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Native Freshwater Mussels (Bivalvia: Unionidae) and Infestation by Zebra Mussels at the Lost Mound Unit of the Upper Mississippi River National Wildlife and Fish Refuge

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ABSTRACT

We characterized the unionid community and extent of zebra mussel infestation along a 21 km reach of the upper Mississippi River known as the Lost Mound Unit of the Upper Mississippi River National Wildlife and Fish Refuge, formerly the Savanna Army Depot. Unionids were present at 81% of the 79 sites sampled totaling 2,440 individuals of 26 species. Catch per unit effort (CPUE) averaged 119.7 ± 107.0 SD unionids/hour (range = 0 to 402.0). Unionids were relatively abundant (CPUE ≥100 unionids/hour) at 34.2% of the sample sites, and of these sites, 66.7% had ≥10 live species. Young were found for up to 77% of the species including the federally endangered *Lampsilis higginsii*. Relative abundance of *L. higginsii* ranged from 0.9 to 2.6% of the community at the four sites it was found alive, which is well within the criteria established for areas of essential habitat. Frequency of unionids infested by at least one zebra mussel (*Dreissena polymorpha*) was 9.1%, with an average of 0.4 ± 1.8 SD zebra mussels/unionid. Species richness in the Pool 12 unionid sanctuary was similar to that observed during studies in 1987 and 1990, prior to the zebra mussel invasion.

INTRODUCTION

The Lost Mound Unit of the Upper Mississippi River National Wildlife and Fish Refuge (Lost Mound Unit), formerly the Savanna Army Depot, is a >3,800 ha tract of bottomland hardwood forest and upland sand prairie-sand savanna bordering the Mississippi River in extreme northwest Illinois, Jo Daviess and Carroll counties. The riverine portion of the refuge consists of an extensive network of backwater lakes and sloughs and several channel border islands. Limited sampling in the area has revealed a potentially diverse

unionid community, including the federally endangered *Lampsilis higginsii* and several Illinois and Iowa listed species (Cawley 1990). No comprehensive study of the area has been done. A portion of the refuge above Lock and Dam 12 was designated as a unionid sanctuary (IDNR 2000) prior to the arrival and spread of the exotic zebra mussel (*Dreissena polymorpha*) (Tucker et al. 1993, Cope et al. 1997), which has devastated many North American mussel stocks (Schloesser et al. 1996).

The objectives of this study were to determine distribution, abundance, and species composition of unionids in the Lost Mound Unit of the upper Mississippi River, to measure extent of zebra mussel infestation on unionids, and to determine effects of zebra mussels at the unionid sanctuary.

MATERIALS AND METHODS

We sampled 79 sites in the upper Mississippi River and its backwaters between River Miles 544.5 and 558.4 from 11 to 16 September 2001 (Figure 1). Fourteen sample sites were within the unionid sanctuary above Lock and Dam 12 at Bellevue, Iowa. We sampled the majority of sites while diving with surface supplied air, but some areas were shallow enough to wade on hands and knees. At each site we did a timed search to measure unionid abundance as catch per unit effort (CPUE) and to estimate species richness (Strayer and Smith 2003). We searched for unionids by moving hands in a sweeping motion on the substrate surface and by probing the substrate with fingers. We sampled sites for 3 to 40 min (mean = 15.5 min ± 8.1 SD). We usually abandoned sites in ≤10 min if we found ≤5 unionids, thus allowing greater coverage of the study area. We concentrated samples along channel borders, side channels, and the head and toe of islands, and we avoided sampling the navigation channel, which is periodically dredged. We also searched the shoreline for shells at several sites, but did not include these data in the total time sampled. We recorded Universal Transverse Mercator (UTM) coordinates (NAD83, Zone 15) for each site with a Trimble Pathfinder® Global Positioning System.

All live and most dead unionids encountered were placed in a mesh bag until the end of the search period, and except for those kept as vouchers, were returned to the river following processing. Dead unionids with tissue present, or shiny nacre and intact periostracum were categorized as recently dead, and those with chalky nacre and worn periostracum, other than normal umbonal erosion, were categorized as weathered dead. We recorded length (anterior-posterior axis) to the nearest millimeter for all unionids except for some individuals of *Amblema plicata*. Zebra mussels attached to individual unionids were removed and counted. We did not estimate zebra mussel abundance on other substrates at sample sites. We also recorded aquatic snails, fingernail clams (Sphaeriidae), and Asian clams (*Corbicula fluminea*) when encountered. Nomenclature follows Turgeon et al. (1998), and voucher specimens were deposited in the Illinois Natural History Survey Mollusk Collection, Champaign.

RESULTS

Unionid Community Characterization

We collected 2,440 individuals representing 26 species in 20.4 hr of sampling (Table 1). Included were six individuals of *Lampsilis higginsii*, which were collected alive at four

sites, the Illinois and Iowa Threatened *Ellipsaria lineolata* and Illinois Threatened *Ligumia recta*, which were collected at three and nine sites, respectively, and the Iowa Endangered *Pleurobema sintoxia* and Iowa Threatened *Strophitus undulatus*, which were collected at one site each. We found weathered shells of an additional eight species, and three species represented by museum specimens were not found during this study (Table 1).

Amblema plicata was the most abundant and widespread species, comprising 35.1% of all individuals and occupying 64.6% of sites. Other relatively abundant species included *Obliquaria reflexa* (17.9%), *Fusconaia flava* (9.2%), *Lampsilis cardium* (6.1%), *Quadrula quadrula* (6.5%), *Pyganodon grandis* (6.0%), and *Obovaria olivaria* (6.0%) (Table 1). These species also were some of the most broadly distributed species in the study area along with *Leptodea fragilis*, *Lasmigona complanata*, *Potamilus ohiensis*, *Quadrula pustulosa*, *Q. nodulata*, *Truncilla donaciformis*, and *T. truncata* (Table 2). Length frequency distributions indicated that up to 77% of the 26 species we found alive had recent recruits to their populations, which we define as Amblemines ≤40mm, Anodontines and Lampsilines ≤60mm, and *Toxolasma* and *Truncilla* ≤10mm (Table 3). Included among these were three small (43, 50, and 62mm) *L. higginsii* that we estimated at three (one individual) and four (two individuals) years of age based on external annuli.

We found at least one live unionid at 81.0% of the sample sites (Table 2), and CPUE averaged 119.7 ± 107.0 SD unionids/hour (range = 0 to 402.0). Unionids were absent or sparse (≤25 unionids/hour) at 40.5% of the sites sampled. There were 27 sites (34.2%) with CPUE ≥100 unionids/hour, 14 sites (17.7%) with CPUE ≥200 unionids/hour, and six sites (7.6%) with CPUE ≥300 unionids/hour. Of the sites with CPUE ≥100 unionids/hour, 66.7% had ≥10 live species.

Unionid Sanctuary

In 4 hr of sampling, we collected 664 individuals of 20 species, including one live *Lampsilis higginsii*. *Amblema plicata* (36.6%), *Obliquaria reflexa* (23.5%), and *Quadrula quadrula* (13.1%) were the most abundant species in the sanctuary, and *A. plicata*, *Megalonaias nervosa*, *Q. quadrula*, *Leptodea fragilis*, and *O. reflexa* seemed more abundant in the sanctuary than in the downstream portion of the study area. We found live unionids at all but one sample site (Table 2), and CPUE averaged 166.8 ± 116.6 SD unionids/hour (range = 0 to 351.0). Of the 14 sites sampled in the sanctuary, eight had CPUE ≥100 unionids/hour, five had CPUE ≥200 unionids/hour, and one had CPUE ≥300 unionids/hour. Five sites had ≥10 species. Species richness of live unionids and relative abundance of most species appeared similar in this study to samples collected in 1987 and 1990, prior to the establishment of zebra mussels (Table 4).

Zebra Mussels

Infestation of unionids by zebra mussels was rare throughout most of the study area (Table 2). Zebra mussels were observed infesting unionids at only 35.9% of the sites where live unionids were collected. Overall frequency of unionids infested by at least one zebra mussel was 9.1%, with an average of 0.4 ± 1.8 SD zebra mussels/unionid. Frequency of zebra mussel infestation was 30.0% (average zebra mussels/unionid = 1.2 ± 3.4 SD; range = 0 to 33) in the unionid sanctuary compared to 1.3% (average zebra mus-

sels/unionid = 0.02 ± 0.2 SD; range = 0 to 7) in the remainder of the study area, and 89.6% of all zebra mussel infested unionids were from the sanctuary.

DISCUSSION

Our estimate of species richness at the Lost Mound Unit is similar to other recent upper Mississippi River studies which rarely find >30 extant species within a given river reach (Havlik and Stansberry 1978, Theil 1981, Havlik 1983, Miller 1988, Holland-Bartels 1990, Hornbach et al.1992, Hart et al. 2002). The presence of 11 species that were found only as weathered shells or museum specimens suggest that up to 30% of the historic unionid community might have been lost from this river reach, although it is unlikely that we found all extant species in the area. Several of these species are currently rare in the upper Mississippi River (Havlik and Sauer 2000), some of which were apparently historically rare as well (e.g., *Elliptio crassidens*, *Lasmigona costata*, and *Plethobasus cyphyus*) (van der Schalie and van der Schalie 1950). The decline in unionid species richness from this river reach almost certainly occurred prior to the arrival of zebra mussels, and is likely attributable to the degradation of natural riverine habitat (Scarpino 1985, Afinson 2003).

Species richness and relative abundance of unionids in the sanctuary appeared similar in this study compared to samples collected in 1987 and 1990, prior to the establishment of zebra mussels (Table 4), and any variation in relative abundance of species among years could be due to site selection and sampling methods (E. Cawley, Loras College, Dubuque, Iowa, pers. comm.). Cawley (1990) found the unionid community below Lock and Dam 12 to be as diverse as within the sanctuary above the dam, with mostly young (<50mm in length) *Lampsilis higginsii* occurring at a relative abundance of 3.3%. This is well above the 0.25% relative abundance criteria used to establish areas of essential habitat for this species (U. S. Fish and Wildlife Service 2004). Cawley (1990) correctly suggested this area be included within the unionid sanctuary. We also found *L. higginsii* to be relatively abundant on the Iowa side of the river at Sites 23 (1.7%) and 26 (2.6%) adjacent to channel border islands along Harrington Slough, and at Site 39 (1.9%) at the head of Bowman Island, all of which were areas with relatively high unionid species richness. These areas should also be considered as essential *L. higginsii* habitat.

Zebra mussels were not abundant in this river reach during our study. The low number of zebra mussels might be related to an extensive zebra mussel die-off that occurred in other reaches of the upper Mississippi River during late summer 2001 (see news article by Nissen 2003), or it might be characteristic of their overall abundance in this area. By comparison, in 1995 Cope et al. (1997) found the density of zebra mussels averaged 8,000/m^2 on colonization samplers at Lock and Dam 12, the second highest density among 18 lock and dam sites sampled in the upper Mississippi River. Abundance of zebra mussel larvae at Lock and Dam 12 was also found to be among the highest in the upper Mississippi River in summer 1998 and 1999 (Stoeckel et al. 2004). This corresponds to Ecological Specialists, Inc., (O'Fallon, Missouri, unpubl. data) finding in 2000 that zebra mussels infested >99% of unionids sampled, encrusting 41% of unionid shells on average, in the reach just below the dam. We noted patches of zebra mussel byssal threads on the shells of live unionids at several sites, as well as areas where unionids were generally free of byssal threads, suggesting zebra mussel infestation was previously variable in the study

area. We are uncertain as to why zebra mussel infestation was relatively higher above the dam in the unionid sanctuary during our study.

At the time of this study, not more than a decade had passed since zebra mussels became established throughout much of the upper Mississippi River (Tucker et al. 1993). Unionids are surviving in most of the Lost Mound Unit, and there is no compelling evidence that zebra mussels have affected species richness, but the long-term affects of zebra mussels on unionids in this river reach and the upper Mississippi River are unknown. Some localized areas, however, appear to have been heavily affected by zebra mussels, such as the unionid bed that was known to occur along the Illinois bank below Crooked Slough (Sites 59, 60, 63, 64, and 65) (J. Nickols, Savanna, Illinois, pers. comm.). Few live unionids were collected in this area, and dead zebra mussel shells made up an estimated 50% of the substrate, an indication their density was previously high. We also found numerous freshly dead unionid shells with dried tissue, as well as zebra mussel shells, washed up on the bank in a windrow at Site 59.

The predominantly sand environment in this river reach might benefit unionids. They are known to burrow into the substrate in fall and re-emerge in spring (Amyot and Downing 1997, Watters et al. 2001), and this activity can smother or detach zebra mussels from unionids inhabiting soft substrates (Nichols and Wilcox 1997). Additionally, sand is a less suitable substrate for the colonization of large zebra mussel populations (Mellina and Rasmussen 1994, Toczylowski et al. 1999) (although see Berkman et al. 2000 for lake populations), and in such habitat, unionids are the primary sites for settling zebra mussels (Hunter and Bailey 1992, Toczylowski et al. 1999), as opposed to areas with gravel and cobble where zebra mussels accumulate on the substrate as well as on unionids. Therefore, fish (Tucker et al. 1996, Mitchell et al. 2000, Magoulick and Lewis 2002) or other predators (Hamilton et al. 1994, Perry et al. 1997, Mitchell et al. 2000) might be removing zebra mussels from unionids. Also, unionids heavily infested with zebra mussels are not able to burrow as well in mixed gravel substrates (Tucker 1994, Nichols and Wilcox 1997) so the attached zebra mussels survive. The reach below Crooked Slough might illustrate these points. Substrate below Crooked Slough had a relatively large component of gravel and cobble (up to 90% in some areas), which might explain why zebra mussels were apparently so damaging to unionids in this area. To identify conditions in which unionids can coexist with zebra mussels long term, we must have a better understanding of the population dynamics of zebra mussels in large rivers and of their interactions with unionids.

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Figure 1. Sampling sites and unionid catch per unit effort (CPUE) in the Mississippi River at the Lost Mount Unit of the Upper Mississippi River National Wildlife and Fish Refuge, Illinois and Iowa.

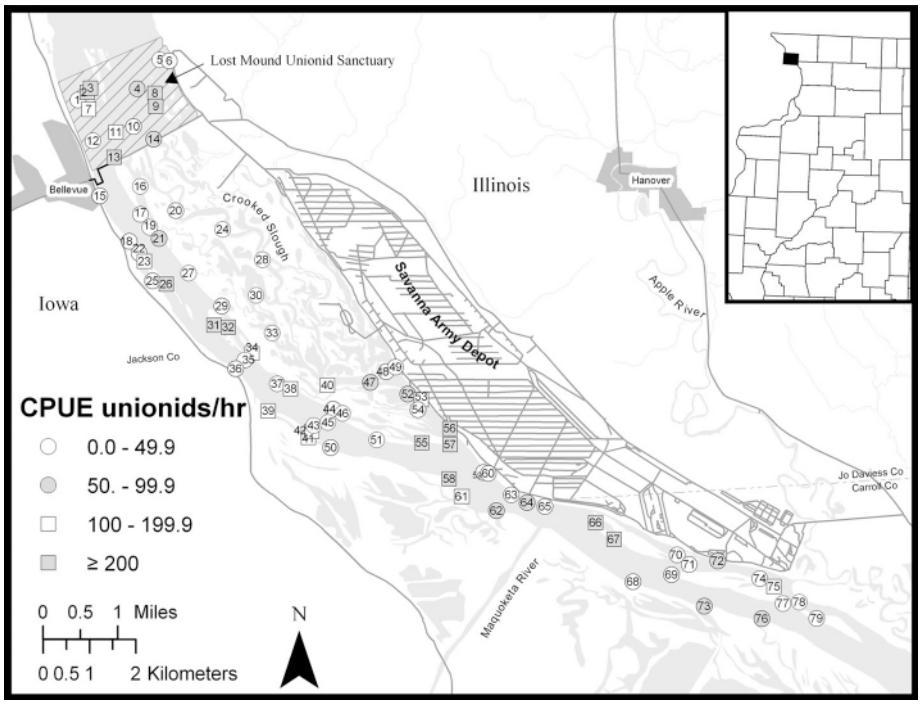

Table 1. Species composition and relative abundance of unionids in the Mississippi River at the Lost Mound Unit of the Upper Mississippi River National Wildlife and Fish Refuge, Illinois and Iowa.

Species	Museum[1]	No. live	% Relative abundance	% Frequency (live only)	% Frequency (live + dead)	Protection status[2]
Subfamily Ambleminae						
Amblema plicata	x	856	35.08	64.6	73.4	
Cyclonaias tuberculata		w[3]	0.00	0.0	5.1	ILT, IAT
Elliptio crassidens	x	-----	-----	-----	-----	ILT
Elliptio dilatata	x	w	0.00	0.0	5.1	ILT
Fusconaia ebena	x	w	0.00	0.0	10.1	ILT
Fusconaia flava	x	224	9.18	39.2	51.9	
Megalonaias nervosa	x	32	1.31	15.2	22.8	
Plethobasus cyphyus	x	w	0.00	0.0	1.3	ILE, IAE
Pleurobema sintoxia		1	0.04	1.3	5.1	IAE
Quadrula metanevra	x	20	0.82	6.3	11.4	
Quadrula nodulata	x	23	0.94	15.2	25.3	
Quadrula pustulosa	x	52	2.13	24.1	30.4	
Quadrula quadrula	x	159	6.52	44.3	54.4	
Tritogonia verrucosa	x	w	0.00	0.0	3.8	IAE
Subfamily Anodontinae						
Alasmidonta marginata	x	-----	-----	-----	-----	
Anodonta suborbiculata		2	0.08	2.5	2.5	
Arcidens confragosus	x	8	0.33	8.9	16.5	
Lasmigona complanata	x	20	0.82	19.0	25.3	
Lasmigona costata		w	0.00	0.0	1.3	
Pyganodon grandis	x	147	6.02	41.8	55.7	
Strophitus undulatus	x	1	0.04	1.3	3.8	IAT
Utterbackia imbecillis		7	0.29	3.8	10.1	
Subfamily Lampsilinae						
Actinonaias ligamentina	x	w	0.00	0.0	5.1	
Ellipsaria lineolata	x	9	0.37	3.8	8.9	ILT, IAT
Lampsilis cardium	x	149	6.11	41.8	51.9	
Lampsilis higginsii	x	6	0.25	5.1	5.1	FE, ILE, IAE
Lampsilis siliquoidea	x	-----	-----	-----	-----	
Lampsilis teres	x	w	0.00	0.0	3.8	IAE
Leptodea fragilis	x	29	1.19	19.0	49.4	
Ligumia recta	x	11	0.45	11.4	16.5	ILT
Obliquaria reflexa	x	436	17.87	51.9	59.5	
Obovaria olivaria	x	146	5.98	38.0	45.6	
Potamilus alatus	x	3	0.12	3.8	21.5	
Potamilus ohiensis	x	16	0.66	12.7	27.8	
Toxolasma parvus	x	17	0.70	8.9	17.7	
Truncilla donaciformis	x	24	0.98	13.9	19.0	
Truncilla truncata	x	42	1.72	20.3	30.4	
Total live unionids		2,440				
Total live species		26		81.0		
Total species (live + dead)	32	34			88.6	
CPUE (unionids/hour)		119.7				
Effort (minutes)		1,223				

[1] Illinois Natural History Survey Mollusk Collection, and K. S. Cummings and C. A. Mayer, pers. comm.
[2] FE = federally endangered, ILE = Illinois endangered, ILT = Illinois threatened, IAE = Iowa endangered, IAT = Iowa threatened.
[3] w = weathered dead,

Table 2. Species composition and abundance[1] of unionids at sample sites[2] in the Mississippi River at the Lost Mound Unit of the Upper Mississippi River National Wildlife and Fish Refuge, Illinois and Iowa.

	Site[3]						
Species	1	2	3	4	6	7	8
Subfamily Ambleminae							
Amblema plicata		50	74	13	1	12	23
Fusconaia flava		22	12	1		7	
Megalonaias nervosa		1	1	3	2		1
Pleurobema sintoxia							
Quadrula metanevra							
Quadrula nodulata							2
Quadrula pustulosa		4				1	
Quadrula quadrula		6	11	7		8	2
Subfamily Anodontinae							
Anodonta suborbiculata							
Arcidens confragosus				2	1		
Lasmigona complanata			2				
Pyganodon grandis			1	3	1		2
Strophitus undulatus							
Utterbackia imbecillis			4			1	
Subfamily Lampsilinae							
Ellipsaria lineolata							
Lampsilis cardium	1	6	2			2	
Lampsilis higginsii		1					
Leptodea fragilis		1	3			1	1
Ligumia recta							
Obliquaria reflexa		16	3	17		8	29
Obovaria olivaria	2	5	1			1	
Potamilus alatus							
Potamilus ohiensis				2		2	
Toxolasma parvus							
Truncilla donaciformis			2				
Truncilla truncata			1	2			1
Total no. live unionids	3	112	117	50	5	43	61
No. live unionid species	2	10	13	9	4	10	8
CPUE (unionids/hour)	22.5	268.8	351.0	100.0	30.0	129.0	244.0
ZM[4] per unionid (mean ± SD)	0	0.23±0.70	0.44±1.03	0.76±1.41	0	0.77±1.32	0.10±0.31
Total no. ZM	0	25	52	38	0	33	6
Frequency ZM infestation (%)	0	12.5	23.9	40.0	0	39.5	9.8
Sample effort (minutes)	8	25	20	30	10	20	15
UTM easting	217474	217683	217760	218764	219498	217691	219140
UTM northing	4685905	4686056	4686139	4686052	4686606	4685688	4685933

[1] Data are numbers of live individuals.

[2] Only sample sites with at least one live unionid are included. No live unionids were collected at the following UTM coordinates: 219438 E 4686597 N, 218684 E 4683955 N, 218366 E 4682790 N, 218826 E 4683061 N, 220392 E 4682904 N, 219591 E 4682019 N, 221203 E 4682195 N, 221009 E 4681438 N, 221299 E 4680607 N, 222055 E 4678542 N, 222361 E 4678585 N, 222691 E 4678760 N, 223387 E 4678138 N, 226894 E 4676453 N, 232225 E 4674013 N

[3] Sites 1 to 14 are inside the unionid sanctuary.

[4] ZM = zebra mussels

Table 2. continued

Species	Site[3] 9	10	11	12	13	14	15
Subfamily Ambleminae							
Amblema plicata	53	2	2		4	9	2
Fusconaia flava	2		1		1		
Megalonaias nervosa	2	2	4		12		
Pleurobema sintoxia							
Quadrula metanevra							
Quadrula nodulata	1				1		
Quadrula pustulosa					1		
Quadrula quadrula	2	2	13		30	6	
Subfamily Anodontinae							
Anodonta suborbiculata							
Arcidens confragosus					1		
Lasmigona complanata							
Pyganodon grandis	1	2	1			3	
Strophitus undulatus							
Utterbackia imbecillis					2		
Subfamily Lampsilinae							
Ellipsaria lineolata							
Lampsilis cardium				1			
Lampsilis higginsii							
Leptodea fragilis			4		6		
Ligumia recta							2
Obliquaria reflexa	65	2	5		7	4	
Obovaria olivaria				1	2		
Potamilus alatus					1		
Potamilus ohiensis			2				
Toxolasma parvus	1						
Truncilla donaciformis	5						
Truncilla truncata	5				2		
Total no. live unionids	137	10	32	2	70	22	4
No. live unionid species	10	5	8	2	13	4	2
CPUE (unionids/hour)	274.0	40.0	128.0	15.0	233.3	66.0	16.0
ZM[4] per unionid (mean ± SD)	0.19±0.58	1.60±2.76	7.91±7.75	0.50±0.71	4.54±5.83	2.27±3.48	0
Total no. ZM	26	16	253	1	318	50	0
Frequency ZM infestation (%)	12.4	30.0	78.1	50.0	78.6	54.5	0
Sample effort (minutes)	30	15	15	8	18	20	15
UTM easting	219137	218627	218239	217732	218162	219042	217797
UTM northing	4685649	4685250	4685156	4685008	4684621	4684949	4683813

[1] Data are numbers of live individuals.

[2] Only sample sites with at least one live unionid are included. No live unionids were collected at the following UTM coordinates: 219438 E 4686597 N, 218684 E 4683955 N, 218366 E 4682790 N, 218826 E 4683061 N, 220392 E 4682904 N, 219591 E 4682019 N, 221203 E 4682195 N, 221009 E 4681438 N, 221299 E 4680607 N, 222055 E 4678542 N, 222361 E 4678585 N, 222691 E 4678760 N, 223387 E 4678138 N, 226894 E 4676453 N, 232225 E 4674013 N

[3] Sites 1 to 14 are inside the unionid sanctuary.

[4] ZM = zebra mussels

Table 2. continued

Species	Site[3] 17	20	21	22	23	25	26
Subfamily Ambleminae							
Amblema plicata	1		3	4	3	4	38
Fusconaia flava					1	3	15
Megalonaias nervosa							
Pleurobema sintoxia							
Quadrula metanevra					7	1	1
Quadrula nodulata							2
Quadrula pustulosa					4		9
Quadrula quadrula			1	2		1	1
Subfamily Anodontinae							
Anodonta suborbiculata							
Arcidens confragosus							1
Lasmigona complanata					1	2	1
Pyganodon grandis		1	2				2
Strophitus undulatus							
Utterbackia imbecillis							
Subfamily Lampsilinae							
Ellipsaria lineolata					2		
Lampsilis cardium				1	4	2	10
Lampsilis higginsii					1		3
Leptodea fragilis							
Ligumia recta					1	1	1
Obliquaria reflexa			7	8	10		13
Obovaria olivaria	2		1		22	2	10
Potamilus alatus					1		
Potamilus ohiensis							
Toxolasma parvus							
Truncilla donaciformis							1
Truncilla truncata					1		7
Total no. live unionids	3	1	14	15	58	16	115
No. live unionid species	2	1	5	4	13	8	16
CPUE (unionids/hour)	15.0	12.0	84.0	45.0	139.2	48.0	345.0
ZM[4] per unionid (mean ± SD)	0.33±0.58	0	0	0	0.10±0.36	0	0.02±0.13
Total no. ZM	1	0	0	0	6	0	2
Frequency ZM infestation (%)	33.3	0	0	0	8.6	0	1.7
Sample effort (minutes)	12	5	10	20	25	20	20
UTM easting	218647	219408	219006	218557	218660	218801	219095
UTM northing	4683357	4683383	4682805	4682524	4682338	4681908	4681815

[1] Data are numbers of live individuals.

[2] Only sample sites with at least one live unionid are included. No live unionids were collected at the following UTM coordinates: 219438 E 4686597 N, 218684 E 4683955 N, 218366 E 4682790 N, 218826 E 4683061 N, 220392 E 4682904 N, 219591 E 4682019 N, 221203 E 4682195 N, 221009 E 4681438 N, 221299 E 4680607 N, 222055 E 4678542 N, 222361 E 4678585 N, 222691 E 4678760 N, 223387 E 4678138 N, 226894 E 4676453 N, 232225 E 4674013 N

[3] Sites 1 to 14 are inside the unionid sanctuary.

[4] ZM = zebra mussels

Table 2. continued

	Site[3]						
Species	29	31	32	34	35	36	37
Subfamily Ambleminae							
Amblema plicata		11	29	6			
Fusconaia flava	5	5	18	3			
Megalonaias nervosa							
Pleurobema sintoxia							
Quadrula metanevra							
Quadrula nodulata	3		1				
Quadrula pustulosa		1	2				
Quadrula quadrula		9	3	2			
Subfamily Anodontinae							
Anodonta suborbiculata							
Arcidens confragosus		1					
Lasmigona complanata			1	2			
Pyganodon grandis			2	5			
Strophitus undulatus							
Utterbackia imbecillis							
Subfamily Lampsilinae							
Ellipsaria lineolata		2					
Lampsilis cardium		1	11	2			2
Lampsilis higginsii							
Leptodea fragilis			1	1			
Ligumia recta						1	
Obliquaria reflexa	2	26	13	8	1		
Obovaria olivaria		14					
Potamilus alatus							
Potamilus ohiensis				1			
Toxolasma parvus		1					
Truncilla donaciformis			4	1			
Truncilla truncata		10		3			
Total no. live unionids	10	81	85	34	1	1	2
No. live unionid species	3	11	11	11	1	1	1
CPUE (unionids/hour)	30.0	243.0	255.0	102.0	12.0	4.0	24.0
ZM[4] per unionid (mean ± SD)	0	0	0.02±0.15	0	0	0	0
Total no. ZM	0	0	2	0	0	0	0
Frequency ZM infestation (%)	0	0	2.4	0	0	0	0
Sample effort (minutes)	20	20	20	20	5	15	5
UTM easting	220255	220056	220361	220832	220672	220459	221330
UTM northing	4681232	4680864	4680795	4680190	4680054	4679879	4679492

[1] Data are numbers of live individuals.

[2] Only sample sites with at least one live unionid are included. No live unionids were collected at the following UTM coordinates: 219438 E 4686597 N, 218684 E 4683955 N, 218366 E 4682790 N, 218826 E 4683061 N, 220392 E 4682904 N, 219591 E 4682019 N, 221203 E 4682195 N, 221009 E 4681438 N, 221299 E 4680607 N, 222055 E 4678542 N, 222361 E 4678585 N, 222691 E 4678760 N, 223387 E 4678138 N, 226894 E 4676453 N, 232225 E 4674013 N

[3] Sites 1 to 14 are inside the unionid sanctuary.

[4] ZM = zebra mussels

Table 2. continued

	Site[3]						
Species	38	39	40	41	42	44	47
Subfamily Ambleminae							
Amblema plicata	14	6	18	14	12	2	21
Fusconaia flava		2	4	5	1	2	
Megalonaias nervosa	2	1					
Pleurobema sintoxia		1					
Quadrula metanevra		8		3			
Quadrula nodulata			1			1	
Quadrula pustulosa		1	2	1	4		
Quadrula quadrula	1	2	13	2		1	
Subfamily Anodontinae							
Anodonta suborbiculata							
Arcidens confragosus							
Lasmigona complanata		1	1				
Pyganodon grandis	15		14				13
Strophitus undulatus							
Utterbackia imbecillis							
Subfamily Lampsilinae							
Ellipsaria lineolata		5					
Lampsilis cardium		5	3	2	14	2	
Lampsilis higginsii		1					
Leptodea fragilis	1		2				
Ligumia recta		1					
Obliquaria reflexa	2	11	9	1	10	1	9
Obovaria olivaria		6	3	7	7		
Potamilus alatus							
Potamilus ohiensis	1		1				
Toxolasma parvus			8				1
Truncilla donaciformis							1
Truncilla truncata						2	
Total no. live unionids	36	51	79	35	48	11	45
No. live unionid species	7	14	13	8	6	7	5
CPUE (unionids/hour)	144.0	153.0	118.5	123.5	144.0	33.0	90.0
ZM[4] per unionid (mean ± SD)	0.11±0.46	0	0	0	0	0	0.02±0.15
Total no. ZM	4	0	0	0	0	0	1
Frequency ZM infestation (%)	5.6	0	0	0	0	0	2.2
Sample effort (minutes)	15	20	40	17	20	20	30
UTM easting	221608	221094	222411	221920	222003	222492	223339
UTM northing	4679365	4678928	4679384	4678293	4678420	4678861	4679381

[1] Data are numbers of live individuals.

[2] Only sample sites with at least one live unionid are included. No live unionids were collected at the following UTM coordinates: 219438 E 4686597 N, 218684 E 4683955 N, 218366 E 4682790 N, 218826 E 4683061 N, 220392 E 4682904 N, 219591 E 4682019 N, 221203 E 4682195 N, 221009 E 4681438 N, 221299 E 4680607 N, 222055 E 4678542 N, 222361 E 4678585 N, 222691 E 4678760 N, 223387 E 4678138 N, 226894 E 4676453 N, 232225 E 4674013 N

[3] Sites 1 to 14 are inside the unionid sanctuary.

[4] ZM = zebra mussels

Table 2. continued

	Site[3]						
Species	48	49	50	52	53	54	55
Subfamily Ambleminae							
Amblema plicata	2		1	23	26	4	36
Fusconaia flava			1	1	3		25
Megalonaias nervosa							
Pleurobema sintoxia							
Quadrula metanevra							
Quadrula nodulata							3
Quadrula pustulosa			1				
Quadrula quadrula			1	1	2		7
Subfamily Anodontinae							
Anodonta suborbiculata				1			
Arcidens confragosus							
Lasmigona complanata							2
Pyganodon grandis	5			15	13	8	3
Strophitus undulatus							1
Utterbackia imbecillis							
Subfamily Lampsilinae							
Ellipsaria lineolata							
Lampsilis cardium							5
Lampsilis higginsii							
Leptodea fragilis		1					
Ligumia recta							
Obliquaria reflexa			1	3			13
Obovaria olivaria			1				2
Potamilus alatus							
Potamilus ohiensis	1						
Toxolasma parvus						3	1
Truncilla donaciformis							1
Truncilla truncata			1		1		1
Total no. live unionids	8	1	6	44	45	15	100
No. live unionid species	3	1	6	6	5	3	13
CPUE (unionids/hour)	24.0	6.0	36.0	88.0	135.0	45.0	300.0
ZM[4] per unionid (mean ± SD)	0	0	0	0	0.04±0.30	0	0.01±0.10
Total no. ZM	0	0	0	0	2	0	1
Frequency ZM infestation (%)	0	0	0	0	2.2	0	1.0
Sample effort (minutes)	20	10	10	30	20	20	20
223693	223693	223904	222384	224128	224408	224324	224353
UTM northing	4679585	4679673	4678043	4679076	4678936	4678723	4678007

[1] Data are numbers of live individuals.

[2] Only sample sites with at least one live unionid are included. No live unionids were collected at the following UTM coordinates: 219438 E 4686597 N, 218684 E 4683955 N, 218366 E 4682790 N, 218826 E 4683061 N, 220392 E 4682904 N, 219591 E 4682019 N, 221203 E 4682195 N, 221009 E 4681438 N, 221299 E 4680607 N, 222055 E 4678542 N, 222361 E 4678585 N, 222691 E 4678760 N, 223387 E 4678138 N, 226894 E 4676453 N, 232225 E 4674013 N

[3] Sites 1 to 14 are inside the unionid sanctuary.

[4] ZM = zebra mussels

Table 2. continued

	Site[3]						
Species	56	57	58	59	60	61	62
Subfamily Ambleminae							
Amblema plicata	106	10	33	1	2	8	16
Fusconaia flava	14	6	12			5	3
Megalonaias nervosa	1						
Pleurobema sintoxia							
Quadrula metanevra							
Quadrula nodulata							
Quadrula pustulosa			2				1
Quadrula quadrula	1		2				2
Subfamily Anodontinae							
Anodonta suborbiculata		1					
Arcidens confragosus	1	1					
Lasmigona complanata	1		2			1	1
Pyganodon grandis	4	13	6			1	1
Strophitus undulatus							
Utterbackia imbecillis							
Subfamily Lampsilinae							
Ellipsaria lineolata							
Lampsilis cardium	1	5	9		3		
Lampsilis higginsii							
Leptodea fragilis							
Ligumia recta							
Obliquaria reflexa	4	33	13			2	3
Obovaria olivaria			4			1	
Potamilus alatus							
Potamilus ohiensis		1					
Toxolasma parvus		2					
Truncilla donaciformis	1	6					
Truncilla truncata			1				
Total no. live unionids	134	78	84	1	5	18	27
No. live unionid species	10	10	10	1	2	6	7
CPUE (unionids/hour)	402.0	234.0	252.0	2.3	15.0	108.0	64.8
ZM[4] per unionid (mean ± SD)	0.03±0.17	0.01±0.11	0	0	0	0	0
Total no. ZM	4	1	0	0	0	0	0
Frequency ZM infestation (%)	3.0	1.3	0	0	0	0	0
Sample effort (minutes)	20	20	20	26	20	10	25
UTM easting	224978	224961	224886	225624	225725	225128	225845
UTM northing	4678273	4677927	4677193	4677277	4677247	4676792	4676436

[1] Data are numbers of live individuals.

[2] Only sample sites with at least one live unionid are included. No live unionids were collected at the following UTM coordinates: 219438 E 4686597 N, 218684 E 4683955 N, 218366 E 4682790 N, 218826 E 4683061 N, 220392 E 4682904 N, 219591 E 4682019 N, 221203 E 4682195 N, 221009 E 4681438 N, 221299 E 4680607 N, 222055 E 4678542 N, 222361 E 4678585 N, 222691 E 4678760 N, 223387 E 4678138 N, 226894 E 4676453 N, 232225 E 4674013 N

[3] Sites 1 to 14 are inside the unionid sanctuary.

[4] ZM = zebra mussels

Table 2. continued

	Site[3]						
Species	63	64	66	67	68	69	70
Subfamily Ambleminae							
Amblema plicata		6	46	68		1	2
Fusconaia flava			14	21			
Megalonaias nervosa							
Pleurobema sintoxia							
Quadrula metanevra							
Quadrula nodulata			4	3			
Quadrula pustulosa			7	7		1	
Quadrula quadrula		2	7	4		1	
Subfamily Anodontinae							
Anodonta suborbiculata							
Arcidens confragosus							
Lasmigona complanata				1			
Pyganodon grandis		1	1	4			
Strophitus undulatus							
Utterbackia imbecillis							
Subfamily Lampsilinae							
Ellipsaria lineolata							
Lampsilis cardium		7	8	16		1	
Lampsilis higginsii							
Leptodea fragilis		1					
Ligumia recta						1	
Obliquaria reflexa			35	18			1
Obovaria olivaria	1		24	3		5	
Potamilus alatus				1			
Potamilus ohiensis			4				
Toxolasma parvus							
Truncilla donaciformis					1		
Truncilla truncata			1	1			
Total no. live unionids	1	17	151	147	1	10	3
No. live unionid species	1	5	11	12	1	6	2
CPUE (unionids/hour)	6.0	51.0	348.5	352.8	6.0	40.0	25.7
ZM[4] per unionid (mean ± SD)	0	0	0	0.01±0.08	0	0	0
Total no. ZM	0	0	0	1	0	0	0
Frequency ZM infestation (%)	0	0	0	0.7	0	0	0
Sample effort (minutes)	10	20	26	25	10	15	7
UTM easting	226187	226517	227960	228330	228677	229515	229666
UTM northing	4676756	4676563	4676028	4675640	4674703	4674796	4675212

[1] Data are numbers of live individuals.

[2] Only sample sites with at least one live unionid are included. No live unionids were collected at the following UTM coordinates: 219438 E 4686597 N, 218684 E 4683955 N, 218366 E 4682790 N, 218826 E 4683061 N, 220392 E 4682904 N, 219591 E 4682019 N, 221203 E 4682195 N, 221009 E 4681438 N, 221299 E 4680607 N, 222055 E 4678542 N, 222361 E 4678585 N, 222691 E 4678760 N, 223387 E 4678138 N, 226894 E 4676453 N, 232225 E 4674013 N

[3] Sites 1 to 14 are inside the unionid sanctuary.

[4] ZM = zebra mussels

Table 2. continued

Species	Site[3] 71	72	73	74	75	76	77	79
Subfamily Ambleminae								
Amblema plicata	1	15	1		12	5		
Fusconaia flava		9						
Megalonaias nervosa								
Pleurobema sintoxia								
Quadrula metanevra								
Quadrula nodulata						1		
Quadrula pustulosa					2	1		
Quadrula quadrula		1	3					
Subfamily Anodontinae								
Anodonta suborbiculata								
Arcidens confragosus								
Lasmigona complanata					1			
Pyganodon grandis		1			1		1	1
Strophitus undulatus								
Utterbackia imbecillis								
Subfamily Lampsilinae								
Ellipsaria lineolata								
Lampsilis cardium	1	2	3	1	11	5		
Lampsilis higginsii								
Leptodea fragilis			2		1	3		
Ligumia recta			2					1
Obliquaria reflexa		1	7			14		1
Obovaria olivaria	2	3	1	2	5	6		
Potamilus alatus								
Potamilus ohiensis				1				
Toxolasma parvus								
Truncilla donaciformis					1			
Truncilla truncata						3		
Total no. live unionids	4	32	19	4	34	38	1	3
No. live unionid species	3	7	7	3	8	8	1	3
CPUE (unionids/hour)	48.0	96.0	51.8	24.0	102.0	99.1	12.0	18.0
ZM[4] per unionid (mean ± SD)	0	0.29±1.30	0	0	0	0	0	0
Total no. ZM	0	9	0	0	0	0	0	0
Frequency ZM infestation (%)	0	6.3	0	0	0	0	0	0
Sample effort (minutes)	5	20	22	10	20	23	5	10
UTM easting	229911	230534	230174	231411	231704	231395	231873	232573
UTM northing	4674987	4675022	4674070	4674574	4674384	4673715	4674006	4673634

[1] Data are numbers of live individuals.

[2] Only sample sites with at least one live unionid are included. No live unionids were collected at the following UTM coordinates: 219438 E 4686597 N, 218684 E 4683955 N, 218366 E 4682790 N, 218826 E 4683061 N, 220392 E 4682904 N, 219591 E 4682019 N, 221203 E 4682195 N, 221009 E 4681438 N, 221299 E 4680607 N, 222055 E 4678542 N, 222361 E 4678585 N, 222691 E 4678760 N, 223387 E 4678138 N, 226894 E 4676453 N, 232225 E 4674013 N

[3] Sites 1 to 14 are inside the unionid sanctuary.

[4] ZM = zebra mussels

Table 3. Length frequency (%) distributions for unionids collected from the Mississippi River at the Lost Mound Unit of the Upper Mississippi River National Wildlife and Fish Refuge, Illinois and Iowa.

	Length category (mm)																					
Species	1-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-110	111-120	121-130	131-140	141-150	151-160	161-170	171-180	(n)	Avg.	Min.	Max.
Subfamily Ambleminae																						
Amblema plicata	----	0.8	7.1	12.3	12.9	14.1	16.6	16.6	12.1	5.3	2.0	0.1	----	----	----	----	----	----	758	61.3	18	111
Fusconaia flava	----	2.2	21.9	29.5	14.7	22.3	7.6	1.8	----	----	----	----	----	----	----	----	----	----	224	42.0	11	79
Megalonaias nervosa	----	----	----	3.1	3.1	----	----	----	----	3.1	3.1	12.5	21.9	34.4	12.5	6.3	----	----	32	125.3	38	158
Pleurobema sintoxia	----	----	----	----	100	----	----	----	----	----	----	----	----	----	----	----	----	----	1	50.0	50	50
Quadrula metanevra	----	----	5.0	40.0	5.0	35.0	15.0	----	----	----	----	----	----	----	----	----	----	----	20	47.2	24	66
Quadrula nodulata	----	----	8.7	39.1	34.8	17.4	----	----	----	----	----	----	----	----	----	----	----	----	23	40.6	22	59
Quadrula pustulosa	----	5.8	21.2	19.2	26.9	21.2	3.8	1.9	----	----	----	----	----	----	----	----	----	----	52	41.4	14	73
Quadrula quadrula	----	0.6	3.8	6.9	15.7	36.5	17.6	13.8	5.0	----	----	----	----	----	----	----	----	----	159	56.9	15	88
Subfamily Anodontinae																						
Anodonta suborbiculata	----	----	----	----	----	----	----	----	----	----	50.0	----	50.0	----	----	----	----	----	2	117.0	108	126
Arcidens confragosus	----	----	----	----	12.5	----	12.5	25.0	----	25.0	----	25.0	----	----	----	----	----	----	8	85.3	44	118
Lasmigona complanata	----	----	----	----	----	----	----	----	----	----	----	25.0	15.0	15.0	35.0	5.0	----	5.0	20	134.5	111	176
Pyganodon grandis	----	----	----	----	----	0.7	----	----	----	3.4	2.7	14.3	21.1	23.1	26.5	7.5	0.7	----	147	132.5	59	162
Strophitus undulatus	----	----	----	----	----	----	----	----	----	----	100	----	----	----	----	----	----	----	1	109.0	109	109
Utterbackia imbecillis	----	----	71.4	28.6	----	----	----	----	----	----	----	----	----	----	----	----	----	----	7	29.0	23	35
Subfamily Lampsilinae																						
Ellipsaria lineolata	----	----	----	----	33.3	22.2	11.1	22.2	11.1	----	----	----	----	----	----	----	----	----	9	58.8	43	84
Lampsilis cardium	----	----	----	1.3	----	2.0	0.7	4.7	10.1	22.1	32.2	23.5	3.4	----	----	----	----	----	149	100.3	32	125
Lampsilis higginsii	----	----	----	----	33.3	----	16.7	16.7	33.3	----	----	----	----	----	----	----	----	----	6	67.2	43	89
Leptodea fragilis	----	----	13.8	3.4	3.4	13.8	24.1	6.9	13.8	6.9	10.3	----	3.4	----	----	----	----	----	29	69.3	22	121
Ligumia recta	----	----	----	----	----	----	----	----	9.1	18.2	9.1	27.3	----	27.3	9.1	----	----	----	11	116.4	84	148
Obliquaria reflexa	----	1.0	16.6	52.1	28.4	1.7	----	0.2	----	----	----	----	----	----	----	----	----	----	409	37.0	18	75
Obovaria olivaria	----	----	14.4	24.7	32.9	21.2	6.2	0.7	----	----	----	----	----	----	----	----	----	----	146	44.0	24	72
Potamilus alatus	----	----	----	----	----	----	----	----	----	33.3	33.3	33.3	----	----	----	----	----	----	3	105.7	91	118
Potamilus ohiensis	----	----	6.3	6.3	----	6.3	31.3	12.5	18.8	12.5	6.3	----	----	----	----	----	----	----	16	70.8	23	110
Toxolasma parvus	11.8	17.6	70.6	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	17	21.9	6	30
Truncilla donaciformis	4.2	41.7	54.2	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	24	20.6	10	30
Truncilla truncata	2.4	7.1	50.0	35.7	4.8	----	----	----	----	----	----	----	----	----	----	----	----	----	42	28.4	9	42

Table 4. Species composition and relative abundance (%) of unionids in the Upper Mississippi River Pool 12 unionid sanctuary.

Species	This study	1990[1]	1987
Subfamily Ambleminae			
Amblema plicata	36.6	36.1	21.1
Elliptio dilatata			0.4
Fusconaia flava	7.2	5.7	6.7
Megalonaias nervosa	4.4	6.5	2.5
Quadrula metanevra		2.5	
Quadrula nodulata	0.6	5.5	
Quadrula pustulosa	0.9	1.9	8.4
Quadrula quadrula	12.7	20.9	7.7
Subfamily Anodontinae			
Arcidens confragosus	0.6	1.1	
Lasmigona complanata	0.3		
Pyganodon grandis	1.7	4.1	
Strophitus undulatus			1.1
Utterbackia imbecillis	1.1	0.5	14.4
Subfamily Lampsilinae			
Ellipsaria lineolata			1.4
Lampsilis cardium	1.7	0.8	1.1
Lampsilis higginsii	0.2	0.3	1.1
Lampsilis teres			
Leptodea fragilis	2.5	0.5	12.3
Ligumia recta			3.5
Obliquaria reflexa	23.8	3.6	3.9
Obovaria olivaria	1.6	0.7	5.3
Potamilus alatus	0.2	4.3	2.5
Potamilus ohiensis	0.9	0.5	
Toxolasma parvus	0.2		
Truncilla donaciformis	1.1	0.6	1.4
Truncilla truncata	1.7	4.6	5.6
No. live individuals	639	635	285
No. live species	20	19	18

[1] 1987 and 1990 data are from E. Cawley, Loras College, Dubuque, Iowa (unpubl. data)