Summary of Zebra Mussel Monitoring Efforts For the Upper Mississippi River 2001 through 2003

"WORKING DRAFT"

Elliott Stefanik
U. S. Army Corps of Engineers
St. Paul District

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INTRODUCTION

The zebra mussel (*Dreissena polymorpha*) has been the subject of intense study since it's discovery in the Great Lakes in the late 1980s, and the Illinois and Upper Mississippi rivers in the early 1990s. Zebra mussels impact aquatic ecosystems in a variety of ways, including decimating native mussel fauna. Considerable research and survey work has been performed on the Upper Mississippi River System (UMRS) relative to these concerns. This work has been performed by a number of different entities, including State and federal agencies, universities and other organizations. Much of this work on zebra mussels in the UMRS was summarized by Ecological Specialists (2001) for the period from infestation (mid1990s) through the year 2000.

Since 2000, additional data has been collected on presence and density of zebra mussel veligers and adults in the UMRS. This report is an update on additional zebra mussel survey work that has been performed on the UMRS from 2000 through 2003, and includes some discussion on observable trends since zebra mussel data was first collected for the UMRS. Discussions below review available data for both veliger and adult life stages. Data has been collected by several State and federal agencies, including the U.S. Army Corps of Engineers, U.S. Fish and Wildlife Service, the National Park Service, U.S. Geological Survey, the Minnesota Department of Natural Resources (DNR), Wisconsin DNR, Iowa DNR and Illinois DNR. This report is a compilation and summary of these recent efforts.

UMRS SURVEYS AND STUDY EFFORTS FOR 2000 TO 2003.

VELIGER STUDIES

UMR Veliger Collection

During the period 2001 through 2003, a substantial, unified veliger sampling effort was pursued on the UMR and select tributaries. This unified effort has been summarized by Stoeckel (2002); and Farr and Alley (2003 and 2004) and is discussed immediately below. Biologists from the USACE and the Departments of Natural Resources (DNR) for Illinois, Iowa, Minnesota and Wisconsin performed the sampling for this effort. Samples were collected from 21 sites along the main channel of the UMR and 20 sites within major tributaries of the UMR. In general, samples were collected once a month during July, August and September. Sample collection and analysis were generally consistent among years.

Hand pumps were used to collect water samples at each site. Sites along the main channel were usually located near the downstream side of lock and dams. At these sites, a minimum of 10 L of water were collected from mid-depth at three separate locations across the channel (i.e., 25%, 50% and 75% of river width) to create a composite sample of at least approximately 30 L. Separate equipment was used to collect samples at UMR tributary sites to prevent cross-contamination. Tributary sites were sampled by collecting up to 10 L at each of three depths (0.2, 0.5 and 0.8 of total depth) and at three locations across the river channel. This resulted in composite samples of up to 90 L for each tributary site per sampling date. All composite samples were poured through a 53 μm mesh nylon filter. Filtered material was washed into a sample container and preserved using a 10% buffered sugar formalin solution.

In the laboratory, zebra mussels were enumerated and measured using crossed polarized lighting and an ocular micrometer. Each sample was thoroughly mixed to suspend contents. A 1 ml subsample was then placed on a Sedgwick-Rafter counter cell for processing. One ml subsamples were examined until at least 100 individuals were enumerated and measured or until $\geq$ 60% of total sample volume was examined. Shell height was obtained for 100 individuals per sample when possible. Veliger abundance and size

distribution were calculated for each sample and date. Veligers were considered to be alive at time of sampling if soft tissue was present inside the shell.

Measured veligers were classified into three major size classes (SC1, SC2, SC3). SC1 comprised veligers <100 μm; these individuals were considered to have recently produced their shell and were newly detectable by cross-polarized lighting. SC3 comprised veligers >200 μm and were defined as at, or nearly at, the pediveliger stage (i.e. capable of settling). SC 2 comprised veligers ≥100 μm, while < 200 μm; these individuals were detectable by crossed polarized lighting, yet not of sufficient size to settle.

UMR Veliger Observations

Veliger Density: During the period 2001 through 2003, zebra mussel veligers were collected below UMR Lock and Dams (L/D) 1 through 19, as well as L/D 22 (Table 1). Average veliger concentrations were typically highest in August, with the lowest concentrations observed in September (Table 1). Concentrations ranged from 800 veligers/L at L/D 6 in 2001, to no veligers observed during a few different months at L/Ds 1 and 2 (Table 2). Veliger concentrations were highest from L/D 4 downstream, with relatively light concentrations at L/D 3 and above. Locations that had relatively high veliger concentrations (average ≥100 veligers/L) include L/D 6, 11, 12, 14 and 16 (Table 2).

During the 2001 through 2003 period the general trend has been a decrease in UMR veliger densities (Table 2; Figures 1-3). Average UMR monthly veliger concentrations declined during each month over the three-year period (Table 2). The reductions in veliger abundance appear to be greatest in the upper pools (e.g., above and including L/D9), with reductions less visible or absent in the lower pools sampled. (Table 2; Figures 1).

Veliger Size Class Frequencies: Because size class frequency would not be expected to vary significantly among years, the results discussed here are for 2003. As expected, SC1 (<100μm) contained the most veligers followed by SC2 (100-200 μm) and SC3 (>200 μm; Figure 2). SC 1 comprised mostly D-stage veligers, whereas both D-stage (smaller) and intermediate (larger) were included in SC 2. SC 3 consisted of mostly umbonal veligers. Site-specific relative abundance estimates for size classes and developmental stages are presented in Figures 2, 3 and 4. D-stage veligers were the most commonly observed form in all samples except at L&D 3 in August. Intermediate-stage veligers were more abundant than umbonal veligers during August, although abundance of these forms was similar in July and September.

Veliger size also may have affected sampling efficiency. Small veliger stages (e.g., <53 μm) would pass through the nylon mesh filters during sample collection. This may be especially evident with veliger observations at L/D 4. Pool 4 is known to have high adult zebra mussel densities, yet veliger densities at L/D 4 were only beginning to increase toward the peak veliger densities observed at L/D 6. The reason for this may be that veligers are in fact present at higher densities below L/D 4, however the sampling techniques utilized are inadequate to detect their true concentrations.

UMR Lagrangian Veliger Survey

As a part of the veliger study above, Sullivan (John Sullivan, Wisconsin DNR, personal communication. 2004) conducted a Lagrangian survey for veligers of the UMR between Lake Pepin (Pool 4) and Clayton, Iowa (Pool 10) during the period August 12-16, 2002 (Figure 5). Sullivan described Lagrangian sampling as attempting to sample the same mass of water as it flows downstream. The primary purpose of this survey was to assess changes in zebra mussel veliger abundance, veliger size distribution and water quality as water moved from Lake Pepin downstream through Pool 10. Samples were collected in a

manor similar to those discussed above. However, samples were not necessarily collected immediately downstream of a L/D.

Sullivan's observations included low veliger abundance at the downstream end of Lake Pepin, an increase in veliger density as water flowed downstream into Pool 8, a decrease in density through Pool 9, and a subsequent increase in veliger density in Pool 10 (Figure 5). Sullivan observed greater veliger density at several locations compared to the August densities observed by Farr and Alley (2004) (Table 2 and Figure 5). The reasons for these differences are unknown, although they may be attributed to differences in sampling design.

Sullivan also estimated veliger flux, defined as the number of veligers moving past any point in the river at a given time. Veliger flux was estimated by calculating veliger density by river discharge. Peak veliger flux was bimodal, with peaks estimated in Pool 8 and Pool 10. Estimated flux for these two peaks was between 300 and 400 million veligers per second.

Sullivan did not observe discernable trends in veliger size as water was sampled from upstream to downstream.

Table 1. Average density (veligers/L) of zebra mussel veligers in samples collected within the UMR during 2001-2003.

Averages for the period 2001 through 2003				
	Veliger Abundance (#/L)			
Lock and Dam	**July**	**Aug**	**Sept**	**Average for All months**
1	0.0	0.0	0.1	0.0
2	0.6	0.7	0.1	0.5
3	1.1	1.1	1.8	1.3
4	23.0	40.2	17.3	26.9
5	81.7	90.4	23.9	65.3
5A	169.1	86.0	37.7	97.6
6	341.3	147.6	48.7	179.2
7	136.7	85.9	29.5	84.0
8	127.6	108.4	23.1	86.3
9	31.3	97.4	23.6	50.8
10	52.8	135.0	37.3	75.0
11	114.4	147.0	63.6	108.3
12	90.3	165.0	61.2	105.5
13	116.5	114.2	55.2	95.3
14	85.4	251.0	37.8	124.7
15	54.4	182.9	32.2	89.8
16	95.6	187.3	16.3	99.7
17	40.1	94.8	19.3	51.4
18	57.7	121.9	16.0	65.2
19	44.3	44.5	3.1	30.6
2	36.1	15.8	3.6	18.5
Average	**81.0**	**100.8**	**26.2**	**69.3**

Summarized from Stoeckel 2002; Farr and Alley 2003 and 2004.

Table 2. Density (veligers/L) of zebra mussel veligers in samples collected within the UMR during the period 2001 through 2003. Locations marked with gray highlight indicate samples that leaked prior to sample analysis. NA indicates where samples were not collected during the specified year.

	Veliger Abundance (#/L)								
	July			August			September		
L&D	2001	2002	2003	2001	2002	2003	2001	2002	2003
1	NA	0	0	NA	0	0	NA	0.1	NA
2	1.7	0.2	0	2	0.2	0	0.1	0.3	0
3	2.5	0.7	0.2	2	0.9	0.4	3.2	1.3	0.9
4	49.5	19.3	0.3	118	0.9	1.8	49.4	1.2	1.3
5	147.1	98.1	0	248.6	17.2	5.4	64.8	3.4	3.4
5A	263.6	243.3	0.3	224	29.2	4.8	103.7	7.6	1.7
6	809	214.7	0.3	284.6	152.2	5.9	101.5	14	30.5
7	238.8	170	1.4	172.7	69	15.9	41.4	18.8	28.2
8	177.9	203.5	1.3	185.8	121.7	17.7	19.9	36.7	12.6
9	33.6	59	1.4	233.1	42.9	16.3	21.8	36.6	12.3
10	67.7	89.7	0.9	196.3	83.9	124.7	74.3	0.2	NA
11	138.4	203.6	1.3	240.9	157.5	42.7	68.8	58.3	NA
12	95.2	174.4	1.3	210.5	215.3	69.1	69	53.3	NA
13	197.7	149.4	2.5	143.8	163.6	35.3	72.6	37.8	NA
14	100.2	70.6	NA	331.7	341.1	80.3	NA	37.8	NA
15	64.5	97.2	1.6	83.9	358.1	106.8	41	23.3	NA
16	141.6	143.1	2	48.9	274.2	238.7	12.8	19.7	NA
17	57.7	59.8	2.8	63.1	NA	126.5	13.4	25.2	NA
18	90.9	80.6	1.5	17.3	268.5	80	8.2	23.8	NA
19	80.1	51.3	1.4	10.5	109.6	13.5	2.5	3.6	NA
24	NA	66.3	5.9	NA	26.7	4.9	NA	3.6	NA
Average	145.1	104.5	1.3	148.3	121.6	47.2	42.7	19.4	10.1

Sources: Stoeckel 2002; Farr and Alley 2003 and 2004, unpublished COE reports.

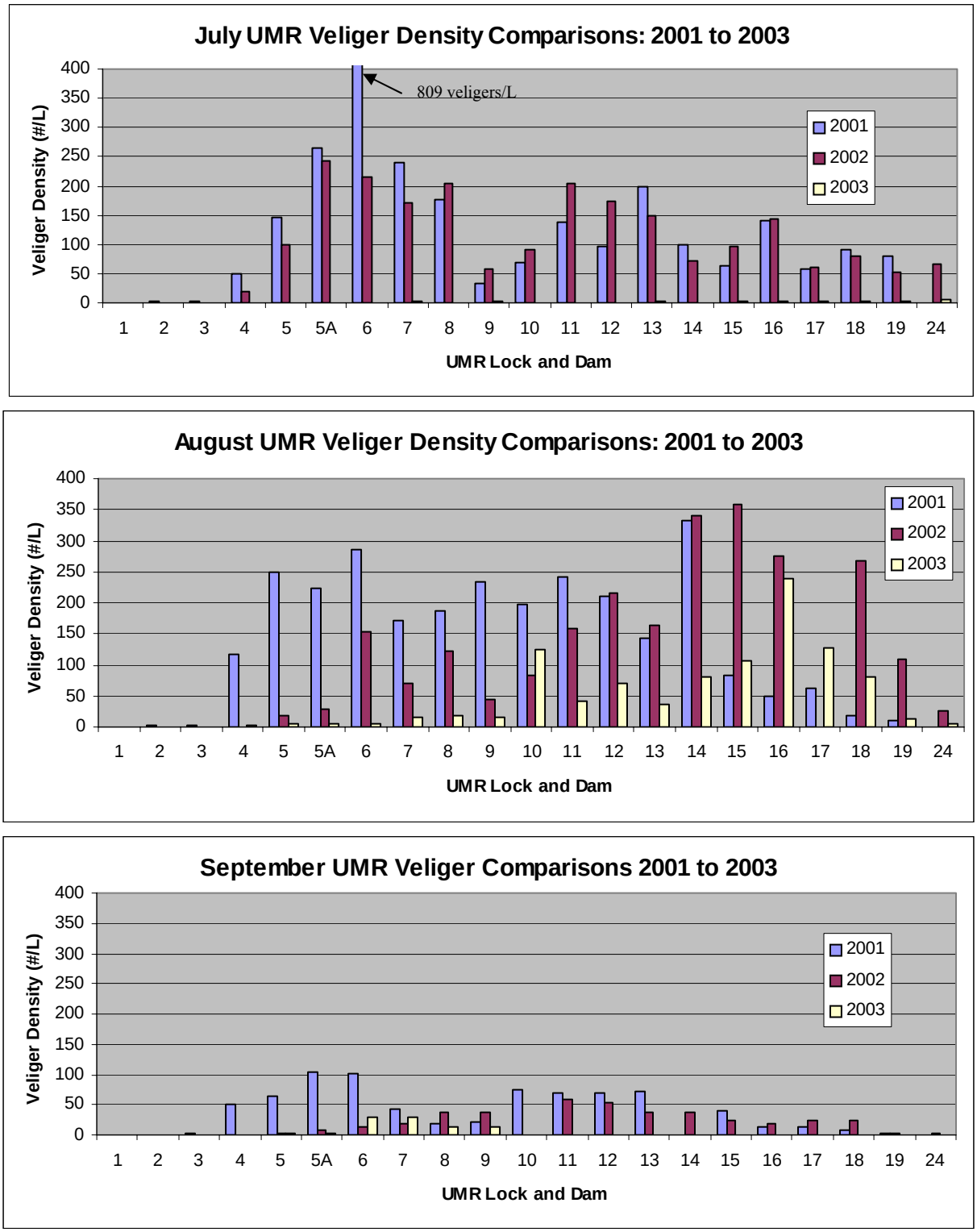

Figure 1. Zebra mussel veliger densities for Upper Mississippi River Locks and dams (L/D), as observed for the months of July, August and September during the period 2001 through 2003. Density estimates are from single observed samples collected immediately downstream of the L/D indicated. Density for L/D 6 during July 2001 was 809 veligers/L. Density data not collected from L/D 14 in July 2003. Veliger sample not collected from L/D 17 in August 2002. Samples during September 2003 were only collected at L/Ds 2 through 9. (Sources: Stoeckel 2002; Farr and Alley 2003 and 2004, unpublished COE reports.)

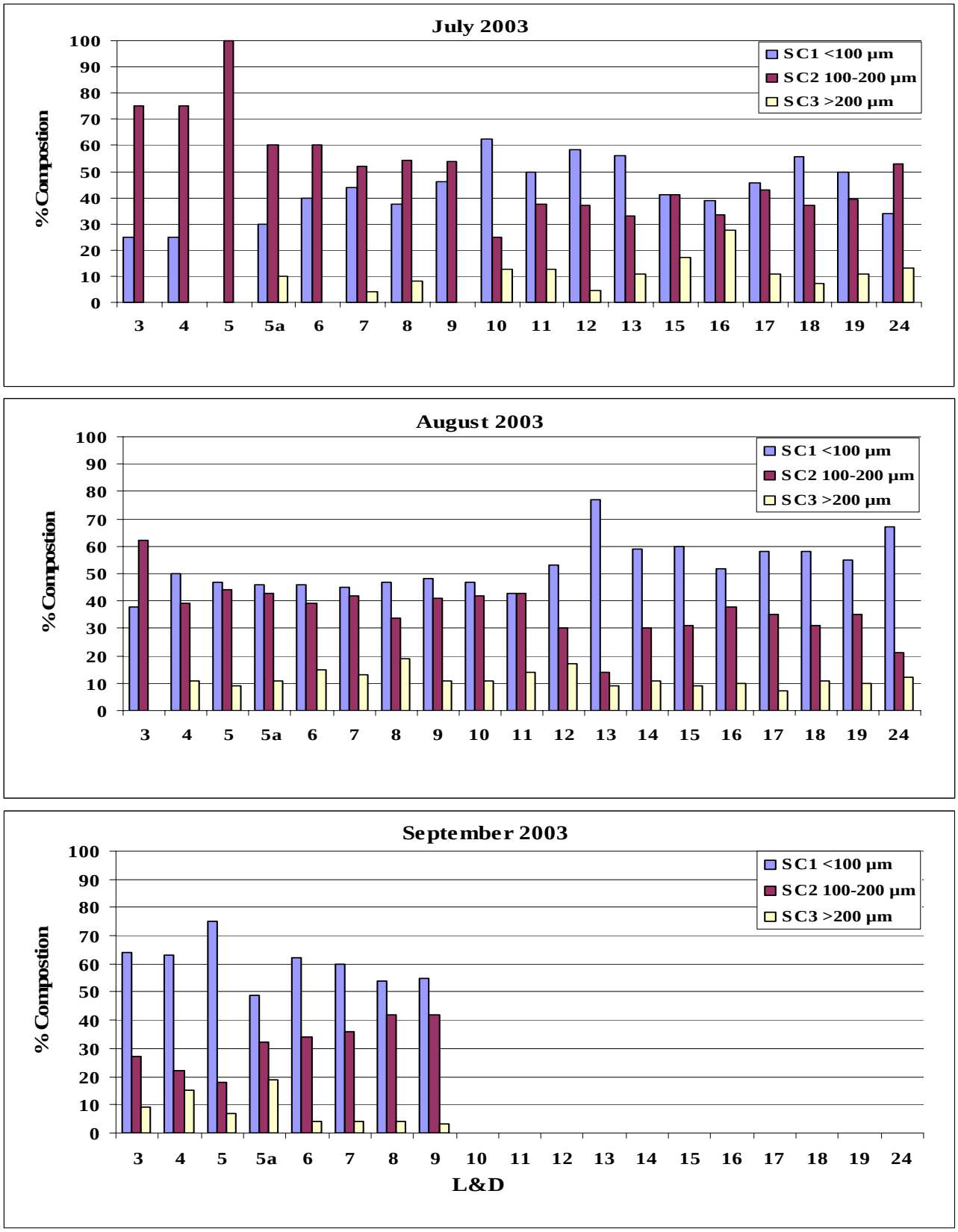

Figure 2. Relative abundance of each size class of veligers collected from the UMR during July, August and September, 2003. Samples during September 2003 were only collected at L/Ds 2 through 9 (Source: Farr and Alley 2004).

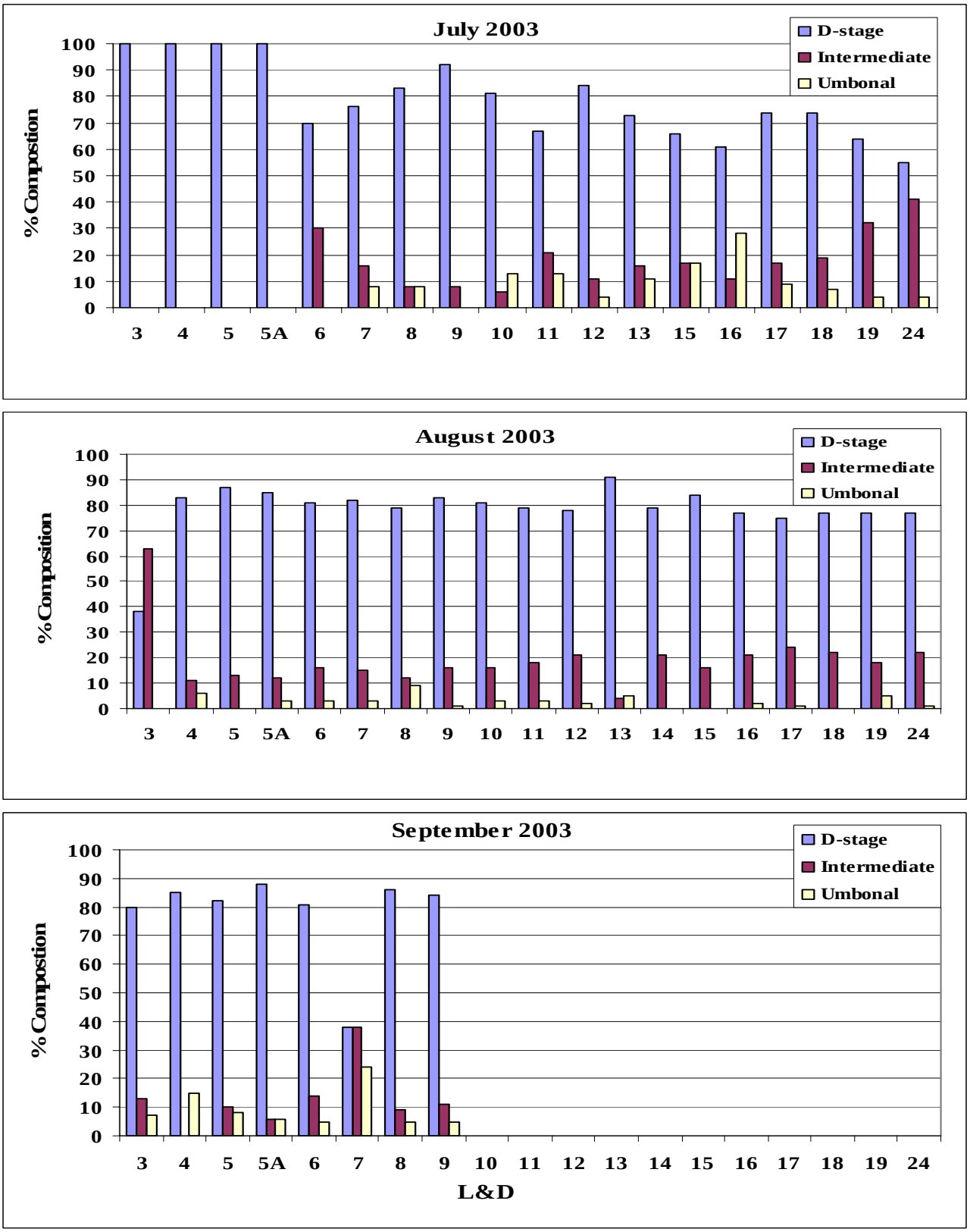

Figure 3. Relative abundance of each developmental stage of veligers collected from the UMR during July, August and September, 2003. Samples during September 2003 were only collected at L/Ds 2 through 9. (Source: Farr and Alley 2004).

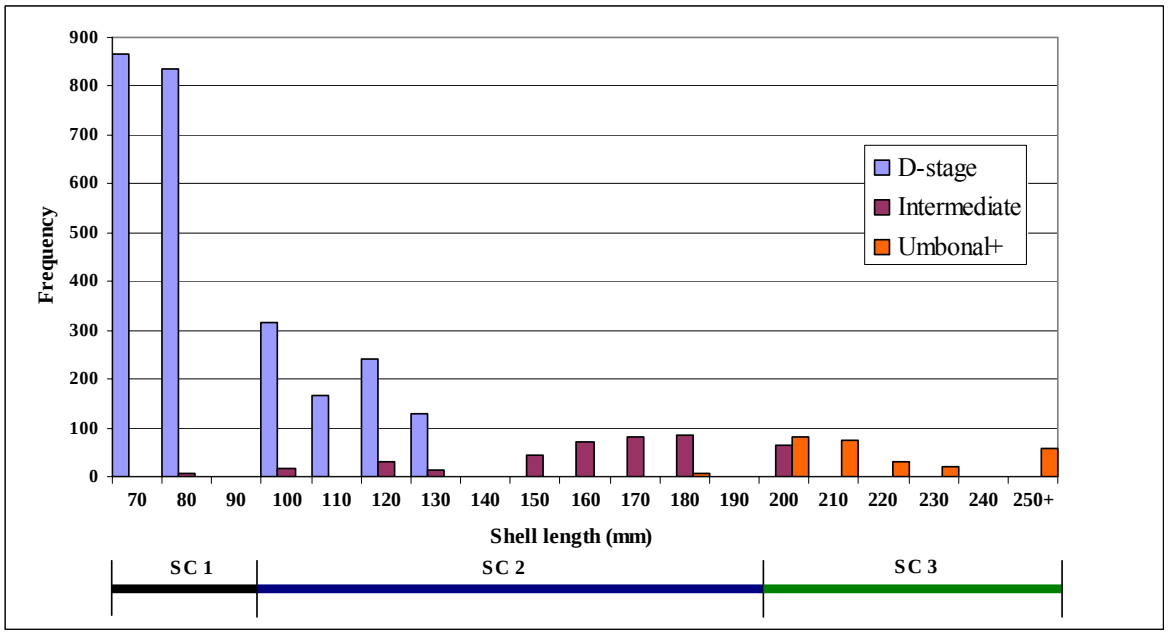

Figure 4. Frequency distributions for separate size classes (SC1-SC3) and developmental stages. Pediveligers were rarely observed in any samples; these data were combined with umbonal-stage counts. (Source: Farr and Alley 2004).

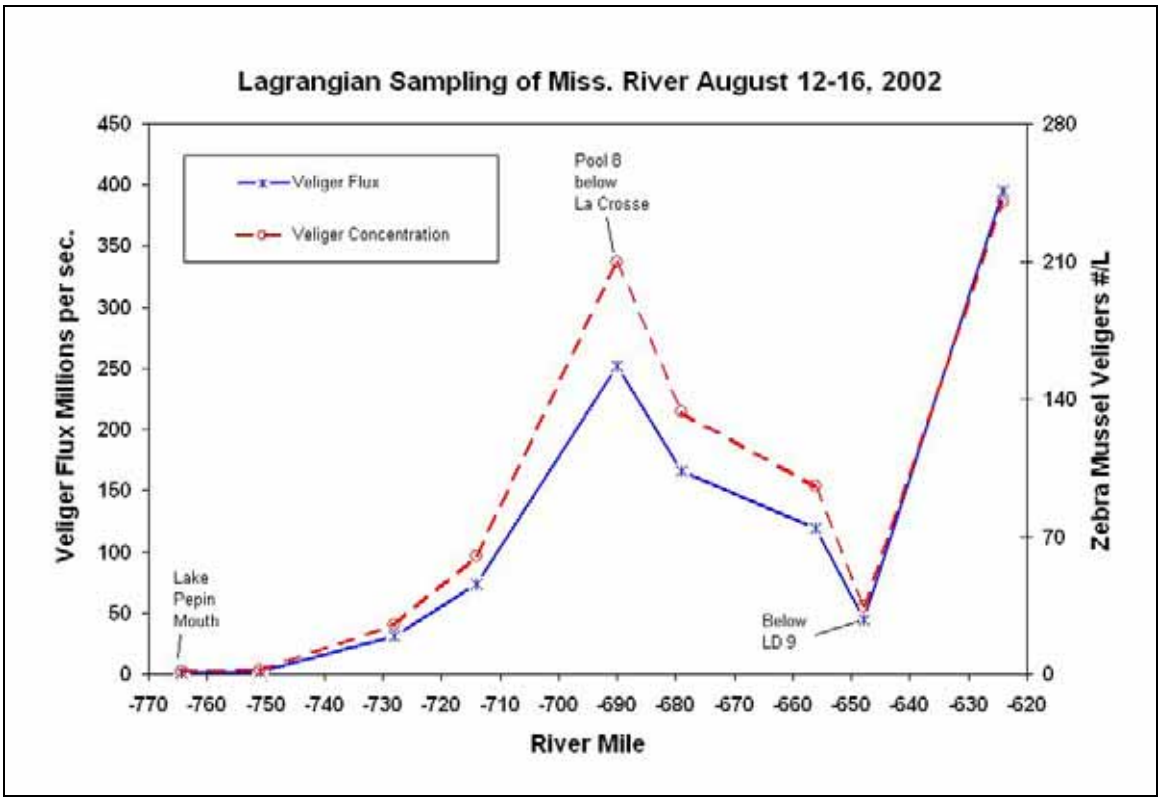

Figure 5. Zebra mussel veliger densities and estimated veliger flux for Upper Mississippi River during Lagrangian sampling performed between River Miles 770 and 620 during the period August 12 through 16, 2002 (Source: John Sullivan, Wisconsin DNR, Personal Communication).

UMR Tributary Veliger Observations

During the period 2001 through 2003, zebra mussel veligers have been observed on some UMR tributaries, however the veliger concentrations have been substantially lower (Table 3). The number of tributaries where veligers were observed has decreased during the period, with only the St. Croix River containing veligers during 2003. It is possible that veligers observed in tributary samples during 2001 and 2002 were due to either contamination of tributary samples with UMR veligers, or due to an influx of veligers from the UMR. Backwater effects that occurred at the tributary sampling locations near the confluence of the UMR could result in the introduction and collection of veligers, even though veligers were not present within tributary flows. Tributary sample collection in 2002 and 2003 may have resulted in better sample collection and, thus, absence of veligers.

In addition to the discussed veliger monitoring, Karns (2004) discussed monitoring efforts for early veliger settlment on the St. Croix River. Sampling in 2003 was performed from the Sunrise River downstream to Stillwater. No zebra mussels were observed.

Table 3. Abundances (ind/L) of live and dead zebra mussel veligers taken in tributaries of the UMR during 2001-2003. NA indicates where samples were not collected during the specified year.

	Veliger Abundance (#/L)								
	July			**August**			**September**		
Tributaries	**2001**	**2002**	**2003**	**2001**	**2002**	**2003**	**2001**	**2002**	**2003**
	Live Veligers								
Chippewa R.	0	0	0	0	0	0	0	0	0
St. Croix R. (Hudson)*	0.07	0	0	0.6	0	0	0.22	0	0
St. Croix R. (Prescott)	0.01	4.53	0	2.39	0	0.62	2.03	0	0.64
Black R.	0	0	0	0.02	0	0	0	0	0
Waspi River	NA	0.02	0	NA	0.02	0	NA	0	0
Wis. R.	NA	0.39	0	NA	0.36	0	NA	0.02	0
Iowa R. - mouth	NA	0.11	0	NA	0	0	NA	0	0
Cedar R. - mouth	NA	0	0	NA	0	0	NA	0	0
UMR I 694	0	0	0	0	0	0	0	0	0
	Dead Veligers								
Chippewa R.	0	0	0	0	0	0	0	0	0
St. Croix R. (Hudson)*	0.01	0	0	0.06	0	0	0.22	0	NA
St. Croix R. (Prescott)	1	0.47	0	0.02	0	0.12	0.08	0	0.06
Black R.	0	0	0	0.02	0	0	0	0	0
Waspi River	NA	0.04	0	NA	0.02	0	NA	0	NA
Wis. R.	NA	0.12	0	NA	0.36	0	0.02	0	NA
Iowa R. - mouth	NA	0.11	0	NA	0	0	NA	0	NA
Cedar R. - mouth	NA	0	0	NA	0.17	0	0	0	NA
UMR I 694	0	0	0	0	0	0	0	0	NA

*-2001 sample taken at confluence with Kinnickkinnic River.
Sources: Stoeckel 2002; Farr and Alley 2003 and 2004, unpublished COE reports.

UMR ADULT ZEBRA MUSSEL DENSITIES

Adult zebra mussels densities have been observed in the UMR through a number of different efforts by State and federal agencies. The efforts described below are some of the more thorough attempts to quantitatively identify UMR zebra mussel densities. The discussion below describes observations on adult zebra mussel from upstream to downstream, as well as including observations for the St. Croix River. It should be noted that, given the variable distribution of zebra mussels and the differing sampling protocol employed by the authors, zebra mussel population levels and trends may be conflicting, even within the same UMR Pool. However, the observations provide valuable insight into the current distribution and recent trends in relative adult abundance.

Sampling Methods

Sample methods varied by study. In general, most quantitative work included the excavation of ¼-m^2 quadrat samples of the river substrate. Sample contents were removed, rinsed, identified and counted. In some cases, a subsample was taken from a sample to provide an estimate of zebra mussel density. In some instances zebra mussels were measured. The number of samples collected and the collection sites are discussed below, where appropriate. Other substantial differences in sample collection are also noted. Please refer to the identified studies for complete discussion of methods.

An alternative method to sampling by quadrat was performed by the Long Term Resource Monitoring Program (LTRMP). The LTRMP utilizes a winch-mounted 23×23-cm (0.052-m^2) standard Ponar grab to observe annual trends of select macroinvertebrate populations, including zebra mussels, within the trend pools of the UMRS. These include Pools 4, 8, 13 and 26, as well as the Open River below St. Louis, Missouri. Zebra mussels were included as a part of the sampling effort in 1995, thus providing a consistent dataset for comparison.

Detailed explanation of the methods employed by the LTRMP has been provided by USGS (2004). In short, sampling was performed at sites randomly selected among the 5 UMR trend pools. Aquatic strata sampled included contiguous backwaters, main channel borders, impounded areas, and side channels. For Pool 4, the impounded area is in the form of Lake Pepin. Annual sampling was conducted at about 120 sites per pool. Sample allocation was based on several criteria, including surface area of the aquatic area in each study reach, ability to sample within a specific strata, and the productivity of the taxa in each aquatic area. Sampling included a single ponar grab conducted at each randomly selected site.

Sampling for zebra mussels through the LTRMP is often performed in soft substrates. Since zebra mussels typically attach to hard substrates the LTRMP data may not provide density estimates reflective of areas with high colonizations. However, this approach does provide a consistent, randomized sampling protocol and provide insight into the relative changes in zebra mussel population levels over time. Therefore, results should be considered in terms of general trends as opposed to absolute density estimates.

Adult Zebra Mussel Abundance

UMR: Coon Rapids Dam through Pool 3

Kelner and Davis (2002) performed mussel surveys on several sites within the UMR, including areas above Coon Rapids Dam (upstream of the Twin Cities), areas adjacent to the St. Anthony Falls lock and dams, and Pools 1, 2, and upper 3 (Kelner and Davis 2002). Sample methods consisted of timed diver searches and hand collection of mussels while wading, snorkeling, and diving. A limited number of quantitative samples also were collected.

Kelner and Davis (2002) did not observe any zebra mussels above Lock and Dam 1. They also concluded that zebra mussels were sparse within UMR Pools 2, 3 and the lower Minnesota River (MNR). During hand collection surveys within Pools 2, 3 and the MNR only about 1% of live native mussels collected had at least one zebra mussel attached. The number of individual zebra mussels attached to native mussels was minimal (mean 1.1, range of 1 to 4; Kelner and Davis 2002). Zebra mussel infestation was greatest in Upper Pool 3 (2.6% native mussels infested) followed by lower MNR (1.7%), and lower Pool 2 (0.9%). The middle and upper reaches of Pool 2 (i.e., upstream of the Interstate 494 Highway bridge) had essentially no infestation by zebra mussels (Kelner and Davis 2002). Quantitative sampling by Kelner and Davis (2002) resulted in collection of zebra mussels from only one location in lower Pool 2 where density was 0.1/m2.

Kelner and Davis (2002) concluded that zebra mussels were not reproducing since the zebra mussels observed were large (>15mm) isolated adult individuals. Very few zebra mussels were observed attached to the substrate and no discernable difference in zebra mussel infestation was observed between 2000 and 2001.

Kelner and Davis (2002a) performed transect diver searches (hand collection) for native unionids in Pool 3 along the left descending bank, across from Diamond Island, during 2001. This included general observations for zebra mussels. Out of eight transects that were up to 500 feet long, a total of 6 zebra mussels were collected.

UMR Pool 4

Anecdotal observations have suggested a possible decrease in adult zebra mussel abundances in Lake Pepin (Mike Davis, Minnesota DNR, personal communication 2004). Davis (2003) performed sampling in Lake Pepin (Pool 4) and compared results to recent historical sampling in similar locations. Seven sites were sampled representing both sides of the lake, five of which were also sampled during 1997. Quantitative samples were collected from the 1-2 meter depth contour and a qualitative visual or tactile assessment made at each 1-meter depth interval until a depth was reached where no zebra mussels were detected.

Although older adult zebra mussels were absent at most sites, new recruitment of young adults was occurring at every site sampled during this effort. A single cohort from 2003 was present at four of the seven sites including those in the upper half of Lake Pepin and the site at the outlet of the lake. In the lower sections of the lake a dense population of zebra mussels representing two distinct and abundant cohorts were sampled. At this site (RM 766.3, right descending bank (MN shore)) measured density was 10,152/m^2 in the first sample, and 8,896/m^2 in the second. This compares to measured densities at this location of about 11,100 m^2 in 1996 and about 22,600 m^2 in 1997. A large deposit of empty zebra mussel shells covered the bottom out to the 4-meter depth contour. Beyond that depth to 7 meters young of the

year zebra mussels were found colonizing rocks and empty native mussel shells. Zebra mussel density at other sites ranged from an average of 48/m^2 to 1,814/m^2.

Conversely, LTRM sampling for zebra mussels has been variable for Pool 4, with no strong, apparent trends over the period 1995 through 2002 (Figure 6 and Table 4; USGS 2004). Peak abundance may have occurred in 2001, however density estimates were within one standard error unit of previous yearly estimates (Figure 6 and Table 4; USGS 2004). No sampling was performed in 2003.

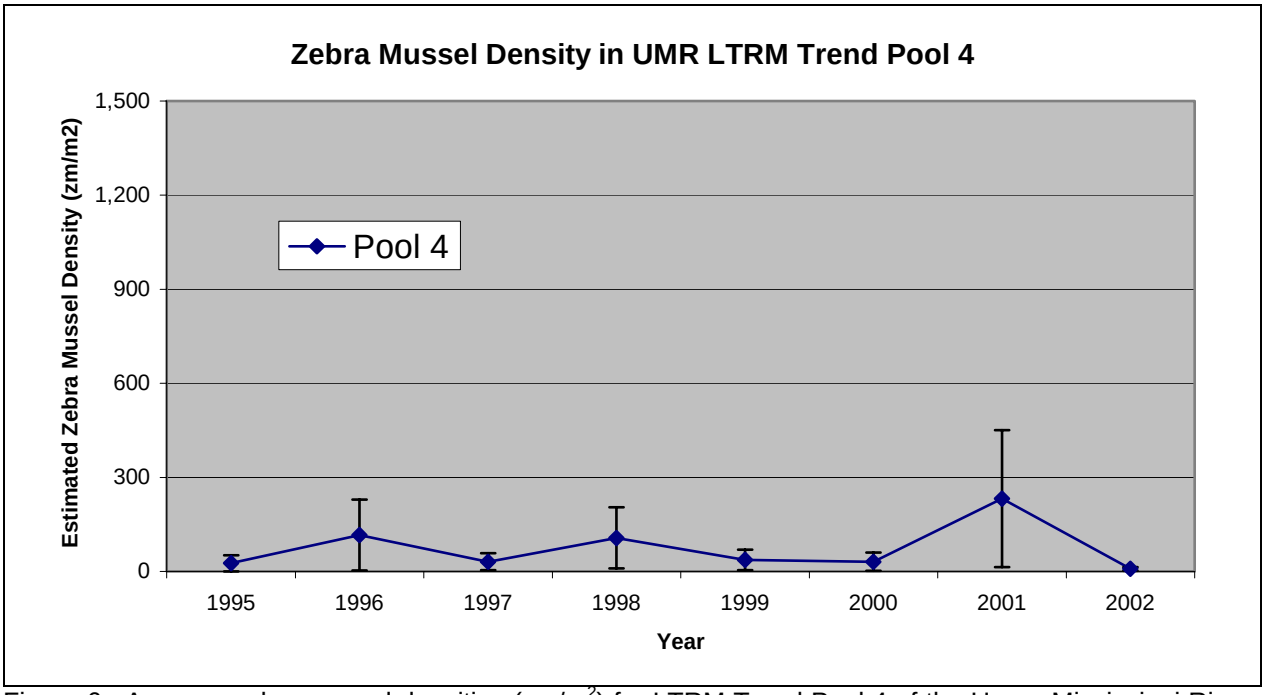

Figure 6. Average zebra mussel densities (zm/m^2) for LTRM Trend Pool 4 of the Upper Mississippi River during the period 1995 through 2002 (number per square meter; ±1 standard error). Source: USGS 2004.

Table 4. Mean zebra mussel density (#/m^2), number of sites sampled, and Standard Error (SE) by aquatic strata for Pool 4 during the period 1995 through 2002. Source: USGS 2004.

Year	Backwater contiguous			Impounded[a]			Side channel			Main channel border		
	Mean density[b]	n[c]	± 1 SE	Mean density	n	± 1 SE	Mean density	n	± 1 SE	Mean density	n	± 1 SE
1995	1	56	1	34	44	34	0	10	0	17	11	17
1996	0	50	0	159	44	156	2	17	2	13	10	10
1997	3	55	2	1	44	1	7	11	5	673	11	603
1998	1	57	1	110	44	110	19	11	17	609	9	396
1999	17	55	10	45	44	40	21	10	17	17	11	14
2000	1	56	1	14	44	14	16	11	11	440	9	423
2001	2	57	1	321	44	302	0	10	0	0	8	0
2002	40	57	25	1	44	1	0	10	0	23	10	23

[a] Impounded area for Pool 4 is Lake Pepin, a Tributary Delta Lake
[b] mean density = zebra mussels/m^2
[c] n = number of sites sampled

UMR Pool 7

Kelner and Davis (2002a) also performed mussel sampling in UMR Pool 7 at four sites, each sampled in 1995 and resampled in 2001. Observations included ¼-m^2 quadrat substrate samples to estimate the density and size structure of zebra mussel and native mussel species (please see Kelner and Davis 2002a for specific collection techniques). Habitats sampled included main channel boarder and side channel habitat. Quadrats were collected by divers, with 30 total substrate samples (10 ¼-m^2 quadrats from each of 3 subsites at each primary sampling site). In 2001, thirty samples were collected from Sites 1, 3 and 4, and 20 samples from Site 2. Subsites at Site 2 included the scour hole at the tip of the wing dam associated with the site. In 2001 this scour hole had apparently been washed free of mussels by the recent flood and so samples were not collected there.

Table 5. Quantitative zebra mussel observations by Kelner and Davis (2002a) from upper UMR Pool 7. Sites sampled included main channel boarder and side channel habitat.

	Zebra mussel density (#/m^2)		Percent unionid colonized (%)	
Site	1995	2001	1995	2001
1	83.73	117.6	20	79.7
2	19.2	92.4	44	85.6
3	4.8	56.1	8.7	52.6
4	7.73	145.1	12.9	75.7
Average	28.9	102.8	21.4	73.4

UMR Pool 8

USGS (2004) has observed zebra mussel densities in Pool 8 for the period 1995 through 2003. Estimated average annual densities were highly variable, especially at higher density estimates. Pool 8 observations include relatively low abundance from 1995 through 1998, an increase in density from 1999 through its peak in 2001, followed by dramatic reductions in 2002 and 2003 (Figure 6 and Table 6; USGS 2004).

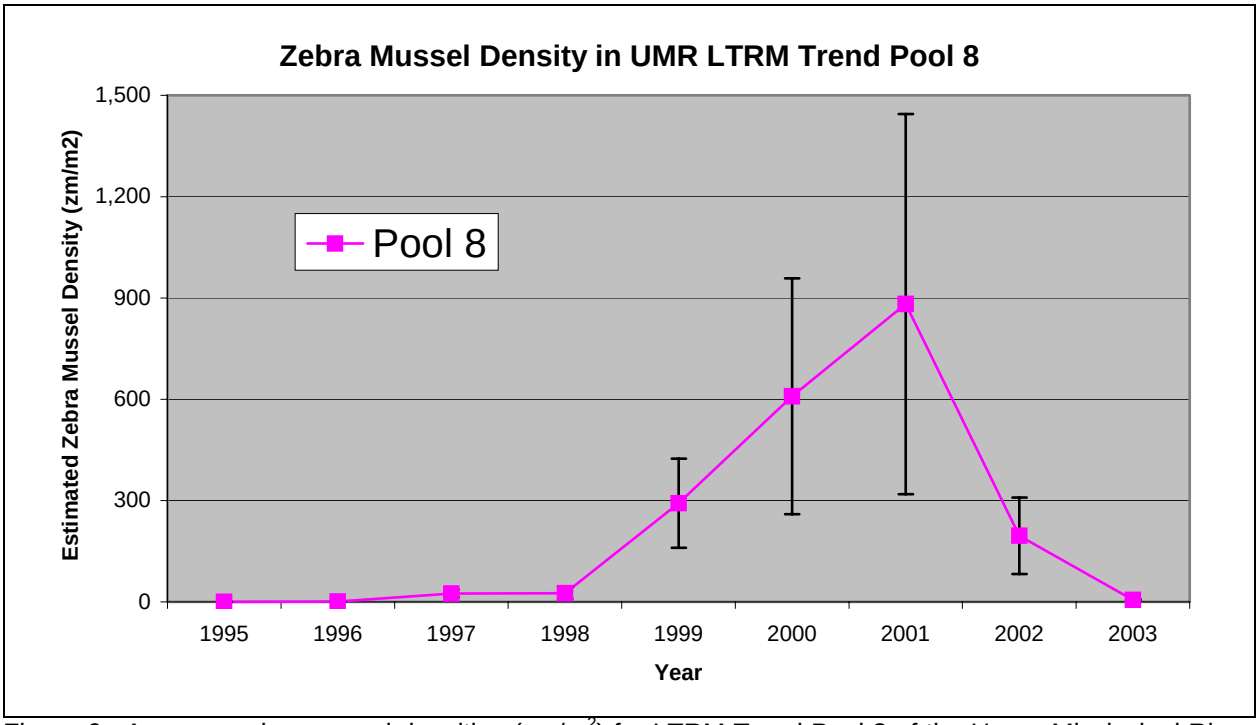

Figure 6. Average zebra mussel densities (zm/m^2) for LTRM Trend Pool 8 of the Upper Mississippi River during the period 1995 through 2003 (number per square meter; ±1 standard error). Source: USGS 2004.

Table 6. Mean zebra mussel density (#/m^2), number of sites sampled, and Standard Error (SE) by aquatic strata for Pool 8 during the period 1995 through 2003. Source: USGS 2004.

Year	Backwater contiguous			Impounded			Side channel			Main channel border		
	Mean density[a]	n[b]	± 1 SE	Mean density	n	± 1 SE	Mean density	n	± 1 SE	Mean density	n	± 1 SE
1995	0	31	0	0	49	0	1	19	1	0	10	0
1996	0	31	0	1	49	1	1	19	1	0	10	0
1997	3	34	2	37	49	15	29	19	17	6	10	4
1998	1	34	1	43	47	27	1	18	1	56	10	39
1999	34	31	21	1553	49	1115	326	19	182	81	10	54
2000	1	31	1	825	48	413	1014	18	690	225	10	219
2001	8	31	6	1609	49	953	543	19	536	26	9	14
2002	14	31	14	337	49	178	158	19	124	12	10	8
2003	0	31	0	12	49	3	2	19	2	0	10	0

[a] mean density = zebra mussels/m^2

[b] n = number of sites sampled

UMR Pools 9 through 26 and the Open River

The following discussion is largely from sampling and report preparation by Farr et. al (Final Report 2002; Draft Report In Preparation 2003 and 2004) as a part of their monitoring of essential and secondary habitat areas for *Lampsilis higginsi*. Additional discussion is provided by further monitoring by the LTRMP Program (USGS 2004).

Essential Habitat Monitoring

Quantitative sampling for zebra mussels was performed during the summers of 1995, 2001, 2002 and 2003 Farr et. al (Final Report 2002; Draft Report In Preparation 2003 and 2004) at the following locations:

- Pool 9, RM 661 at Whiskey Rock Island near Lansing, IA
- Pool 10, RM 643 near Harpers Ferry Slough, IA – Harpers Slough
- Pool 10, RM 635 near Prairie du Chien, WI - East channel, West channel, downriver of the
- Pool 10, Highway 18 bridge and a barge turning basin in the northern part of the East channel
- Pool 10, RM 618 near Guttenberg, IA – McMillan Island
- Pool 11, RM 608 near Cassville, WI, both within and outside of the mussel relocation area
- Pool 13, RM 556, near Bellevue, IA
- Pool 14, RM 505 near Cordova, IL
- Pool 15, RM 485, near Moline, IL
- Pool 17, RM 450, near Muscatine, IA
- Pool 19, RM XXX, near Burlington
- Pool 24 RM 300, near Hannibal, MO

Sampling at these locations was intended to help focus monitoring and survey efforts in a way to enhance understanding of *Lampsilis higginsii* distribution and population variability. These surveys have also provided additional data on zebra mussel density.

Sampling was not performed at all locations each year. Habitat sampled usually included abundant and diverse native mussel beds. Because zebra mussels tend to attach to hard substrates, such areas typically have high zebra mussel densities. Although variable among sites, the quantitative samples included from 10 to 25 ¼-m^2 quadrats collected from two to five locations at each site.

Observed zebra mussel densities had great spatial and temporal variation. During the four years sampled, densities ranged from almost 3 to almost 17,000 zm/m^2 (Figures 4 to 8). Densities were typically highest at sampling sites in Pool 10, with substantially lower densities within downstream sampling sites (Figures 4 to 7).

During 1995 zebra mussel densities were relatively low immediately following the zebra mussels introduction to the UMR. Densities ranged from about 1,000 zm/m^2 to about 50 zm/m^2 at sites sampled (Figure 4).

Zebra mussel densities were substantially higher in some locations in 2000, with densities ranging from 9,000 to about 17,000 zm/m^2 for three of four sampling sites in Pool 10 (Figure 5). However, McMillan Island (pool 10), as well as sites in other pools had substantially lower densities. The Burlington site (Pool 19) had about 4,000 zm/m^2, while McMillan Island and sites in pools 9, 14, 15 and 17 had less than 500 zm/m^2 (Figure 5).

In 2001 zebra mussel densities were generally lower for the three high-density sites observed in Pool 10, with densities ranging from 4,500 to about 9,000 zm/m^2 (Figure 6). However, sites in other pools had increased densities. The Burlington site (Pool 19) had about 4,000 zm/m^2, while sites in pools 9, 14, 15 and 17 had densities from about 1,700 to 3,400 zm/m^2 (Figures 6).

In 2002 zebra mussel densities were lower for most sites observed, with densities ranging from 5,000 to 3 zm/m^2. However, Whiskey Rock (Pool 9), which was sampled the previous year, had an increase from about 1,700 zm/m^2 in 2001 to about 3,300 zm/m^2 in 2002 (Figure 7).

In 2003 zebra mussel densities crashed for sites in Pools 10 and 11, compared to 2002. Sampling at Cordova (Pool 14), and Burlington (Pool 19) did find higher zebra mussel densities compared to those in Pools 10 and 11, though both sites had lower densities relative to early sampling (Figures 4 to 8).

In most cases, adult zebra mussel populations sampled between 2001 and 2003 had a modal size distribution (Appendix A). Only a few locations had bi-modal populations, or populations with a broad size distribution (e.g., Figures A3, A5, A7, A10 and A15; Appendix A).

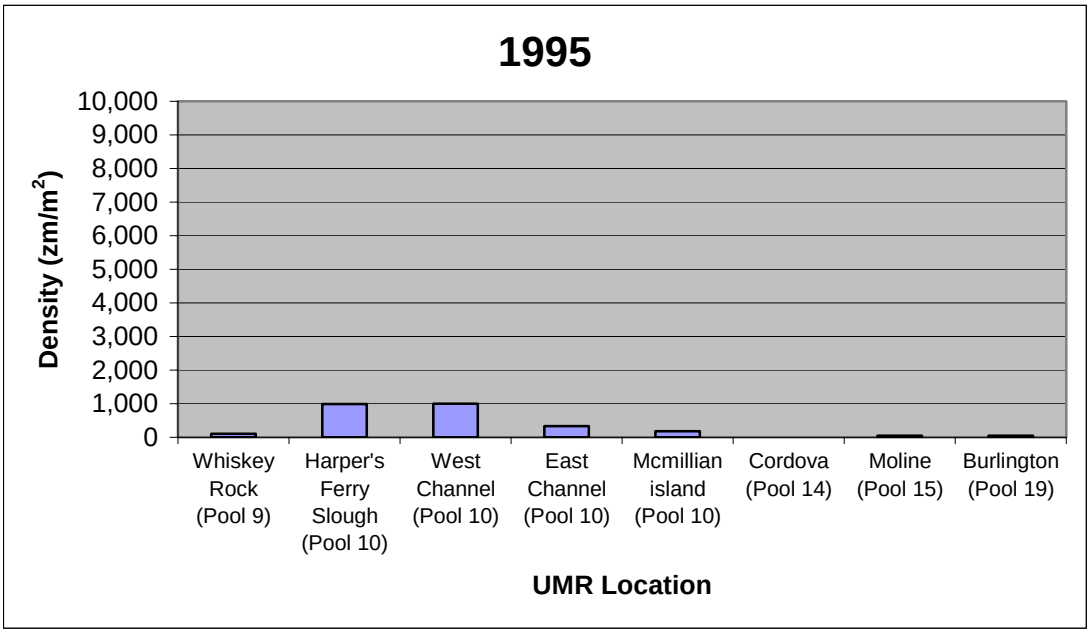

Figure 4. Average zebra mussel densities (zm/m^2) for selected sites of the Upper Mississippi River during 1995.

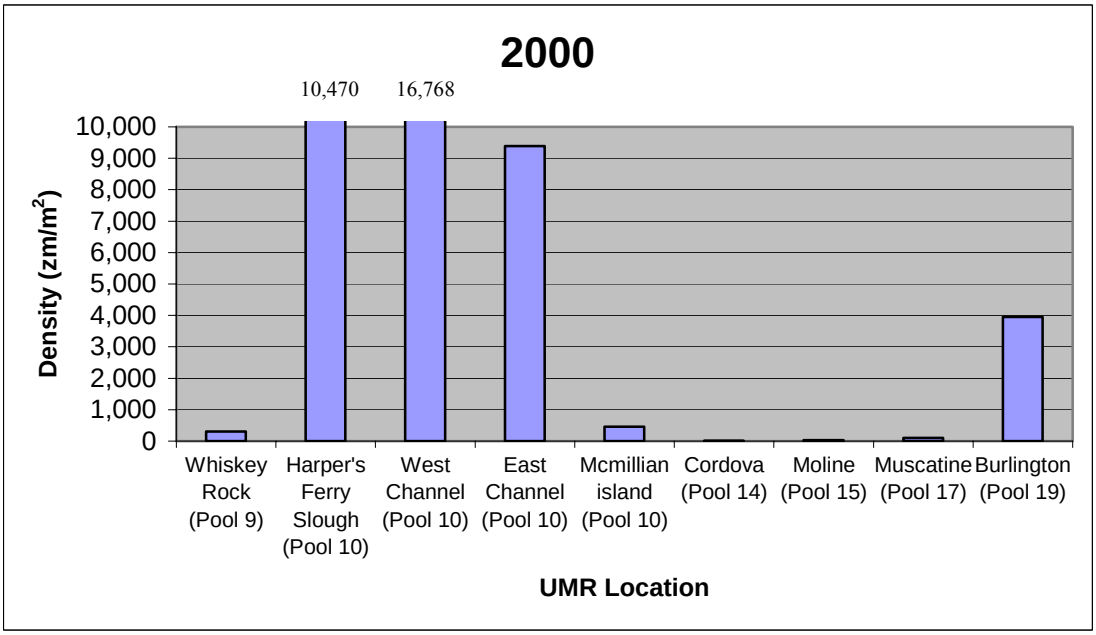

Figure 5. Average zebra mussel densities (zm/m^2) for selected sites of the Upper Mississippi River during 2000. Average Density was 10,470 zm/m2 for Harper's Ferry Slough, and 16,768 for the West Channel.

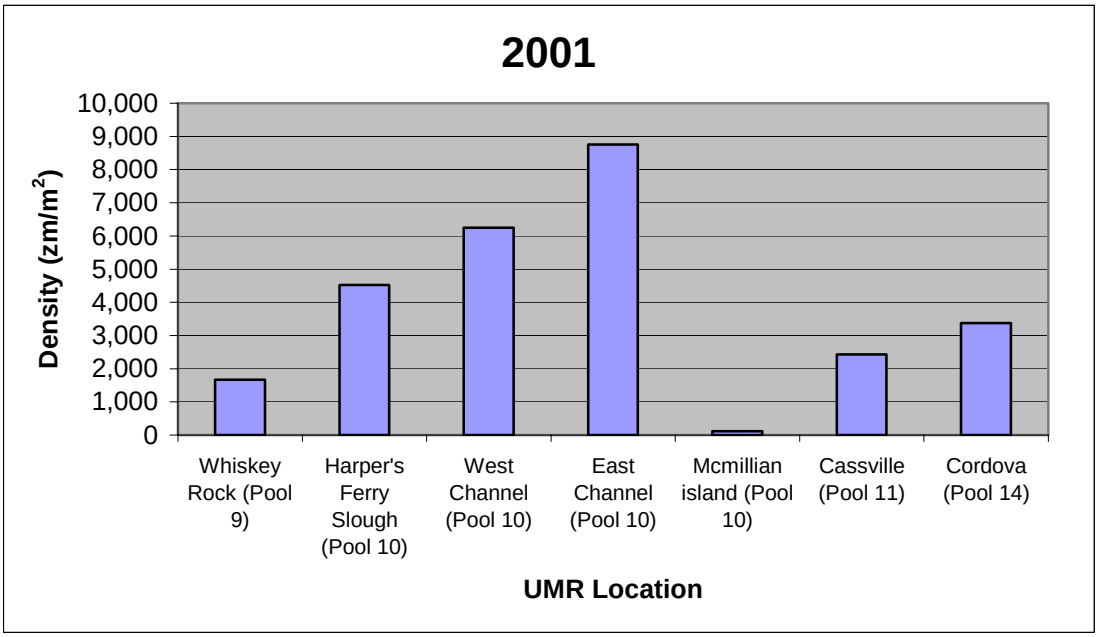

Figure 6. Average zebra mussel densities (zm/m^2) for selected sites of the Upper Mississippi River during 2001.

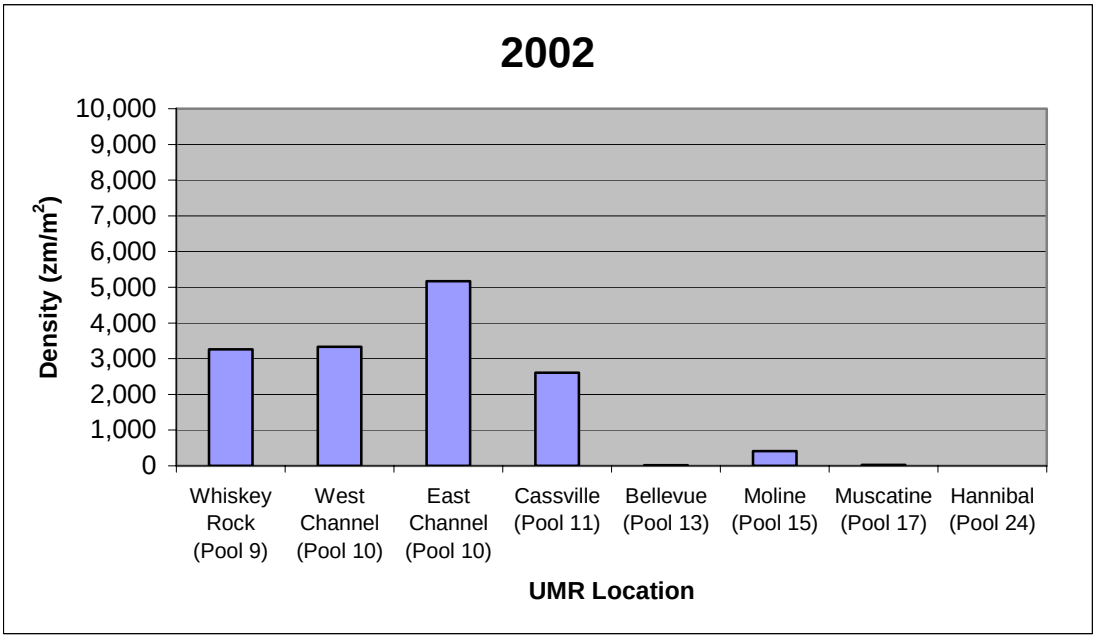

Figure 7. Average zebra mussel densities (zm/m^2) for selected sites of the Upper Mississippi River during 2002.

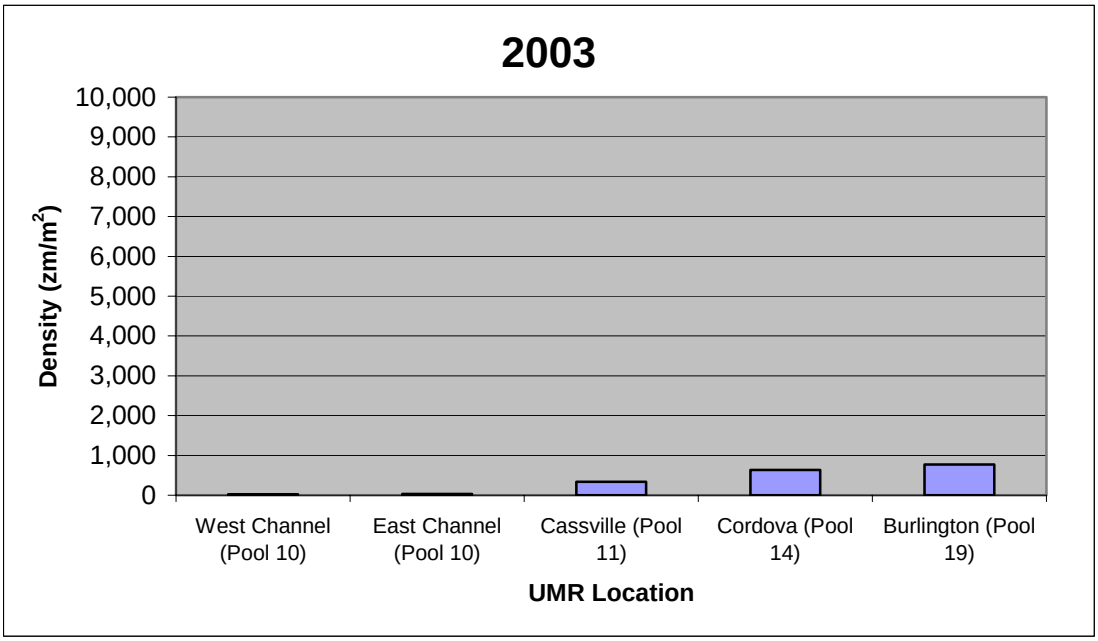

Figure 8. Average zebra mussel densities (zm/m^2) for selected sites of the Upper Mississippi River during 2003.

LTRMP Zebra Mussel Monitoring in Pools 13, 26 and Open River

USGS (2004) has observed zebra mussel densities in Pools 13 and 26, as well as the open River during the period 1995 through 2003. Estimated average annual densities were highly variable, especially at higher density estimates. Estimated zebra mussel densities were highest in Pools 13, with lower estimated densities in Pool 26 and the Open River. Annual variability was quite high for Pools 13, with no strong, apparent trends over time. However, similar to Pool 8, Pool 13 also had extremely low abundance during 2003. Due to budget constraints, Pool 26 was not sampled in 2003. Density estimates for Pool 26 and the Open River have remained below that of the upper pools. Zebra mussel sampling was discontinued in 2001 in the Open River reach.

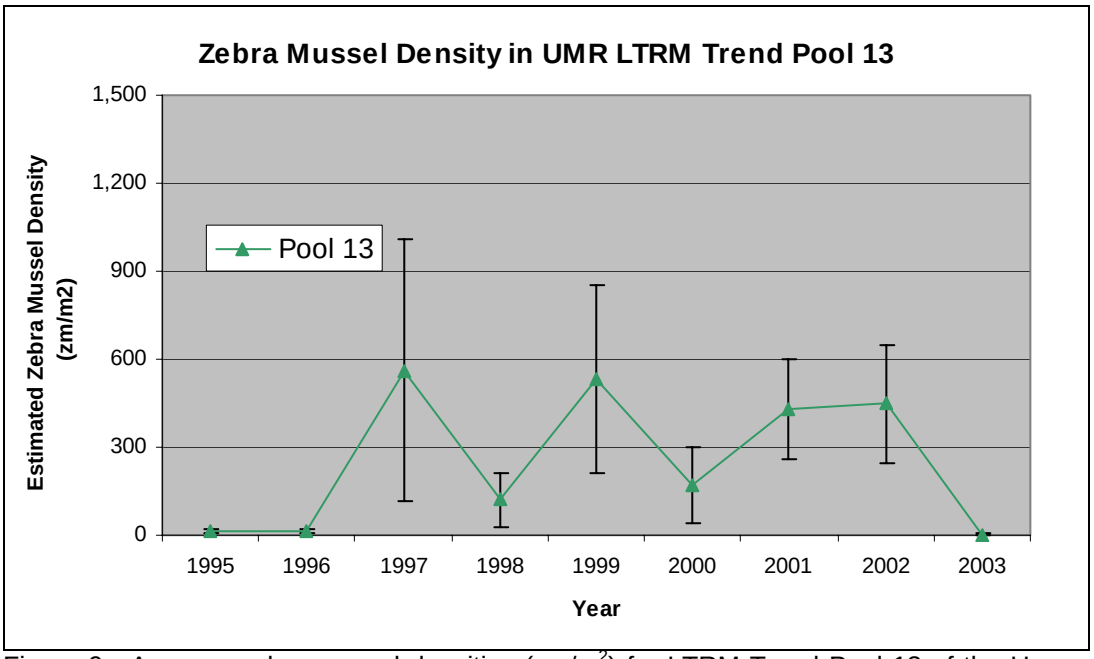

Figure 9. Average zebra mussel densities (zm/m^2) for LTRM Trend Pool 13 of the Upper Mississippi River during the period 1995 through 2003 (number per square meter; ±1 standard error). Source: USGS 2004.

Table 7. Mean zebra mussel density (#/m^2), number of sites sampled, and Standard Error (SE) by aquatic strata for Pool 13 during the period 1995 through 2003. Source: USGS 2004.

Year	Backwater contiguous			Impounded			Side channel			Main channel border		
	Mean density[a]	n[b]	± 1 SE	Mean density	n	± 1 SE	Mean density	n	± 1 SE	Mean density	n	± 1 SE
1995	1	44	1	17	45	10	5	11	5	18	15	15
1996	6	43	6	15	47	5	18	13	18	28	15	15
1997	2	43	1	755	46	685	7	14	6	1762	15	1141
1998	25	43	25	157	46	111	158	14	158	203	15	148
1999	171	43	155	974	46	503	12	14	6	399	15	399
2000	1	42	1	223	47	144	246	14	180	360	15	359
2001	4	43	2	898	46	306	3	13	3	308	15	271
2002	3	43	2	962	46	394	268	14	251	31	15	20
2003	0	43	0	3	45	2	3	14	3	5	15	5

[a] mean density = zebra mussels/m^2
[b] n = number of sites sampled

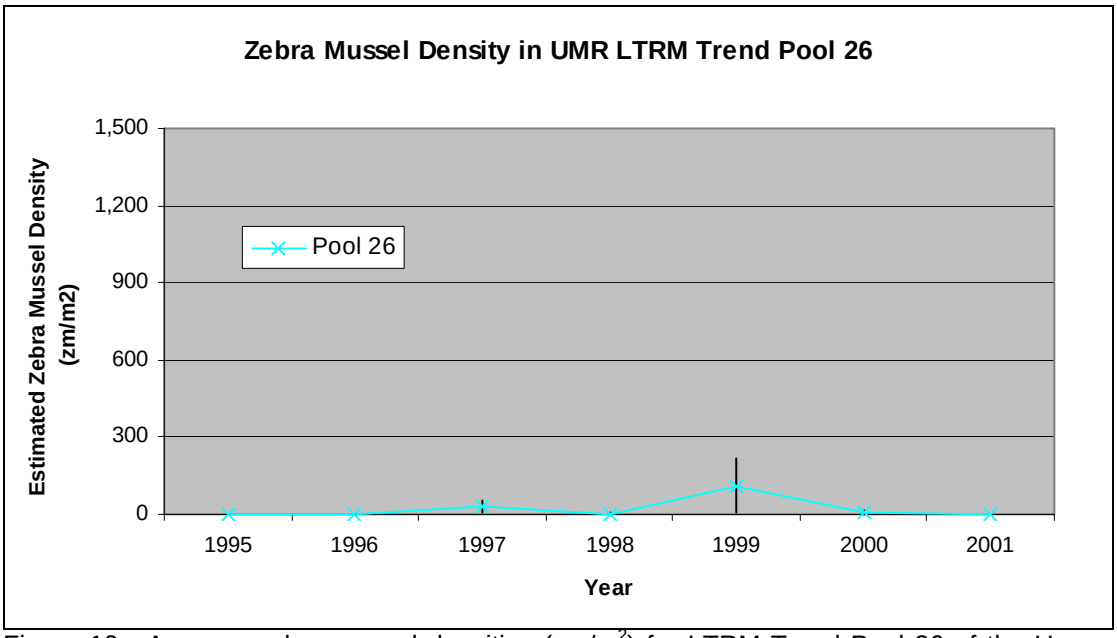

Figure 10. Average zebra mussel densities (zm/m^2) for LTRM Trend Pool 26 of the Upper Mississippi River during the period 1996 through 2002 (number per square meter; ±1 standard error). Source: USGS 2004).

Table 8. Mean zebra mussel density (#/m^2), number of sites sampled, and Standard Error (SE) by aquatic strata for Pool 26 during the period 1995 through 2002. Source: USGS 2004.

Year	Backwater contiguous			Impounded			Side channel			Main channel border		
	Mean density[a]	n[b]	± 1 SE	Mean density	n	± 1 SE	Mean density	n	± 1 SE	Mean density	n	± 1 SE
1995	0	39	0	4	27	3	—[c]	1	—	—[c]	–	—
1996	0	37	0	11	25	11	0	32	0	0	18	0
1997	0	12	0	0	30	0	2	30	1	1	15	1
1998	0	12	0	418	12	310	0	31	0	25	17	23
1999	0	40	0	7	27	7	0	33	0	2	17	2
2000	0	40	0	0	28	0	5	34	2	175	16	170
2001	0	35	0	6	27	4	14	35	13	4	18	3
2002	0	28	0	0	27	0	0	34	0	0	15	0

[a] mean density = zebra mussels/m^2

[b] n = number of sites sampled

[c] Sampling not completed because of high water

St. Croix River

Observations by the National Park Service (Karns 2004) during the fall of 2003 documented adult zebra mussels within the lower St. Croix River. Quantitative sampling identified densities as high as 1,560 adults/m^2. The highest concentrations of adult zebra mussels appear to be in the lower 6 miles of the St. Croix River between the Kinnickinnic narrows and the confluence with the UMR at Prescott, Wisconsin. However, a group of 22 adults was qualitatively observed during a 20-minute timed dive near the I-94 bridge at Hudson. Single adults have been observed as far upstream as Stillwater, Minnesota.

DISCUSSION

The limited spatial and temporal scope of zebra mussel veliger and adult sampling on the UMRS limits statistical detection of changes and interpretation of the results. Veligers were collected from single sampling events each months. Adult zebra mussel density estimates were also limited by spatial extent and sampling intensity.

The 2001 through 2003 data suggest that zebra mussel reproduction and adult densities in the UMR vary widely across space and time. Veliger and adult zebra mussel data strongly suggests that zebra mussels continue to occur in low abundance above L/D 3. Conversely, adult abundance was much greater from Pool 4 downstream, with veliger abundance increasing markedly from L/Ds 4 through L/D 6, the latter of which had some of the highest observed veliger densities among sites sampled. Veliger abundance may have been affected by an inability to effectively detect the smallest veliger stages, therefore observed densities may have been lower than actual densities. The dramatic change in both adult and veliger abundance could suggest that the lentic conditions of Lake Pepin may be a critical component to zebra mussel recruitment for Pool 4 and downstream locations.

Although zebra mussels have been much more abundant at and below Pool 4, recent observations from Pool 4 through about Pool 11 might suggest that zebra mussel populations may have at least temporarily

declined. These areas observed some of the highest adult and veliger densities in 2001, yet also saw dramatic changes with an apparent population crash in 2003. This trend might be the result of decreased adult abundances in Lake Pepin (pers. obs., Mike Davis – MN DNR).

In the lower impounded reach (e.g., pools 12 through 26) adult zebra mussel populations may colonize at lower levels, but maintain their population with lower variability. Veliger density data may show a similar pattern. The persistence of greater veliger abundance in Pools 12-18 (albeit lower than 2001-02) might be the result of adult populations further upriver that are at least partially self-sustaining. If future monitoring indicates that adult densities in the upper portion of the UMR remain low or do not increase, veliger abundances from the lower impounded pools could decline in similar fashion as occurred in the upper Pools in 2003.

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Appendix A

Zebra mussel size distribution

For

Essential Habitat Monitoring Area

of the UMR

Sample Locations for 2001

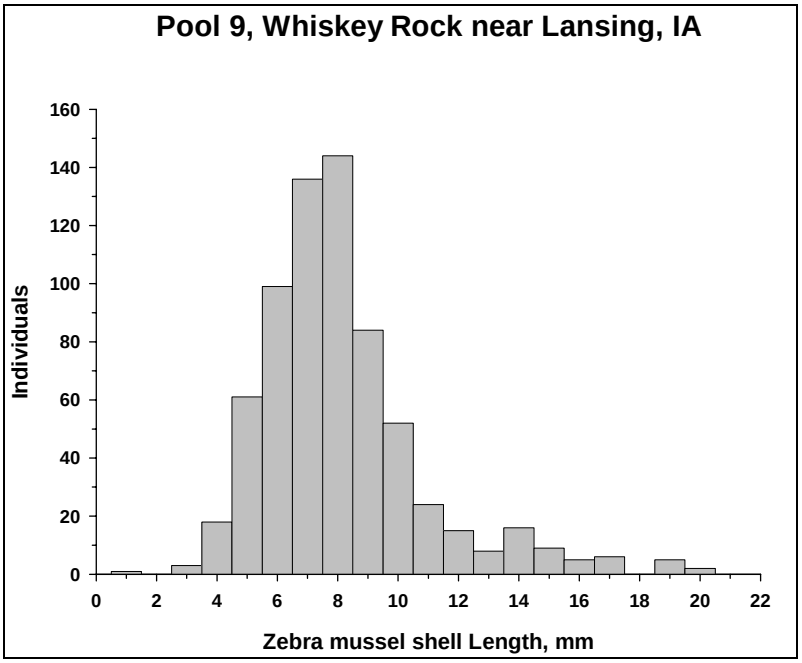

Figure A1. Size distribution of zebra mussels collected in UMR at Whiskey Rock near Lansing, IA in July 2001.

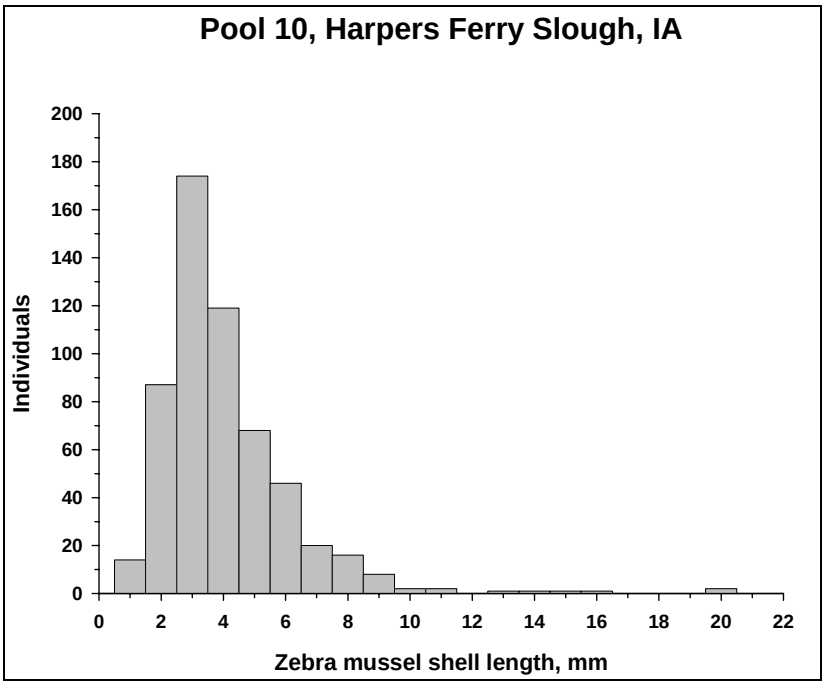

Figure A2. Size distribution of zebra mussels collected in UMR near Harpers Ferry, IA in July 2001.

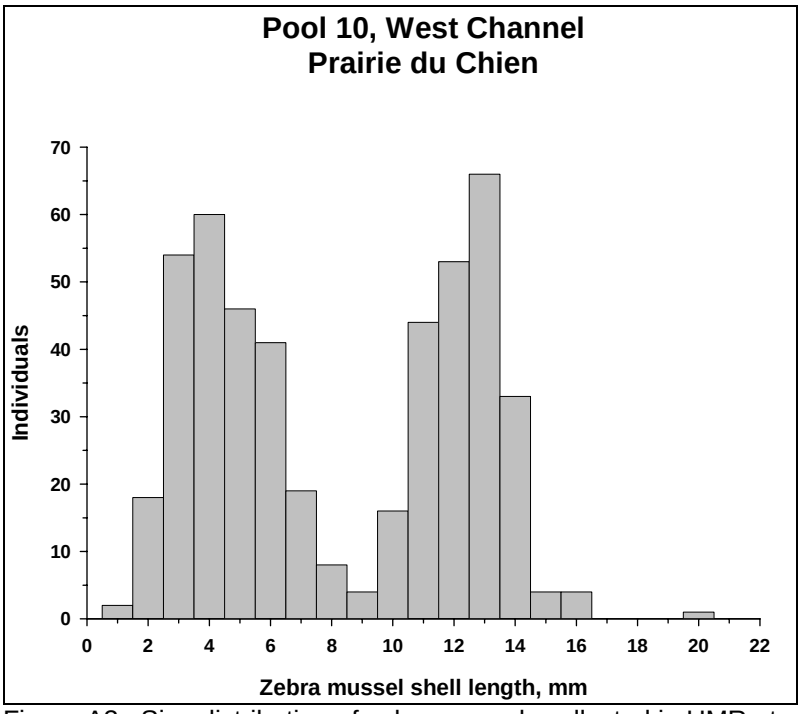

Figure A3. Size distribution of zebra mussels collected in UMR at the West Channel near Prairie du Chien, WI in July 2001.

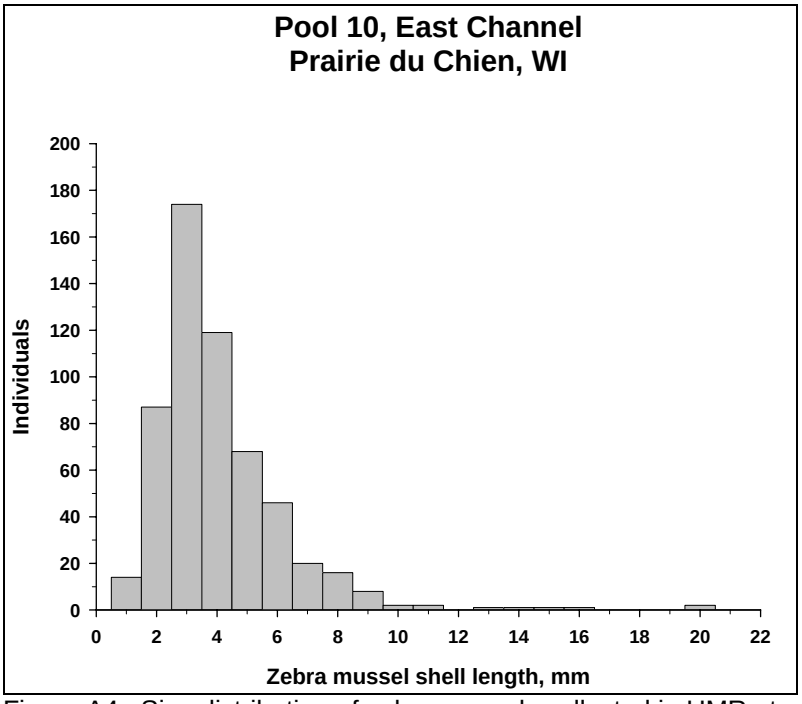

Figure A4. Size distribution of zebra mussels collected in UMR at the East Channel near Prairie du Chien, WI in July 2001.

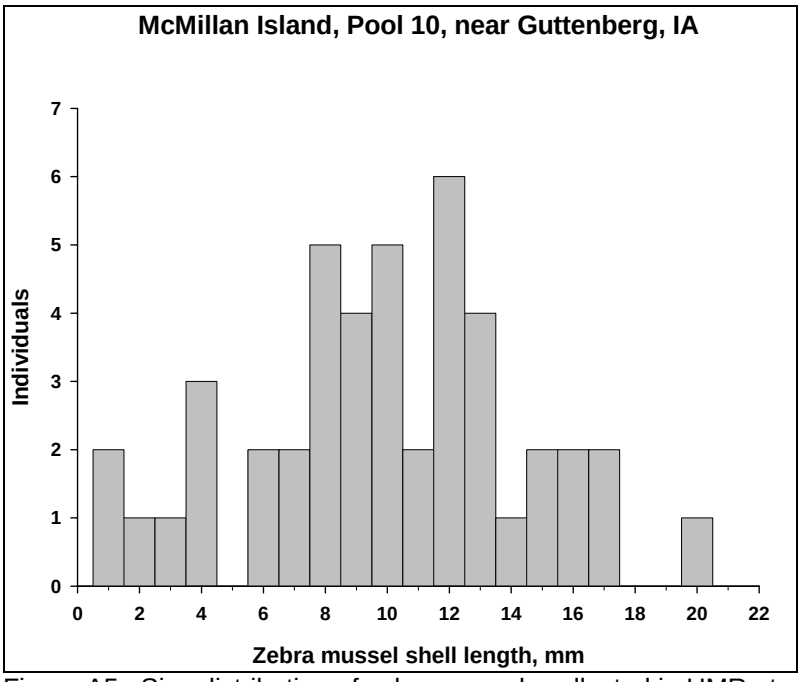

Figure A5. Size distribution of zebra mussels collected in UMR at McMillan Island near Guttenberg, IA in July 2001.

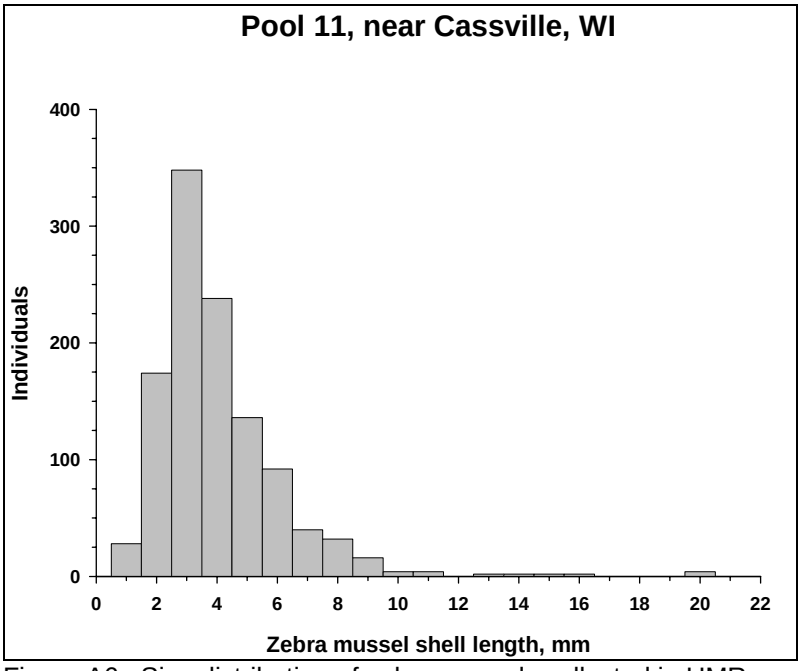

Figure A6. Size distribution of zebra mussels collected in UMR near Cassville, WI in July 2001.

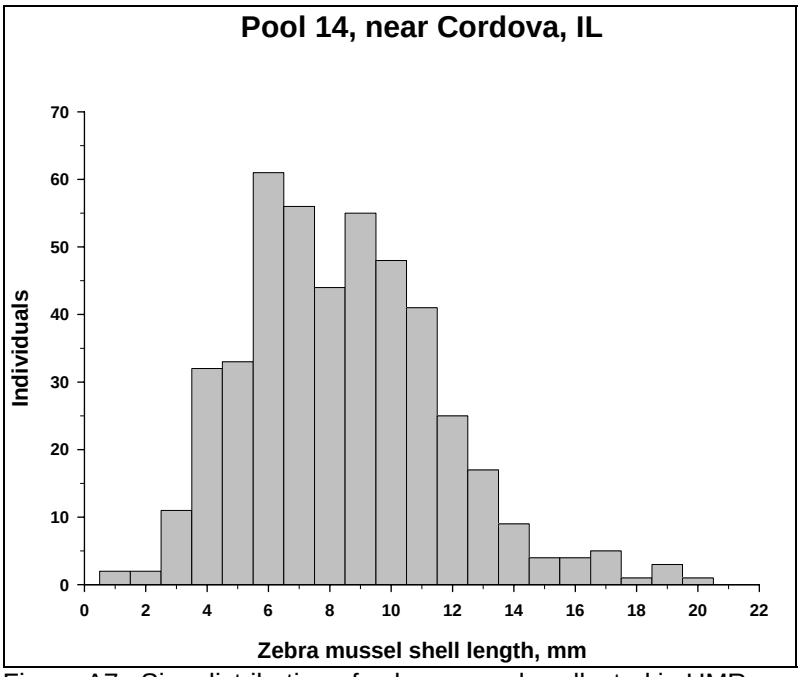

Figure A7. Size distribution of zebra mussels collected in UMR near Cordova, IL in July 2001.

Sample Locations for 2002

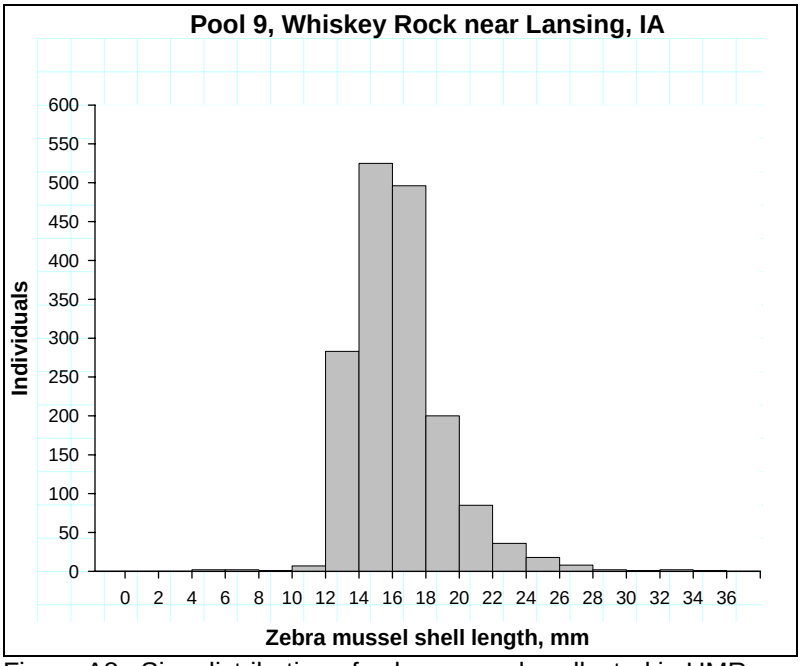

Figure A8. Size distribution of zebra mussels collected in UMR near Lansing, IA in July 2002.

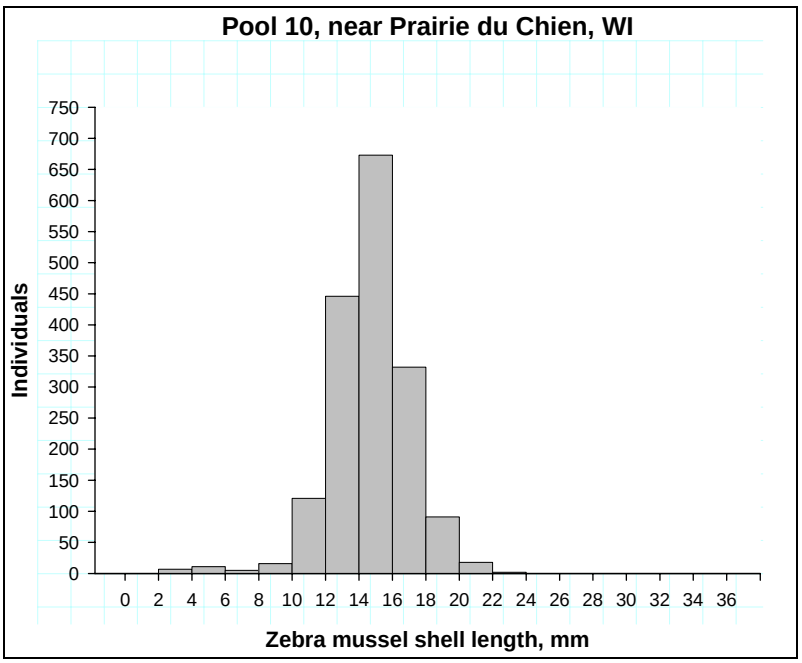

Figure A9. Size distribution of zebra mussels collected in UMR near Prairie du Chien, WI in July 2002.

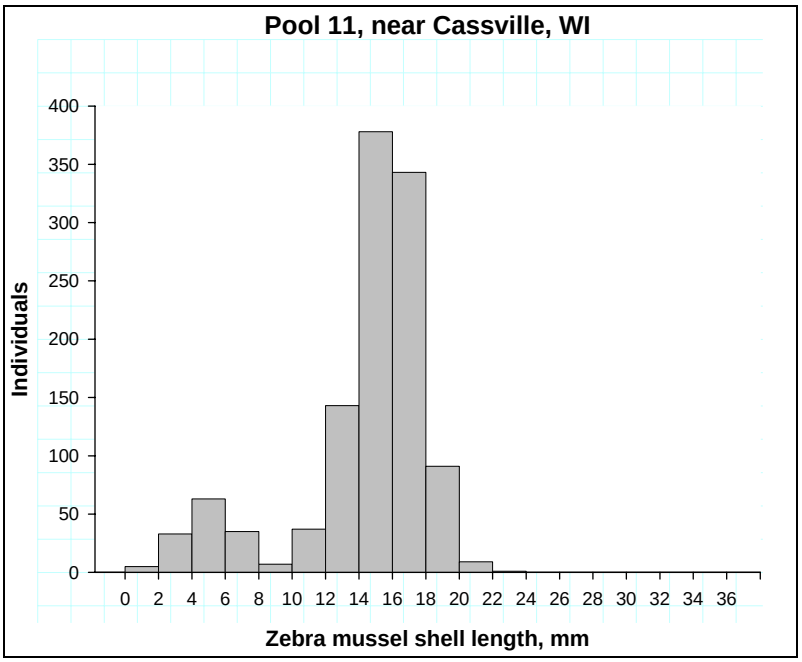

Figure A10. Size distribution of zebra mussels collected in UMR near Cassville, WI in July 2002.

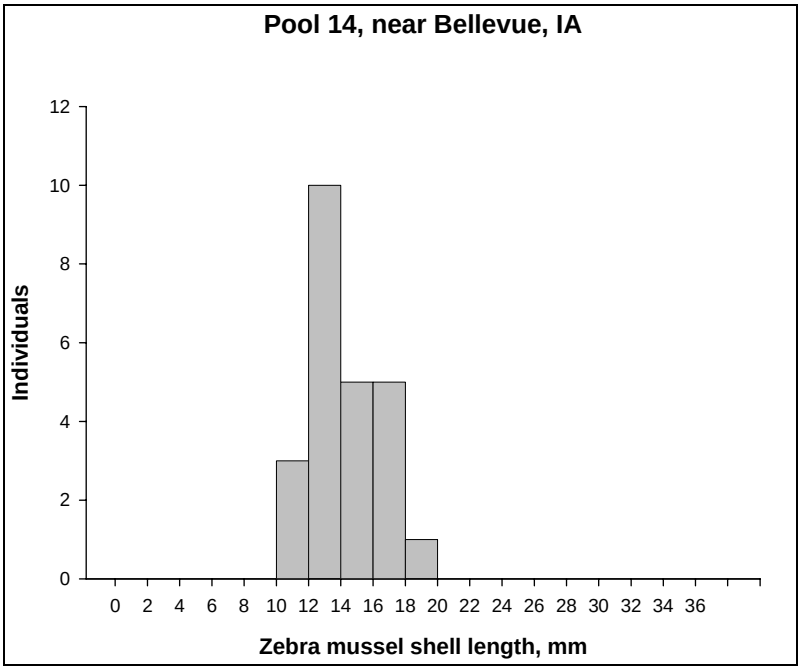

Figure A11. Size distribution of zebra mussels collected in UMR near Bellevue, IA in July 2002.

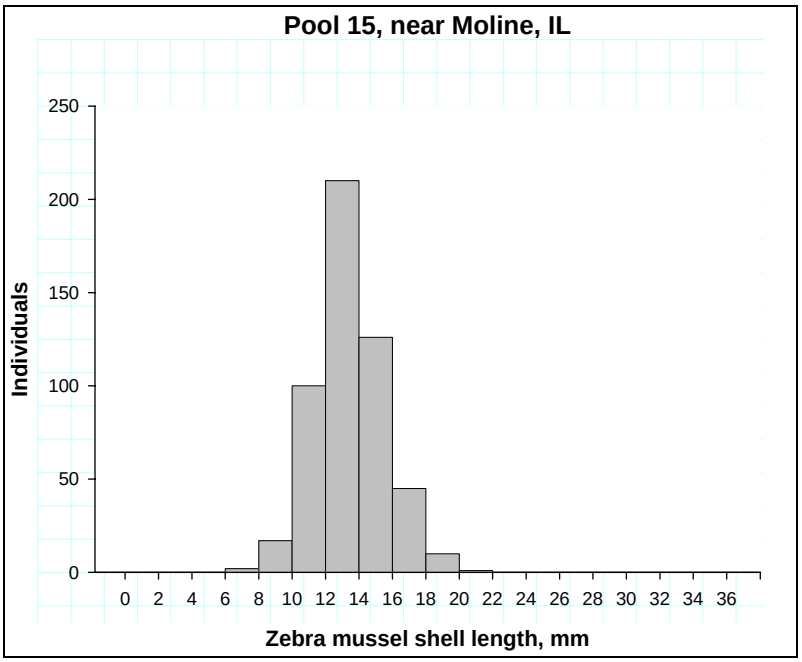

Figure A12. Size distribution of zebra mussels collected in UMR near Moline, IL in July 2002.

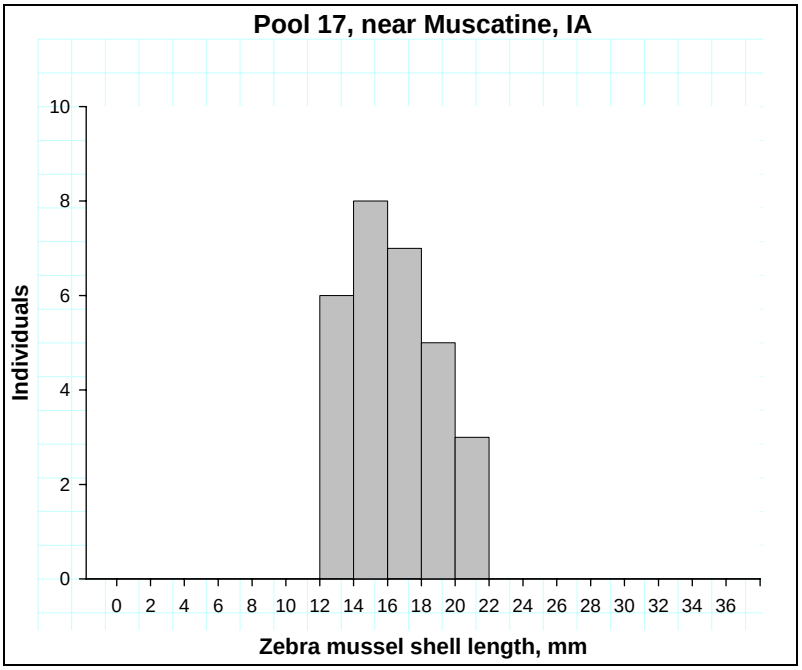

Figure A13. Size distribution of zebra mussels collected in UMR near Muscatine, IA in July 2002.

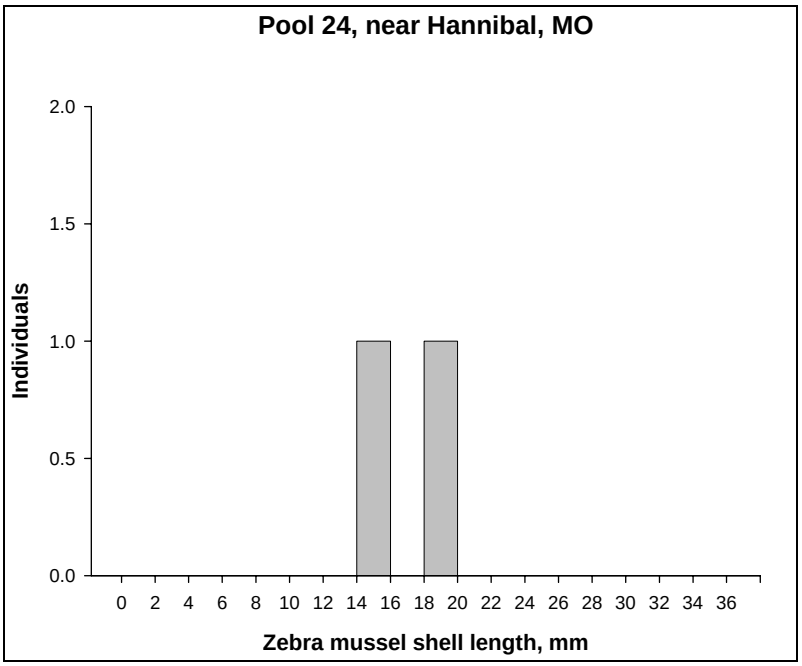

Figure A144. Size distribution of zebra mussels collected in UMR near Hannibal, MO in July 2002.

Sample Locations for 2003

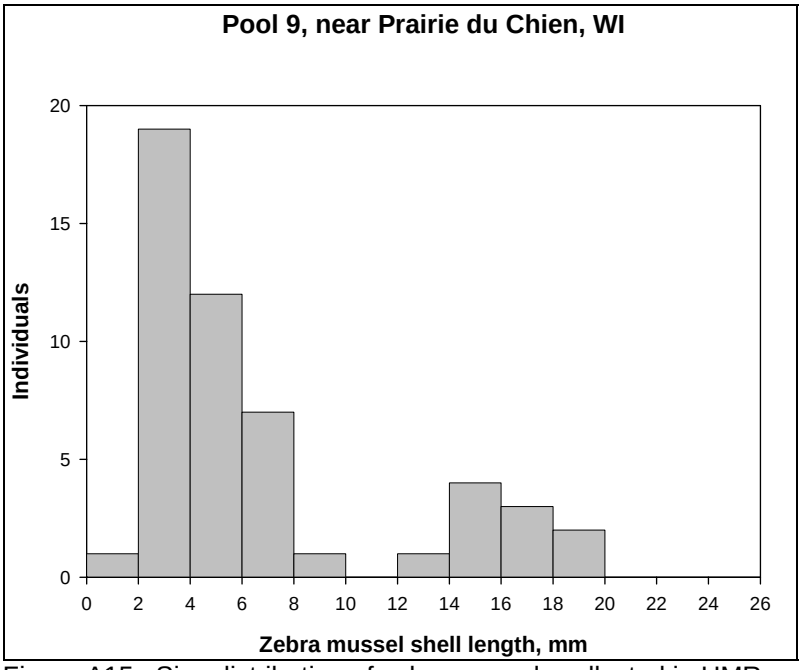

Figure A15. Size distribution of zebra mussels collected in UMR near Prairie du Chien in July 2003.

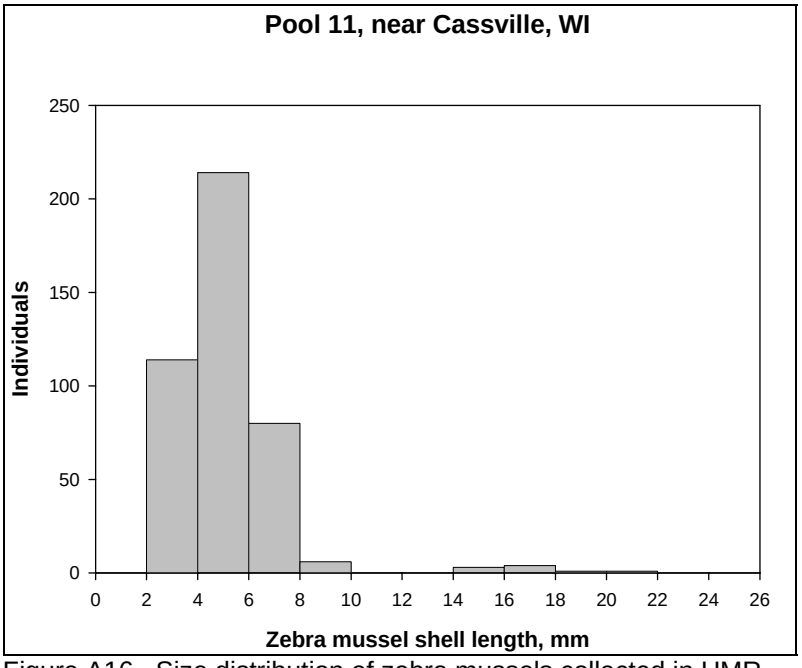

Figure A16. Size distribution of zebra mussels collected in UMR near Cassville in July 2003.

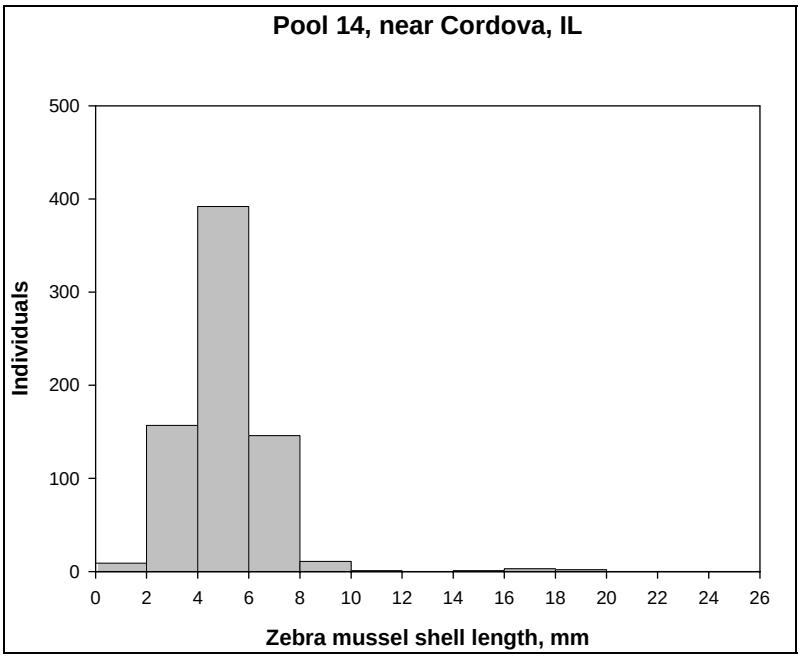

Figure A17. Size distribution of zebra mussels collected in UMR near Cordova in July 2003.

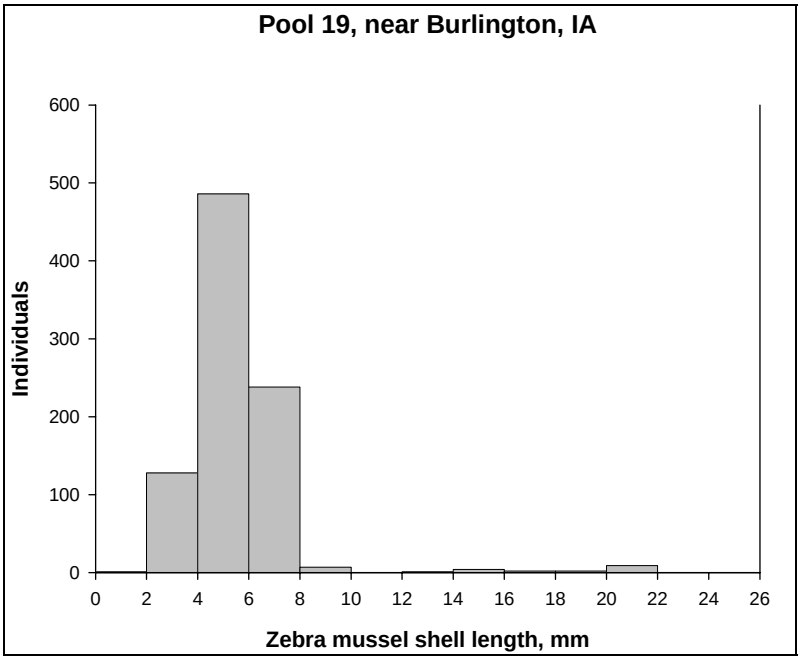

Figure A18. Size distribution of zebra mussels collected in UMR near Burlington in July 2003.