range, it has received relatively little attention. It has had little impact on industry, and its effect on river ecosystems and native unionid mussels is not well known. Several potential ways *C. fluminea* may be impacting native mussels have been proposed by various researchers and are summarized by Strayer (1999). Being filter feeders, *C. fluminea* may compete with unionids for phytoplankton and other food suspended in the water column. *C. fluminea* also can pedal feed, removing edible particles from sediments. Juvenile unionids and sphaeridae (another family of native bivalve) also feed this way, and could potentially complete with *C. fluminea* for these resources. In high densities, *C. fluminea* might kill unionids by ingesting unionid sperm, glochidia, and newly metamorphosed juveniles. Density of *C. fluminea* was not high at any site surveyed. However, they were not targeted by the current surveys due to their small size. Alternate methods would need to be used in order to obtain quantitative density estimates for *C. fluminea*. It seems unlikely that unionids at sites visited in this study would currently be under competitive pressures from *C. fluminea*. However this species is known to have cycles of dramatic fluctuations in population density, so competition pressures could be periodic. Monitoring zebra mussel and Asian clam populations in the Grand and St. Joseph Rivers would help reveal the degree to which unionids in these rivers are at risk from non-native species.

The status of unionid populations mirrors the biological integrity of river systems. The rivers of southern Michigan have undergone direct and indirect impacts over the past century. The unionid communities of the Tittabawassee, Kalamazoo, Grand and St. Joseph Rivers are not only a product of the unique biogeographical and evolutionary history of the region, they also reflect a recent history of impacts from habitat degradation, fluctuating status of fish hosts, and non-native species.

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Appendix I. Numbers of unionids found in each transect in the Tittabawassee River. Any shell found inside or outside transects are listed in the sum column. Unless otherwise noted "shell" = several empty shell were found at the site.

Site	T1									T2								
Transect	1	2	3	4	5	6	7	8		1	2	3	4	5	6	7	8	
Species	# live indvs.								sum	# live indvs.								sum
Actinonaias ligamentina									shell									
Alasmidonta marginata (SpC)									shell									
Amblema plicata									shell									shell
Anodonta grandis									shell						1			1
Elliptio dilatata									shell									
Fusconaia flava																		shell
Lampsilis siliquoidea									shell									shell
Lampsilis ventricosa																		shell
Lasmigona complanata									shell	1								1
Lasmigona costata									shell									
Legumia recta																		
Leptodea fragilis									shell	1								1
Obovaria olivaria (SpC)									1 valve									
Obliquaria reflexa									1 valve									
Ptychobranchus fasciolaris									shell									
Truncilla truncata	2								2		5	1	5		4		2	17
Quadrula pustulosa									shell									
Quadrula quadrula	2		1						3		1	1	3					5

Site	T3									T4									T5								
Transect	1	2	3	4	5	6	7	8		1	2	3	4	5	6	7	8		1	2	3	4	5	6	7	8	
Species	# live indvs.								sum	# live indvs.								sum	# live indvs.								sum
Actinonaias ligamentina			1					1	2										1								1
Alasmidonta marginata (SpC)																											
Amblema plicata									shell																		
Anodonta grandis									shell																		
Elliptio dilatata									shell																		
Fusconaia flava																											
Lampsilis siliquoidea									shell																		
Lampsilis ventricosa																											
Lasmigona complanata									shell																		
Lasmigona costata																											
Legumia recta									shell																		
Leptodea fragilis									shell																		
Obovaria olivaria (SpC)																											
Obliquaria reflexa																											
Ptychobranchus fasciolaris									shell																		
Truncilla truncata			1				1		2																		
Quadrula pustulosa																											
Quadrula quadrula	1		5	2	1	1	2	1	13																		

Appendix II. Numbers of unionids found in each transect in the Kalamazoo River. Any shell found inside or outside transects are listed in the sum column. Unless otherwise noted "shell" = several empty shell were found at the site.

Site	K1									K2									K3											K4									Ka	Kb	Kc	Kd
Transect	1	2	3	4	5	6	7	8		1	2	3	4	5	6	7	8		1	2	3	4	5	6	7	8	9	10		1	2	3	4	5	6	7	8					
Species	# live indvs.								sum	# live indvs.								sum	# live indvs.										sum	# live indvs.								sum				
Actinonaias ligamentina																																						shell		shell	shell	shell
Alasmidonta viridis (SpC)																																						shell				
Amblema plicata																																						shell		shell	shell	shell
Anodonta grandis																																								shell	shell	shell
Anodonta imbecillis				1					1																																shell	shell
Cyclonaias tuberculata (SpC)																																								shell		
Elliptio dilatata																																								shell	shell	shell
Fusconaia flava																										1			1										6	shell	shell	5
Lampsilis siliquoidea																																								shell	shell	shell
Lampsilis ventricosa						1		1	2				1					1												1								1	1		shell	shell
Lasmigona complanata																								1					1									shell			shell	shell
Lasmigona costata																																						shell			shell	shell
Leptodea fragilis																			1					1	1				3				1					1	5		1	4
Ligumia recta																																										shell
Pleurobema sintoxia (SpC)																																								shell		
Strophitus undulatus																									1	1			2						2			2			shell	shell
Truncilla truncata																							2			1			3		1		1	1	1	1		5	3	shell	shell	shell
Quadrula pustulosa								1	1																											1		1	7		shell	5
Quadrula quadrula								1	1																	1	1	3	5	1	1		3	1	6		1	13	4		shell	6

Appendix III. Numbers of unionids found in each transect in the Grand River. Any shell found inside or outside transects are listed in the sum column. Unless otherwise noted "shell" = several empty shell were found at the site.

Site	G1									G2									G3								
Transect	1	2	3	4	5	6	7	8		1	2	3	4	5	6	7	8		1	2	3	4	5	6	7	8	
Species	# live indvs.								sum	# live indvs.								sum	# live indvs.								sum
Actinonaias ligamentina										2								2									
Alasmidonta marginata (SpC)									1 valve									shell									shell
Alasmidonta viridis (SpC)																											shell
Amblema plicata	3	2	1	1	1	1	3		12	12	11	2	9					34	3	1	5	2	1	2			14
Anodonta grandis																		shell	1								1
Cyclonaias tuberculata (SpC)									1 valve	2	2					1		5									shell
Elliptio dilatata																		shell									
Epioblasma triquetra (End)		1							1	1m	1f																
Fusconaia flava									shell	1			2					3	1				3	1			5
Lampsilis ventricosa	2	1	1		1		1		6	1		1	2	1				5	1	1				3			5
Lasmigona costata																											shell
Legumia recta									shell						1			1									
Pleurobema sintoxia (SpC)									1 valve																		
Quadrula pustulosa									shell				1	1		2		4									shell
Quadrula quadrula																											shell
Strophitus undulatus																		shell									shell
Venustaconcha ellipsiformis (SpC)																											shell

Appendix III continued...

Site	G4									G5									G6								
Transect	1	2	3	4	5	6	7	8		1	2	3	4	5	6	7	8		1	2	3	4	5	6	7	8	
Species	# live indvs.								sum	# live indvs.								sum	# indvs.								sum
Actinonaias ligamentina							1		1					1				1									
Alasmidonta marginata (SpC)									shell									shell									shell
Alasmidonta viridis (SpC)																											
Amblema plicata	1	1	1	1		1	1	7	13								2	2			1						1
Anodonta grandis	1								1												1						1
Cyclonaias tuberculata (SpC)																											
Elliptio dilatata									shell																		shell
Epioblasma triquetra (End)																		1 shell									
Fusconaia flava									shell																		shell
Lampsilis ventricosa	1							1	2					3		2		5					1				1
Lasmigona costata									shell																		
Legumia recta																											
Pleurobema sintoxia (SpC)									shell																		
Quadrula pustulosa																											
Quadrula quadrula																											
Strophitus undulatus									shell																		
Venustaconcha ellipsiformis (SpC)																		shell									

Appendix IV. Numbers of unionids found in each transect in the St. Joseph River. Any shell found inside or outside transects are listed in the sum column. Unless otherwise noted "shell" = several empty shell were found at the site.

Site	J1									J2									J3								
Transect	1	2	3	4	5	6	7	8		1	2	3	4	5	6	7	8		1	2	3	4	5	6	7	8	
Species	# live individuals								sum	# indvs.								sum	# indvs.								sum
Actinonaias ligamentina																											shell
Alasmidonta marginata (SpC)																							1	3			4
Alasmidonta viridis (SpC)																											1valve
Amblema plicata																											shell
Anodonta grandis																											
Anodonta imbecillis									1 shell																		
Anodontoides ferussacianus																											
Cyclonaias tuberculata (SpC)																											4 valves
Elliptio dilatata																											shell
Epioblasma triquetra (End)																											2 valves
Fusconaia flava							1		1										1		1						2
Lampsilis ventricosa																										1	1
Lasmigona complanata																			1								1
Lasmigona costata																											shell
Ligumia recta																											shell
Leptodea fragilis								1	1																1		1
Pleurobema sintoxia (SpC)																											
Quadrula pustulosa																											shell
Quadrula quadrula				1					1										3								3
Strophitus undulatus																											
Truncilla truncata			1		3		4	6	14							1		1	6	2	1	3	1		2	5	20

Appendix IV continued...

Site	J4								
Transect	1	2	3	4	5	6	7	8	
Species	# indvs.								sum
Actinonaias ligamentina									shell
Alasmidonta marginata (SpC)									
Alasmidonta viridis (SpC)									
Amblema plicata									
Anodonta grandis									shell
Anodonta imbecillis									
Anodontoides ferussacianus									shell
Cyclonaias tuberculata (SpC)									
Elliptio dilatata									
Epioblasma triquetra (End)									
Fusconaia flava					1			1	2
Lampsilis ventricosa						1			1
Lasmigona complanata									
Lasmigona costata									
Ligumia recta									
Leptodea fragilis	1	1							2
Pleurobema sintoxia (SpC)									
Quadrula pustulosa									
Quadrula quadrula							1		1
Strophitus undulatus									
Truncilla truncata		8	2	18	19	27	24	15	113

Site	J5								
Transect	1	2	3	4	5	6	7	8	
Species	# indvs.								sum
Actinonaias ligamentina									shell
Alasmidonta marginata (SpC)		2		1					3
Alasmidonta viridis (SpC)									1 valve
Amblema plicata									1 shell
Anodonta grandis									
Anodonta imbecillis									
Anodontoides ferussacianus									1 fresh shell
Cyclonaias tuberculata (SpC)									4 valves, 3 shells
Elliptio dilatata									1shell
Epioblasma triquetra (End)									3 female, 6 male valves
Fusconaia flava		2							2
Lampsilis ventricosa									
Lasmigona complanata									
Lasmigona costata									2 shells
Ligumia recta									1 shell
Leptodea fragilis		1							1
Pleurobema sintoxia (SpC)									1 valve
Quadrula pustulosa									
Quadrula quadrula									
Strophitus undulatus									
Truncilla truncata	1	15	1	1		1			19

Site	J6								
Transect	1	2	3	4	5	6	7	8	
Species	# indvs.								sum
Actinonaias ligamentina									
Alasmidonta marginata (SpC)									
Alasmidonta viridis (SpC)									
Amblema plicata									
Anodonta grandis									
Anodonta imbecillis									
Anodontoides ferussacianus									
Cyclonaias tuberculata (SpC)									
Elliptio dilatata									
Epioblasma triquetra (End)									
Fusconaia flava		1	3	6	5	6	1	2	24
Lampsilis ventricosa	1								1
Lasmigona complanata									
Lasmigona costata									
Ligumia recta									
Leptodea fragilis			1				1		2
Pleurobema sintoxia (SpC)	1								1
Quadrula pustulosa									
Quadrula quadrula	1								1
Strophitus undulatus									
Truncilla truncata	17		22	11	17	22	11	14	114

Appendix IV continued...

Site	J7									J8									J9								
Transect	1	2	3	4	5	6	7	8		1	2	3	4	5	6	7	8		1	2	3	4	5	6	7	8	
Species	# indvs.								sum	# indvs.								sum	# indvs.								sum
Actinonaias ligamentina																		shell				1		1	1	5	8
Alasmidonta marginata (SpC)																											shell
Alasmidonta viridis (SpC)																											2 valves
Amblema plicata									shell									shell									
Anodonta grandis																											
Anodonta imbecillis																											
Anodontoides ferussacianus																											
Cyclonaias tuberculata (SpC)																		shell	3		2	2	7		3	3	20
Elliptio dilatata	1	1							2													1	2				3
Epioblasma triquetra (End)																											shell
Fusconaia flava	1		3		1	2	3	2	12				1		3			4	1		1	2		1		2	7
Lampsilis ventricosa	1	1	1	1	2	3			9	1								1				1	1				2
Lasmigona complanata				1					1									shell									
Lasmigona costata																				1		2	2				5
Ligumia recta																		shell									
Leptodea fragilis	2				2		1		5	2	2	1	3		2	2	4	16									
Pleurobema sintoxia (SpC)																		shell				1					1
Quadrula pustulosa																											
Quadrula quadrula				1					1																		
Strophitus undulatus																											
Truncilla truncata	9		15	2	6	2	6	4	44	1			1					2									

Appendix IV continued...

Site	J10								
Transect	1	2	3	4	5	6	7	8	
Species	# indvs.								sum
Actinonaias ligamentina	3		2					1	6
Alasmidonta marginata (SpC)									shell
Alasmidonta viridis (SpC)									
Amblema plicata									
Anodonta grandis									
Anodonta imbecillis									
Anodontoides ferussacianus									
Cyclonaias tuberculata (SpC)									shell
Elliptio dilatata									
Epioblasma triquetra (End)									2 valves
Fusconaia flava	1								1
Lampsilis ventricosa									
Lasmigona complanata									
Lasmigona costata	1								1
Ligumia recta				1					1
Leptodea fragilis									
Pleurobema sintoxia (SpC)									shell
Quadrula pustulosa									
Quadrula quadrula									
Strophitus undulatus									
Truncilla truncata									