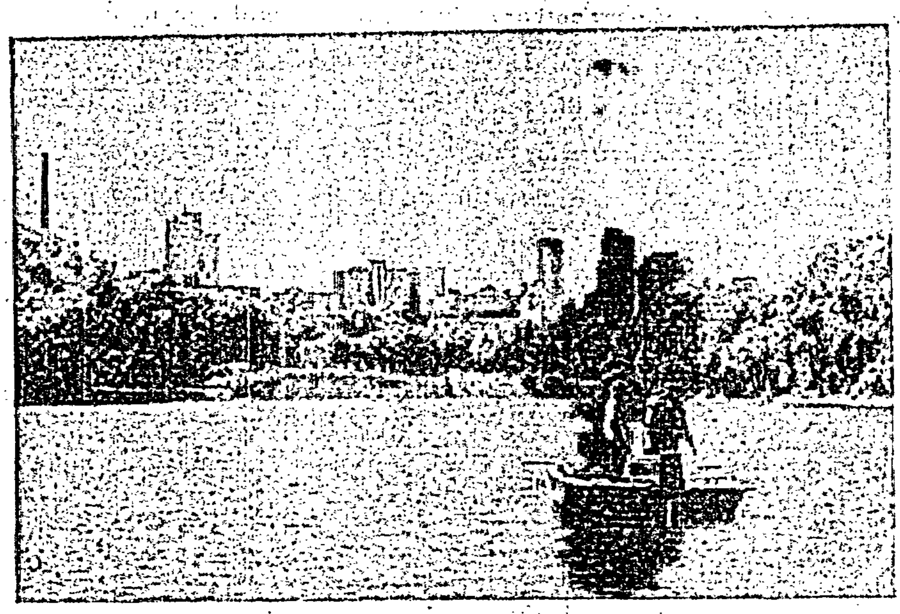
Final Report: Mussel (Bivalvia: Unionidae) survey of the Mississippi National River and Recreation Area Corridor, 2000-01.



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Copies of this report can be obtained by contacting;

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Executive Summary

During 2000 and 2001, we sampled 152 sites for mussels along the entire Mississippi National River and Recreation Area (MNRRA) Corridor which encompasses a 72 mile stretch of the Upper Mississippi River (UMR) (138 sites), a four mile reach of the lower Minnesota River (MNR) near its confluence with the UMR (14 sites), and the lower Rum River (RR) near its confluence with the UMR (one site). The UMR stretch extends from approximately 20 miles north of the Twin Cities, through the Twin Cities, to just below Hastings, MN. Five pools or reaches were surveyed and include from upstream to downstream; Coon Rapids Pool, St. Anthony Falls Pool, and Pools 1, 2, and Upper Pool 3. Sample methods were consistent throughout the study and consisted of timed searches and hand collection of mussels while wading, snorkeling, and diving. Quantitative samples were also collected and mussel bed boundaries mapped at five sites within the UMR. Over 12,000 live mussels representing 28 species were collected with an additional 12 species collected as empty shells. The mussel fauna of UMR Pools 1-3 appears to be recovering since its reported decimation by pollution during the first half of the 1900s. This survey provided clear evidence of recent and ongoing recruitment, and many of the individuals collected were less than 10 years old. Several state listed species were collected including two listed as endangered in Minnesota, rock pocketbook (*Arcidens confragosus*) and wartyback (*Quadrula nodulata*). Recolonization is probably due to improved water quality conditions over the past 15-20 years. Furthermore, mussels are expanding their range above St. Anthony Falls (historically a faunal barrier to upstream dispersal) as fish now circumnavigate the two navigation locks. A total of 16 live species were collected from the St. Anthony Falls Pool including 10 species previously not reported there. Zebra mussels were absent above Lock and Dam 1 and very scarce from UMR Pool 2 and Upper Pool 3 and the lower MNR. These UMR pools differ from those downstream (Pool 4 and below) where zebra mussels are extremely abundant and are decimating the native mussel communities. Ironically, this reach of the Mississippi River between the Twin Cities and Hastings, MN, once nearly a dead zone, may now be one of the last big river mussel refuges in the Midwestern United States.

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1.0 Introduction

In July 1999, the Minnesota Department of Natural Resources (MNDNR)-Division of Ecological Services began a freshwater mussel survey to determine the distribution and abundance of unionoid mussels in Minnesota. During 2000, 60 sites on the Upper Mississippi River (UMR) within the Mississippi National River and Recreation Area (MNRRA) Corridor were sampled for mussels by hand while wading, snorkeling, and diving. This effort was primarily confined to UMR Pools 1, 2, and 3 and survey work within MNRRA remained incomplete. As a result MNRRA aquired funds through the National Park Service Great Lakes Network Inventory and Monitoring Program (NPS I&M) for additional survey work in 2001.

Historically, as many as 41 mussel species including three federally listed species; Higgins' eye pearly mussel (*Lampsilis higginsi*), winged mapleleaf *(Quadrula fragosa)*, fat pocketbook *(Potamilus capax)*, and most state listed species in Minnesota have been found within the MNRRA Corridor (Table 1-1). This constitutes nearly 90% of the mussel species found throughout the state of Minnesota (MNDNR, unpublished data) and approximately 80% of all species found throughout the entire UMR drainage (Havlik and Sauer 2000). However, the mussel fauna of the UMR above Lake Pepin was reportedly decimated by pollution during the first three-quarters of the 1900s (Fuller 1980). In the 1970s, the U.S. Army Corps of Engineers-St. Paul District conducted a mussel survey for the 9-foot navigation project and found only nine live species at one site immediately below the Ford Dam (Lock and Dam 1) and only a few scattered mussels down to Lock and Dam 3 near Red Wing, MN (Fuller 1980). No live mussels were found above the Ford Dam to just above the Falls at St. Anthony. They reported that the mussel community "....shows poor condition. It is very sparse and sporadic.... There was no evidence of recent recruitment...." and they declared "....the outlook for a mussel renaissance in this troubled reach is extremely poor...." and will remain so "...until radical improvement in water quality is accomplished...". Fortunately, there were radical improvements in water quality in the Mississippi River following a successful citizen's campaign in the late 1970s that demanded the separation of storm water and sanitary sewers and higher quality effluent from wastewater treatment facilities primarily in the Twin Cities. The MNDNR's 2000 survey effort in UMR Pools 1-3 documented a recovering mussel community which is probably due to improved water quality conditions over the past 15-20 years.

These baseline data within the MNRRA Corridor are the first step in establishing a long term monitoring program and are crucial for conservation planning of mussel species state and region wide as well as within the corridor. These data will be added to a NPS I&M database on all sensitive plant and animal species nationwide and will ultimately be used for species conservation in NPS managed units. These data will also be entered in the MNDNR's Natural Heritage and Nongame Research Program's Natural Heritage Information System. Ultimately, these data will be used for watershed

Table 1-1. Mussel species recorded[1] from the MNRRA Corridor

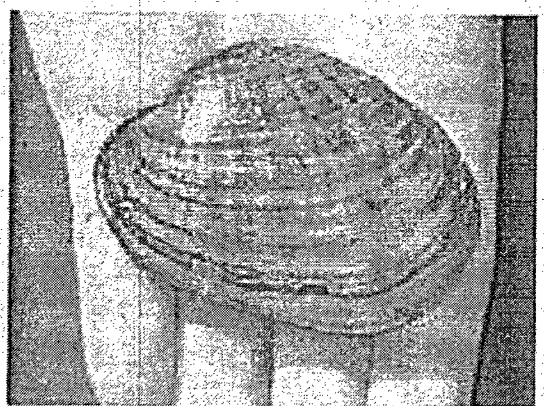
Species	Common name	Status[2]
Actinonaias ligamentina	mucket	MT
Alasmidonta marginata	elktoe	MT
Amblema plicata	threeridge	
Arcidens confragosus	rock-pocketbook	ME
Cumberlandia monodonta	spectaclecase	MT
Cyclonaias tuberculata	purple wartyback	MT
Ellipsaria lineolata	butterfly	MT
Elliptio crassidens	elephant-ear	ME
Elliptio dilatata	spike	MS
Epioblasma triquetra	snuffbox	MT
Fusconaia ebena	ebonyshell	ME
Fusconaia flava	wabash pigtoe	
Lampsilis cardium	plain pocketbook	
Lampsilis higginsi	Higgins eye	ME, FE
Lampsilis siliquoidea	fat mucket	
Lampsilis teres	yellow sandshell	ME
Lasmigona complanata	white heelsplitter	
Lasmigona compressa	creek heelsplitter	MS
Lasmigona costata	fluted-shell	MS
Leptodea fragilis	fragile papershell	
Ligumia recta	black sandshell	MS
Megalonaias nervosa	washboard	MT
Obliquaria reflexa	threehorn wartyback	
Obovaria olivaria	hickorynut	MS
Plethobasus cyphyus	sheepnose	ME
Pleurobema sintoxia	round pigtoe	MT
Potamilus alatus	pink heelsplitter	
Potamilus capax	fat pocketbook	MX, FE
Potamilus ohiensis	pink papershell	
Pyganodon grandis	giant floater	
Quadrula fragosa	winged mapleleaf	ME, FE
Quadrula metaneura	monkeyface	MT
Quadrula nodulata	wartyback	ME
Quadrula pustulosa	pimpleback	
Quadrula quadrula	mapleleaf	
Strophitus undulatus	strange floater	
Toxolasma parvus	lilliput	
Tritogonia verrucosa	pistolgrip	MT
Truncilla donaciformis	fawnsfoot	
Truncilla truncata	deertoe	
Utterbackia imbecillis	paper pondshell	
Total	41	

[1]This study, Fuller 1980

[2]MS=Minnesota species of special concern, MT=Minnesota threatened,
ME=Minnesota endangered, MX=extirpated from Minnesota, FE=federally endangered

management planning by minimizing impacts to mussel species from sources such as water resource development projects and in assigning legal state and federal mussel conservation status.

The MNDNR, under contract with NPS, completed sampling for this survey in the summer of 2001. This report summarizes the results of this mussel survey (2001) as well as previous MNDNR work within the MNRRA Corridor (2000).



L. higginsi.

Q. fragosa (photo courtesy Kevin S. Cummings INHS).

In April 2000, the U.S. Fish and Wildlife Service (USFWS) issued a jeopardy opinion to the U.S. Army Corps of Engineers (USACE) on the federally endangered *L. higginsi* in the Upper Mississippi River system. The USFWS determined the major adverse effect to the continued existence of *L. higginsi* is the upriver transport of nonindigenous zebra mussels (*Dreissena polymorpha*) by commercial and recreational vessels. The USFWS biological opinion listed a Reasonable and Prudent Alternative (RPA) believed necessary to avoid jeopardy for *L. higginsi*. An RPA was for the Corps to develop an *L. higginsi* Relocation Action Plan and a monitoring program for *L. higginsi* and other mussels. As a result *L. higginsi* along with other species listed for protection in Minnesota were relocated from zebra mussel infested waters in Pools 11 and 14 of the Mississippi River to areas within the MNRRA Corridor in 2000 and 2001. These relocation areas were selected based on the results of this survey effort. This report will present total number of mussels and species relocated and their location. Our data should be considered for future monitoring activities.

2.0 Methods

2.1 Study Area

The MNRRA Corridor includes 72 miles (115.9 km) of the Upper Mississippi River (UMR) and four miles (6.4 km) of the lower Minnesota River (MNR) and encompasses approximately 54,000 acres (22,000 ha) of public and private land and water in five Minnesota counties (Figure 2-1). The MNRRA Corridor boundary is somewhat irregular and is roughly defined as the area existing from "bluff to bluff" on each side of the UMR. Lower portions of tributaries of the UMR that fall within this boundary are included in the corridor. The upstream and downstream boundary of the UMR portion of the corridor extends from approximately 20 miles (32 km) north of the Twin Cities near the cities of Dayton and Ramsey, MN (River mile [RM] 879), through the Twin Cities to the Goodhue-Dakota county line just south of Hastings, MN (approximate mid-point of UMR Pool 3 at RM 807). Four pools or reaches and an upper portion of a fifth pool fall within this stretch and include from upstream to downstream; Coon Rapids Pool (CR) (above Coon Rapids Dam), St. Anthony Falls Pool (SAF) (above St. Anthony Falls), and Pools 1, 2, and upper 3. We define a pool as a segment of the river separated by locks and dams. Pool 2 comprises nearly half of the study area (32 miles, 51.5km) and consists of three distinct reaches that differ in habitat and mussel species composition and relative abundance. Therefore, for a more accurate interpretation of the results we have sub-divided Pool 2 into three distinct reaches; Upper Pool 2 (Lock and Dam 1 to the confluence with the Minnesota River), Middle Pool 2 (Minnesota River to the I-494 Bridge at RM 832.5), and Lower Pool 2 (I-494 to Lock and Dam 3) (see Figure 2-1). The lower MNR reach extends from the I-494 Bridge in Bloomington, MN to its confluence with the UMR at Upper Pool 2 in the Twin Cities. Another reach within the MNRRA Corridor included in the study was the lower Rum River (RR) near its confluence with the UMR at Anoka, MN (see Figure 2-1).

2.2 Sampling

The mussel survey was conducted during the Summer/Fall of 2000 and 2001 using two sampling

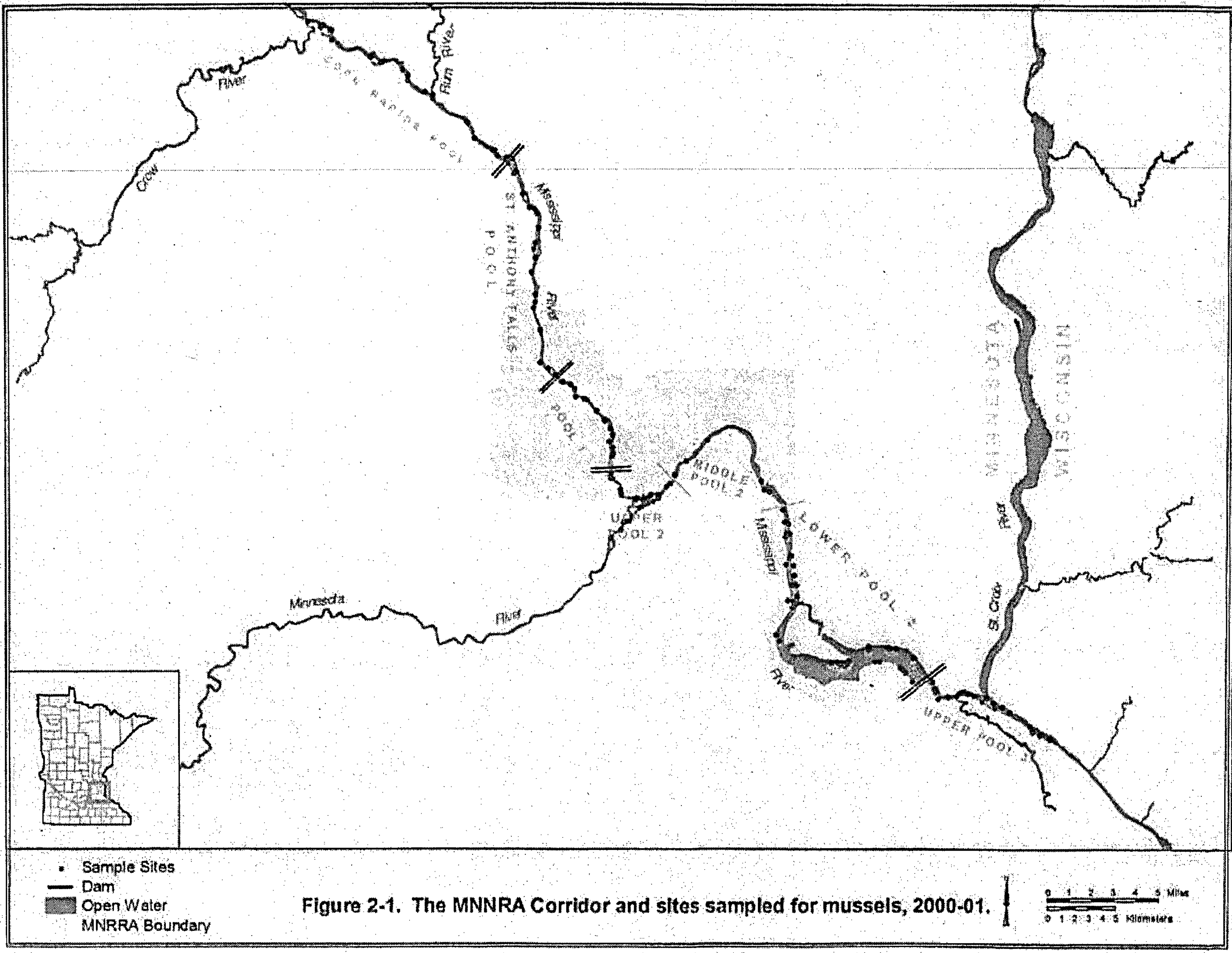


Figure 2-1. The MNNRA Corridor and sites sampled for mussels, 2000-01.

and zebra mussels attached to native mussels collected were counted and destroyed.

2.2.1 Qualitative Sampling (timed searches)

Sites to be sampled were typically identified by consulting a navigation chart and by conducting reconnaissance searches by brailing and/or bank searches. We initially identified areas from the navigation chart that we expected to harbor mussels based on our experience in other reaches of the Mississippi River and mussel habitat preference. These areas were normally along either bank (outside or inside descending), in side channels, in eddies, in-between wing dams, or in other similar habitat. We usually avoided the main channel, eroded or unstable banks, and areas with considerable human disturbance (i.e., barge fleeting/loading facilities, marinas, effluent discharges, trash, etc..). We then conducted reconnaissance searches to better locate sites for our timed searches. Reconnaissance included bank searches for empty shells, locating habitat that appeared favorable (i.e., stable and sufficient flow or wave action to maintain a relatively silt free but stable substrate) and the use of a depth finder to determine bottom contour and depth. During 2000, we also conducted five-minute brail runs. The brail consisted of an eight foot wooden bar with several crowfoot shaped hooks attached to each of 20 x 12 inch long chains. The bar was dragged along the river bottom, downstream, and parallel to the bank. Mussels were captured when they clamped down on the hooks. However, we abandoned this method in 2001 and had equal success in identifying sites to sample from our initial reconnaissance searches. Sites were numbered from upstream to downstream and were continuous throughout the Mississippi River irrespective of reach. The Minnesota and Rum rivers were numbered similarly, starting with Site 1 at the most upstream site.

At each site, two or three divers hand collected all live and dead mussels by crawling along the river bottom, continually sweeping their hands back and forth sifting through the substrate, while looking and feeling for mussels. One-person hour/site was targeted as the search time and sites were typically spaced no more than one mile (1.6 km) apart. Divers typically searched all microhabitats at a particular site with the intent of locating high mussel densities and collecting as many live mussels as possible, thus maximizing the chance of collecting all species present. All mussels collected were placed in mesh bags, brought to the surface, identified to species, counted, and aged by an external annuli count (Neves and Moyer 1988). To compensate for the error associated with aging, mussels were placed in one of three age classes; 1-5, 6-10, and >10 years old. Within each age class, minimum and maximum length were determined for each species (maximum shell length, anterior-posterior axis). We collected at least one live and one empty shell of each species from each river and pool and deposited them at the University of Minnesota's James Ford Bell Museum of Natural History Mollusk Collection. All others were returned to the approximate location where collected. These specimens have been identified in the NPS I&M database. For each site, time spent searching and general habitat conditions (i.e., min. max. depth, substrate [silt/sand/gravel/cobble/boulder], and general riparian zone comments) were

recorded. Catch per unit effort (CPUE) was calculated as the number of individuals collected divided by the time spent searching for mussels (live mussels/hour). One centrally located GPS coordinate was recorded for each site to mark the site's general location.

2.2.2 Quantitative Sampling

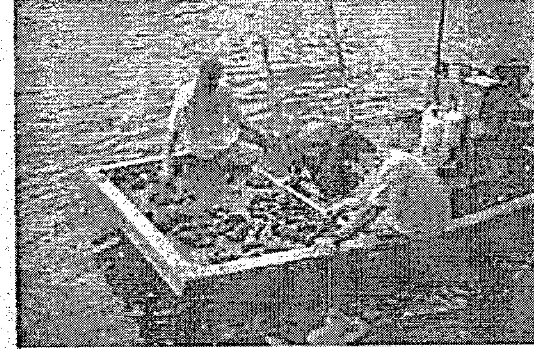
Sites sampled by timed searches that harbored a species rich and/or dense mussel community, or that contained rare species, were chosen as areas to be quantitatively sampled. Quantitative samples were collected in 2001 at five sites, all within the UMR proper. These areas are referred to as Beds 1-5 and as with qualitative sites, are organized from upstream to downstream. Beds 1 and 2 were at the head of the SAF Pool and correspond to qualitative Sites 22 and 29, respectively. Beds 3 and 4 were in Upper Pool 2 and correspond to Sites 58 and 66, respectively. Bed 5 was in Lower Pool 2 and corresponds to Site 97.

At each site, prior to quantitative sampling, divers delineated the approximate boundaries of the bed. Divers traversed the river bottom to estimate mussel density, placing anchored buoys along the perimeter of the bed to aid the surface crew in mapping the beds' boundaries. This also facilitated the placement of individual quadrats within the bed so that the sampling effort was distributed throughout the bed.

A diver collected total substrate samples from each site using a $0.25m^2$ metal frame quadrat with a mesh bag consisting of ¼ inch mesh (6 mm) attached, to receive the collected sample. The number of samples per site ranged from 25 to 40 depending on the size of the bed. Quadrat placement was not random, rather we attempted to distribute the samples throughout the entire bed. Each sample was brought to the surface, fine substrates rinsed through the bag, and all mussels removed. All live native mussels were identified, aged, length measured, number of attached zebra mussels recorded, and then returned to the approximate location where collected. GPS coordinates were recorded along the perimeter of each mussel bed to approximate the area and location of the bed. One-way ANOVA followed by Tukey's multiple comparison test followed by Bonferroni correction was used to compare mussel density among beds.

Diver with a full bag of mussels from a timed search (left).

Working up mussels (right).



3.0 Results

A total of 152 sites (60 and 92 during 2000 and 2001, respectively) were sampled within the MNNRA Corridor via timed dive searches (qualitative) (see Figure 2-1). During 2001, five of these sites were also sampled quantitatively. Overall, 12,290 live mussels representing 28 species were found and an additional 12 species were found as empty shells (Table 3-1). Below are results for qualitative samples, first summarized collectively then organized by reach, followed by quantitative samples organized by site (bed).

3.1 Qualitative Sampling (timed searches)

During qualitative sampling a total of 11,932 live mussels were found including all live (28) and dead (12) species recorded in the study (i.e., no additional species collected in quantitative samples) (see Table 3-1). Sample sites were distributed fairly evenly throughout the study area (see Figure 2-1) and average time spent searching for mussels was slightly greater than one-person hour/site but varied (mean 64.3 person minutes/site ± 34.0 stdev [range 5 to 200]). Overall, average CPUE was 71.4 live mussels/hr, but was highly variable throughout the study (± 93.9 stdev, range 0 to 504 mussels/hr).

Although no federally endangered species were found live, old shells of the federally endangered *L. higginsi* and *Q. fragosa* were collected, an indication of their former presence in the area. Twelve mussel species listed for protection in Minnesota were collected live. These included two listed as endangered, the rock pocketbook (*Arcidens confragosus*) and wartyback (*Quadrula nodulata*) (see Table 3-1). Overall, the mussel fauna within the MNRRA Corridor was dominated (in descending order) by; three-horned wartyback (*Obliquaria reflexa*), threeridge (*Amblema plicata*), deertoe (*Truncilla truncata*), and mapleleaf (*Quadrula quadrula*) (see Table 3-1). However, as with CPUE, individual species occurrence and relative abundance were highly variable among pools and rivers and even among sites within pools. For individual species distributions throughout the MNRRA Corridor see maps in Appendix I and for species, number of individuals collected, and CPUE for each site see tables in Appendix II. For UTM coordinates (NAD 1983) for each site sampled see Appendix III.

The mussel fauna within all reaches of the MNRRA corridor was relatively young indicating that recent reproduction and recruitment of young individuals has occurred throughout the corridor and that until recently, mussels were uncommon. Most species were dominated by young individuals (<11 and <6 years old) (Figure 3-1). However, a few older relict populations consisting of only a few individuals were also present indicating that some species apparently have been present for a long time and have not recently reproduced.

Table 3-1. Overall mussel species richness and relative abundance within the MNRRA Corridor, 2000-01.

Species	Status[1]	Qualitative No.	Qualitative %	Quantitative No.	Quantitative %	Total No.	Total %
Actinonaias ligamentina	MT	6	0.1			6	<0.1
Alasmidonta marginata	MT	3	<0.1			3	<0.1
Amblema plicata		1,899	15.9	94	26.3	1,993	16.2
Arcidens confragosus	ME	30	0.3			30	0.2
Cumberlandia monodonta	MT	D				D	
Cyclonaias tuberculata	MT	D				D	
Ellipsaria lineolata	MT	1	<0.1			1	<0.1
Elliptio crassidens	ME	D				D	
Elliptio dilatata	MS	14	0.1			14	0.1
Epioblasma triquetra	MT	D				D	
Fusconaia ebena	ME	D				D	
Fusconaia flava		927	7.8	24	6.7	951	7.7
Lampsilis cardium		751	6.3	5	1.4	756	6.2
Lampsilis higginsi	ME, FE	D				D	
Lampsilis siliquoidea		203	1.7	D		203	1.7
Lampsilis teres	ME	D				D	
Lasmigona complanata		23	0.2			23	0.2
Lasmigona compressa	MS	1	<0.1			1	<0.1
Lasmigona costata	MS	D		D		D	
Leptodea fragilis		294	2.5	4	1.1	298	2.4
Ligumia recta	MS	218	1.8	7	2.0	225	1.8
Megalonaias nervosa	MT	2	<0.1	1	0.3	3	<0.1
Obliquaria reflexa		2,981	25.0	92	25.7	3,073	25.0
Obovaria olivaria	MS	6	0.1			6	<0.1
Plethobasus cyphyus	ME	D				D	
Pleurobema sintoxia	MT	7	0.1			7	0.1
Potamilus alatus		343	2.9	5	1.4	348	2.8
Potamilus ohiensis		106	0.9	3	0.8	109	0.9
Pyganodon grandis		256	2.1	2	0.6	258	2.1
Quadrula fragosa	ME, FE	D				D	
Quadrula metanevra	MT	1	<0.1			1	<0.1
Quadrula nodulata	ME	179	1.5	9	2.5	188	1.5
Quadrula pustulosa		182	1.5	10	2.8	192	1.6
Quadrula quadrula		1,489	12.5	40	11.2	1,529	12.4
Strophitus undulatus		196	1.6	5	1.4	201	1.6
Toxolasma parvus		D				D	
Tritogonia verrucosa	MT	D				D	
Truncilla donaciformis		52	0.4	D		52	0.4
Truncilla truncata		1,758	14.7	57	15.9	1,815	14.8
Utterbackia imbecillis		4	<0.1			4	<0.1
Total		11,932		358		12,290	
No. live species		28		15		28	
Total species		40		18		40	
No. sites		152		5		152	
Ave. time/site (min) ± stdev.		64.3±34.0				64.3±34.0	
CPUE (no. live/hour) ± stdev.		71.4±93.9				71.4±93.9	

[1]MS=Minnesota species of special concern, MT=Minnesota threatened, ME=Minnesota endangered, MX=extirpated from Minnesota, FE=Federally endangered.

D=Collected as empty shell.

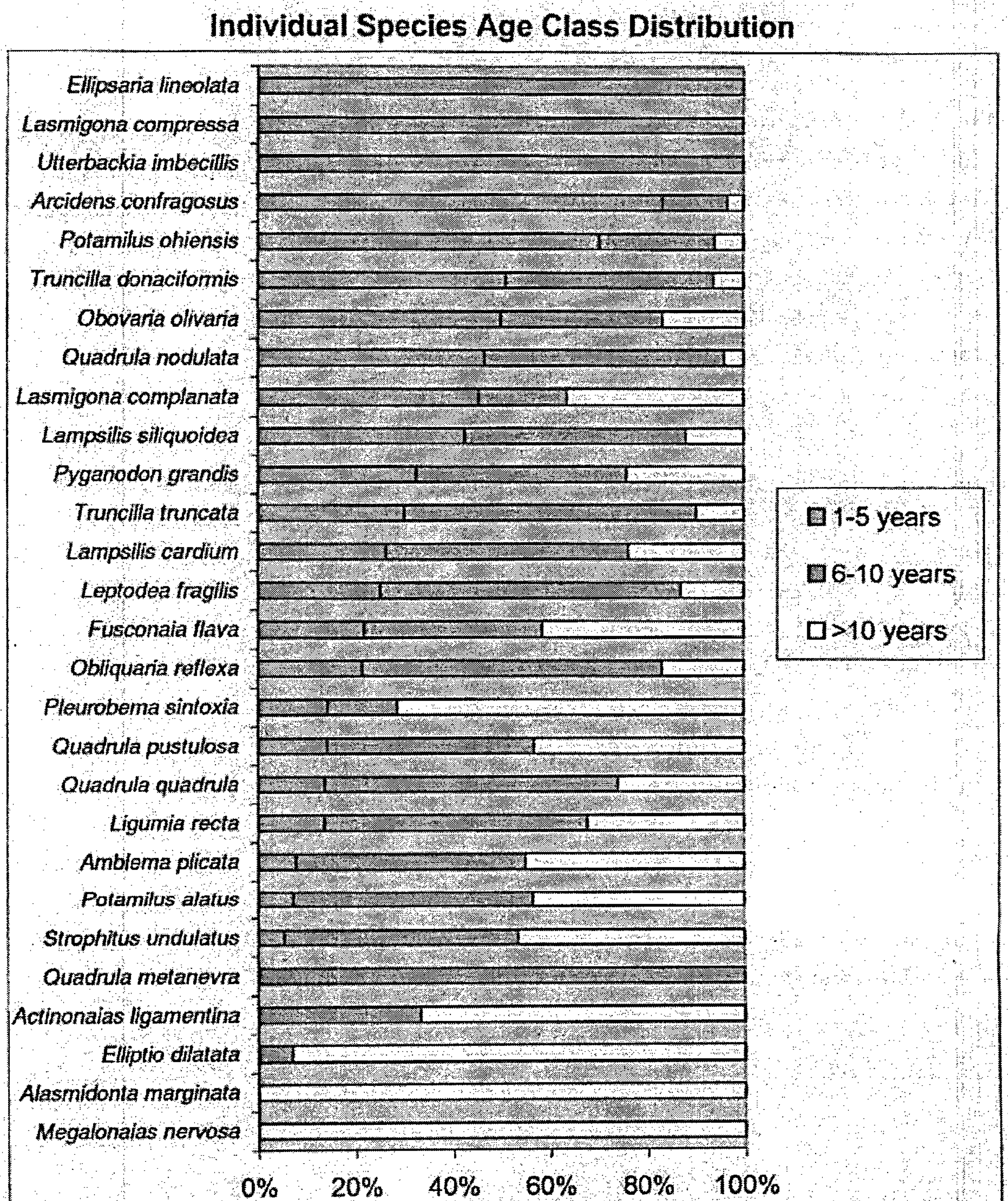


Figure 3-1. Individual species age class distributions from timed searches within the MNRRA Corridor, 2000-01

Below are results by reach, organized from upstream to downstream for the Mississippi River proper followed by the two tributary reaches of the lower Minnesota and Rum rivers.

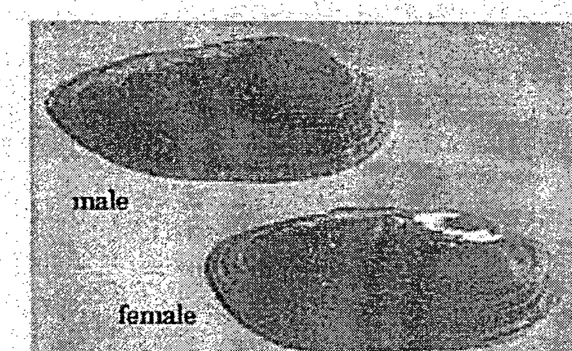
3.1.1 Coon Rapids Pool

Mussel species richness and abundance within the Coon Rapids (CR) Pool was relatively poor compared to the other reaches within the MNRRA Corridor (Figures 3-2 and 3-3). A total of 587 mussels representing six species were collected at 19 sites and average CPUE was 22.0 mussels/hr (Table 3-2). The community was dominated by plain pocketbook (*Lampsilis cardium*) (62.7%) followed by fatmucket (*Lampsilis siliqouidea*) (19.9%) and black sandshell (*Ligumia recta*) (14.8%), respectively. Despite low species richness and abundance, the CR Pool appears to support a healthier population of *L. recta*, a species of special concern in Minnesota, than the other MNRRA reaches.

Habitat in the upper reaches of the pool consisted of alternating riffles, runs, and pools with water depth typically <2m, conditions favored by mussels. However, only Sites 4 and 12 supported an abundant mussel community. Site 4 was at the lower end of NPS Island 101-01 near Goodin Island at approximately river mile 878.2 (Figure 3-4). A total of 229 live mussels were collected including 19 live *L. recta*. *Lampsilis cardium* dominated the community and overall CPUE was 152.7 mussels/hr (Appendix II). Site 12 was in the city limits of Anoka, MN. immediately above the HWY 169 Bridge on the left descending bank. This site was sampled in 2000 when the water was drawn down for repairs of the Coon Rapids Dam. A total of 175 live mussels of six species were collected along a large exposed gravel bar. Catch per unit effort was 105.0 mussels/hr and *L. cardium*, *L. siliqouidea*, and *L. recta* were abundant (see Appendix II).

Mussels were scarce in the downstream portion of the pool. This was probably due to the poorer habitat in the lower pool associated with impoundment (i.e., low flow, silt/sand substrate). Only 19 live mussels of two species were collected at four (13-15, 18) of the seven sites at the lower end of the pool. Mussels were completely absent from Sites 3, 16, 17, and 19 (see Figure 3-4 and Appendix II).

Upper CR Pool near Cloquet Island (Site 6, RM875.5).



L. recta (photo courtesy Kevin S. Cummings INHS).

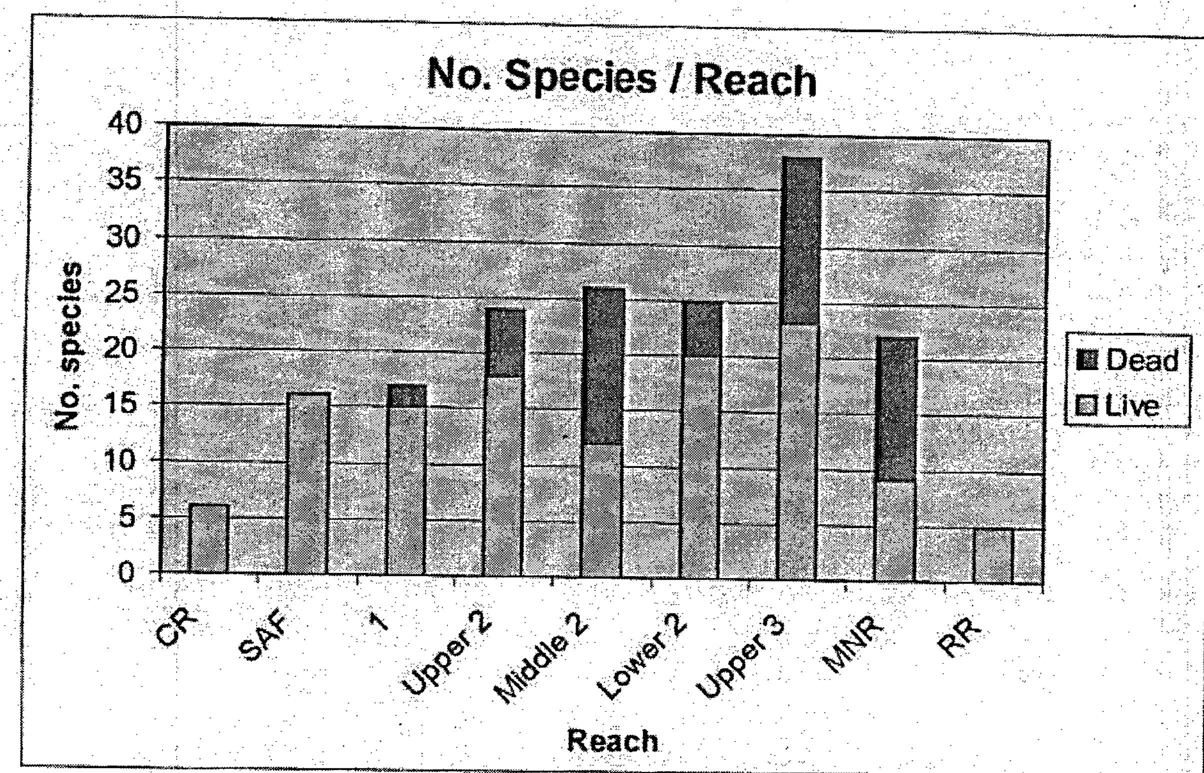


Figure 3-2. Mussel species richness within the MNRRA Corridor reaches from timed searches, 2000-01

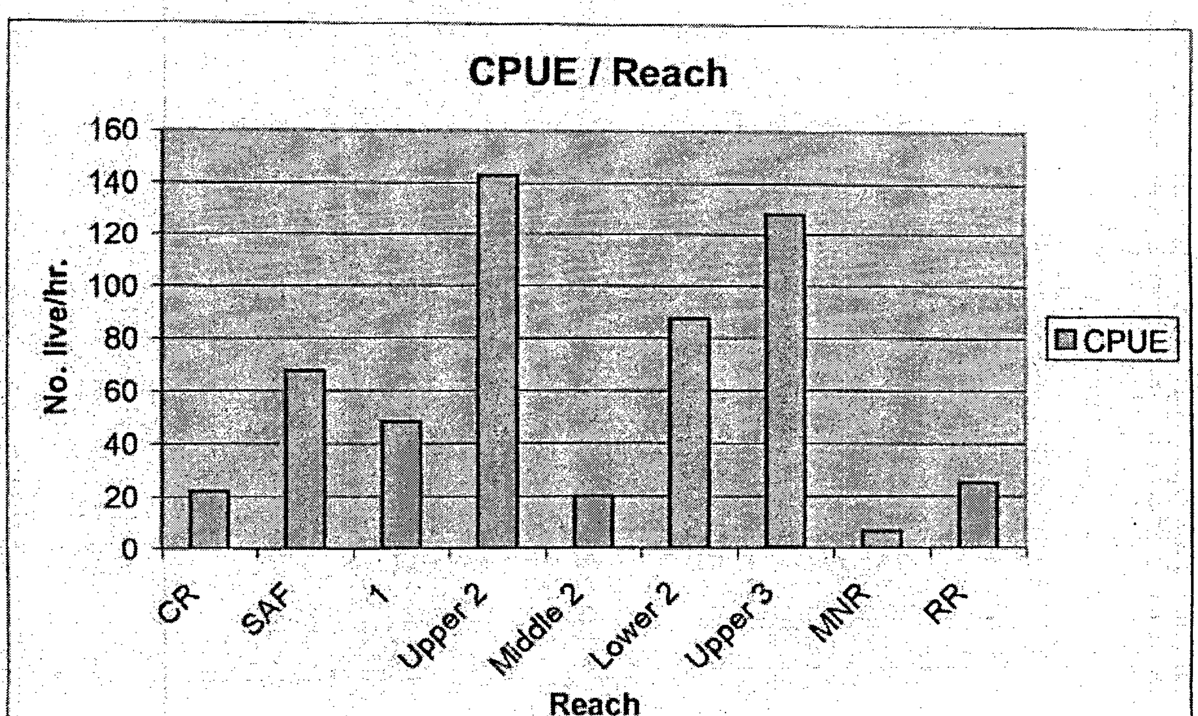


Figure 3-3. Mussel abundance (CPUE) within the MNRRA Corridor from timed searches, 2000-01.

Table 3-2. Mussel species richness and relative abundance for each Mississippi River reach within MNRRA, 2000-01.

	Mississippi River Pool (reach)													
	CR		SAF		1		Upper 2		Middle 2		Lower 2		Upper 3	
Species	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
*Actinonaias ligamentina**											D		6	0.2
*Alasmidonta marginata**							3	0.1					D	
Amblema plicata			35	1.6	173	21.4	675	28.0	100	57.1	293	9.1	622	25.0
*Arcidens confragosus**											26	0.8	4	0.2
*Cumberlandia monodonta**													D	
*Cyclonaias tuberculata**							D		D					
*Ellipsaria lineolata**													1	<0.1
*Elliptio crassidens**									D				D	
*Elliptio dilatata**					D		D		D				14	0.6
*Epioblasma triquetra**													D	
*Fusconaia ebena**									D		D		D	
Fusconaia flava			117	5.4	150	18.6	81	3.4	11	6.3	316	9.9	252	10.1
Lampsilis cardium	366	62.4	265	12.2	8	1.0	71	2.9	D		5	0.2	31	1.2
*Lampsilis higginsi**													D	
Lampsilis siliquoidea	117	19.9	66	3.0	1	0.1	4	0.2	D		D		2	0.1
*Lampsilis teres**													D	
Lasmigona complanata	4	0.7	1	<0.1	D		4	0.2	1	0.6	8	0.2	4	0.2
*Lasmigona costata**													D	
Leptodea fragilis			182	8.4	10	1.2	45	1.9	3	1.7	27	0.8	6	0.2
*Ligumia recta**	87	14.8	89	4.1	1	0.1	37	1.5	D		1	<0.1	2	0.1
*Megalonaias nervosa**													2	0.1
Obliquaria reflexa			138	6.3	62	7.7	349	14.5	35	20.0	1,224	38.2	1,173	47.2
*Obovaria olivaria**							D		D		D		6	0.2
*Plethobasus cyphyus**							D		D		D		D	
*Pleurobema sintoxia**			1	<0.1			D		D		1	<0.1	5	0.2
Potamilus alatus	1	0.2	246	11.3	6	0.7	23	1.0	3	1.7	18	0.6	39	1.6
Potamilus ohiensis			2	0.1	1	0.1	8	0.3	1	0.6	46	1.4	28	1.1
Pyganodon grandis	12	2.0	41	1.9	12	1.5	2	0.1	2	1.1	119	3.7	60	2.4
*Quadrula fragosa**									D				D	
*Quadrula metanevra**							D		D		1	<0.1	D	
*Quadrula nodulata**					28	3.5	62	2.6	4	2.3	78	2.4	7	0.3
Quadrula pustulosa					4	0.5	50	2.1	3	1.7	40	1.2	85	3.4
Quadrula quadrula			302	13.9	237	29.3	202	8.4	11	6.3	668	20.8	67	2.7
Strophitus undulatus			115	5.3	16	2.0	59	2.4			6	0.2	D	
Toxolasma parvus													D	
*Tritogonia verrucosa**									D				D	
Truncilla donaciformis			33	1.5			16	0.7			3	0.1		
Truncilla truncata			543	25.0	99	12.3	719	29.8	1	0.6	325	10.1	69	2.8
Utterbackia imbecillis									D		3	0.1	1	<0.1
Total	587		2,175		808		2,410		175		3,208		2,486	
No. live species	6		16		15		18		12		20		23	
Total species	6		16		17		24		26		25		37	
No. sites	19		20		14		13		9		40		22	
Ave time/site (min) ± stdev	84.2±39.8		96.8±34.8		71.8±26.9		63.3±30.2		58.3±34.3		55.3±28.1		48.5±22.7	
CPUE (No.live/hour) ± stdev	22.0±39.9		67.4±61.3		48.2±36.7		142.9±111.9		20.0±60.5		87.1±99.4		128.3±120.9	

*Listed species; D=Collected as empty shell.

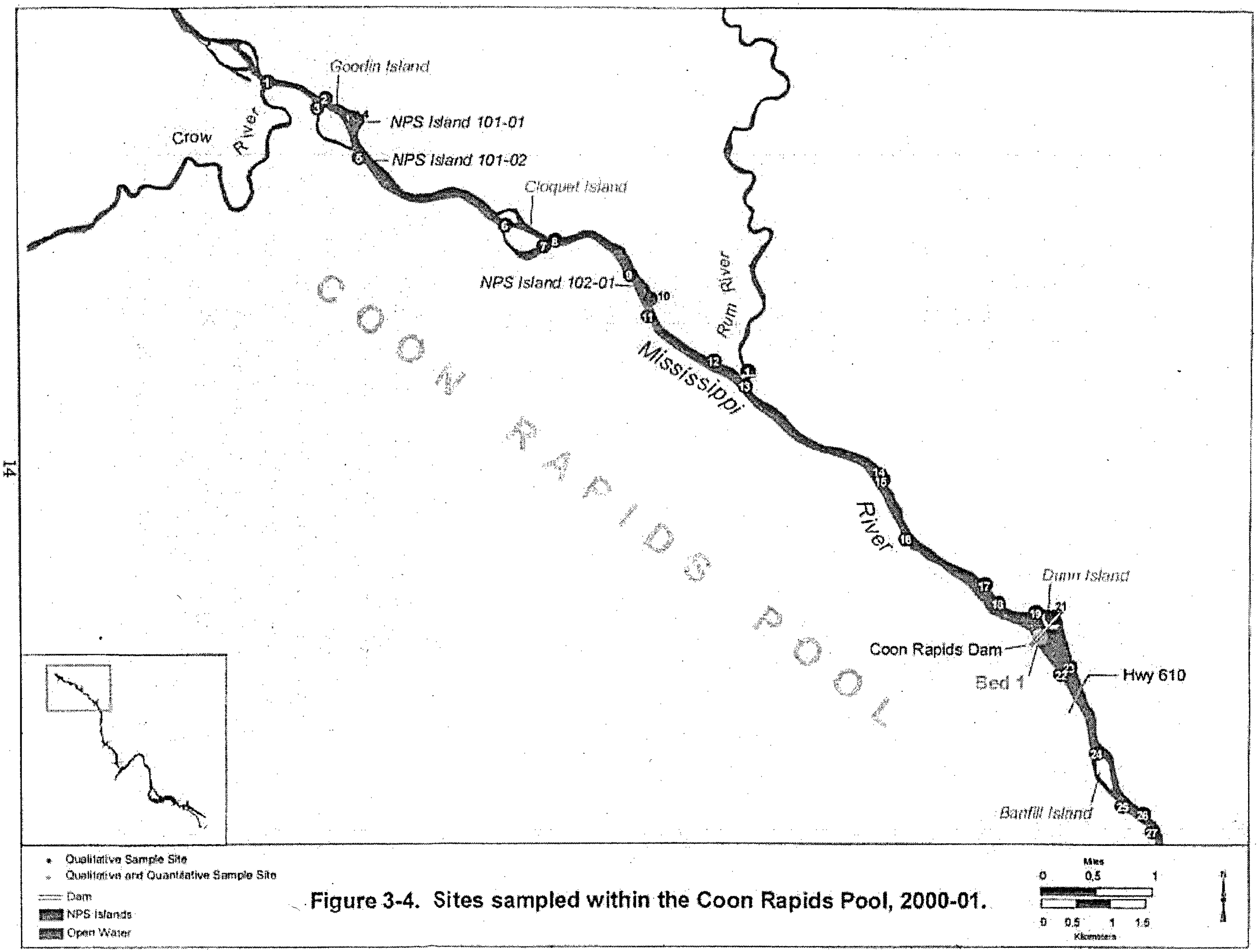


Figure 3-4. Sites sampled within the Coon Rapids Pool, 2000-01.

3.1.2 St. Anthony Falls Pool

Mussel species richness and abundance increased dramatically in the St. Anthony Falls (SAF) Pool from the CR Pool. The mussel fauna closely resembled the community found immediately below the Falls at St. Anthony (Pool 1 and Upper Pool 2) (see Table 3-2). A total of 2,175 mussels of 16 species were collected at 20 sites and average CPUE was moderately high (67.4 mussels/hr) in the SAF Pool. The community was dominated by *T. truncata* (25.0%) with three other species also abundant, *Q. quadrula* (13.9%), *L. cardium* (12.2%), and pink heelsplitter (*Potamilus alatus*) (11.3%) (see Table 3-2). Other common species (>5%) in the pool include fragile papershell (*Leptodea fragilis*) (8.4%), *O. reflexa* (6.3%), wabash pigtoe (*Fusconaia flava*) (5.4%), and the strange floater (*Strophitus undulatus*) (5.3%) (see Table 3-2).

It appears that mussels are expanding their range above St. Anthony Falls, historically a faunal barrier to upstream dispersal but now easily circumnavigated by navigation locks. Of the 16 live species that were collected from the SAF Pool, 10 have not been previously reported above the falls (Dawley 1947, Graf 1997). Several of these "new occurrence" species were common (>5%); *F. flava, L. fragilis, O. reflexa, P. alatus, Q. quadrula*, and *T. truncata* (see Table 3-2). Another species new to the pool, the round pigtoe (*Pleurobema sintoxia*), is listed as threatened in Minnesota.

A relatively young mussel community occurs in the SAF Pool (Figure 3-5). Overall in the SAF Pool, 71% of the individuals collected were <11 years old (70% of the 10 "new" species were <11 years old). Every species was represented by individuals <11 years old and all but one species was represented by individuals <6 years old. This indicates recent recruitment and is similar to other reaches within the MNRRA Corridor (see Figure 3-5). These data indicate that the 10 new species reported from the pool colonized the area recently.

Several sites sampled within the SAF Pool supported a dense and species rich mussel community. As with the CR Pool, these sites were located in the upper portion of the pool where habitat appeared most favorable. Habitat consisted of alternating riffles, runs, and pools and water depth was typically <2m. These sites were distributed from immediately below the Coon Rapids Dam downstream to just below the I-694 Bridge and are designated as Sites 21, 22, 25, 27, 29, 30, 32, and 33 (Figure 3-6). Species richness and abundance (CPUE) ranged from 10 to 13 live species and 82.7 to 204.0 mussels/hr for these sites, respectively (Appendix II). Mussels were most abundant (>200) at Site 21 (adjacent to Dunn Island along the left descending bank) and Site 25 (immediately below Banfill Island). Site 25 also harbored a species rich (12) mussel community and habitat was particularly noteworthy (sand/gravel/cobble compact substrate, 1-2m in depth). Additionally, the West channel adjacent to the next island downstream, Durnam Island, harbored a dense and species rich mussel community (Sites 29, 30, and 32). Finally, Site 33 consisted of a long (300-400m) narrow band of mussels along the

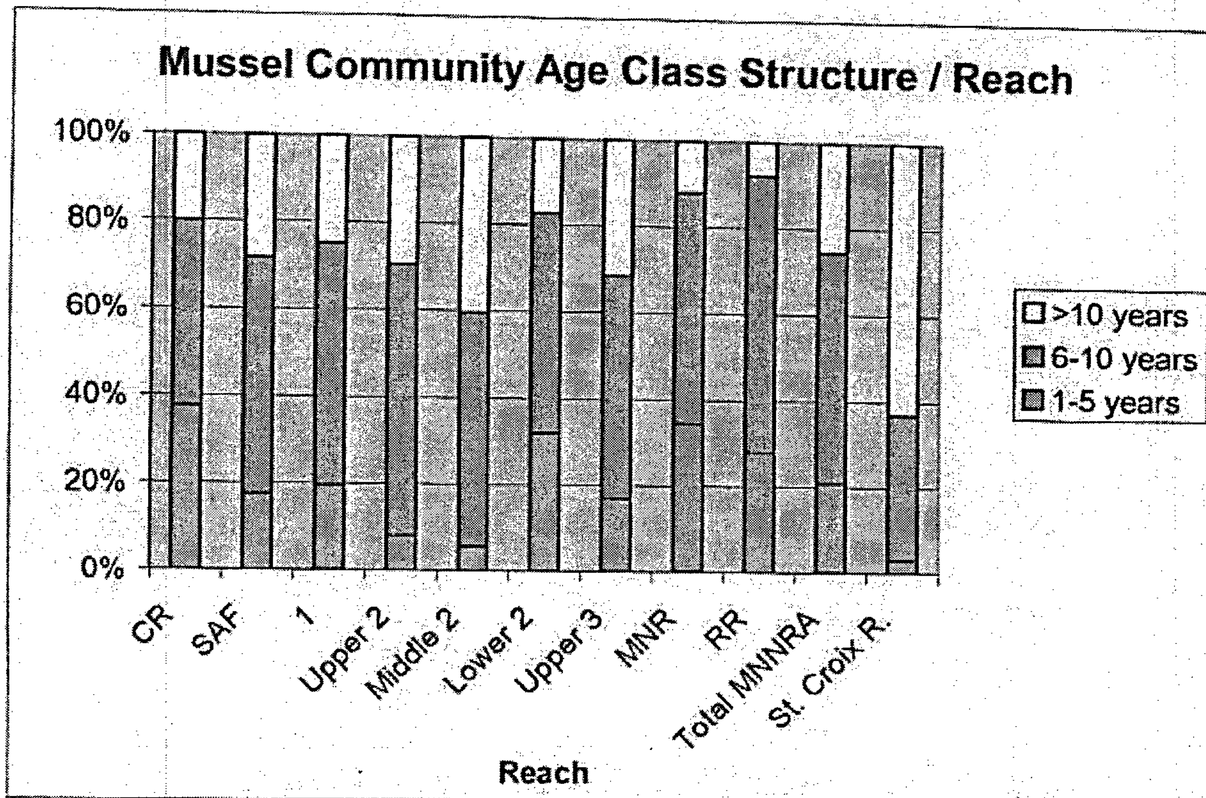
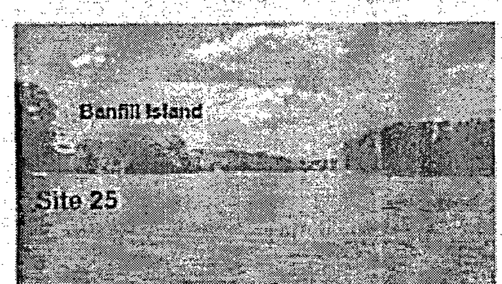


Figure 3-5. Mussel community age class structure for each reach within MNRRA, Total MNRRA, and in the lower St. Croix River, 2000-01.

outside right descending bank, downstream of the I-694 Bridge. Habitat at Site 33 consisted of a run with compacted sand/gravel/cobble substrate and water depth of 1-2m.

Although mussels were not abundant and habitat not as favorable as upstream, the lower portion of the SAF Pool (Sites 34-39) supported 11 live species (Appendix II). As with the lower CR Pool, substrate and flow were less than ideal for mussels due to the impounded nature of the lower SAF pool. This area also lies at the head of the navigation system and within a highly industrial region of Minneapolis. Adverse impacts to the aquatic environment were obvious (considerable barge traffic and loading facilities; trash and debris; and effluent discharges).



Upper SAF Pool near Site 25, looking upstream at Banfill Island (left) (RM 863.5)

The Falls at St. Anthony, from Site 40 between upper and lower St. Anthony Locks (RM 853.5)

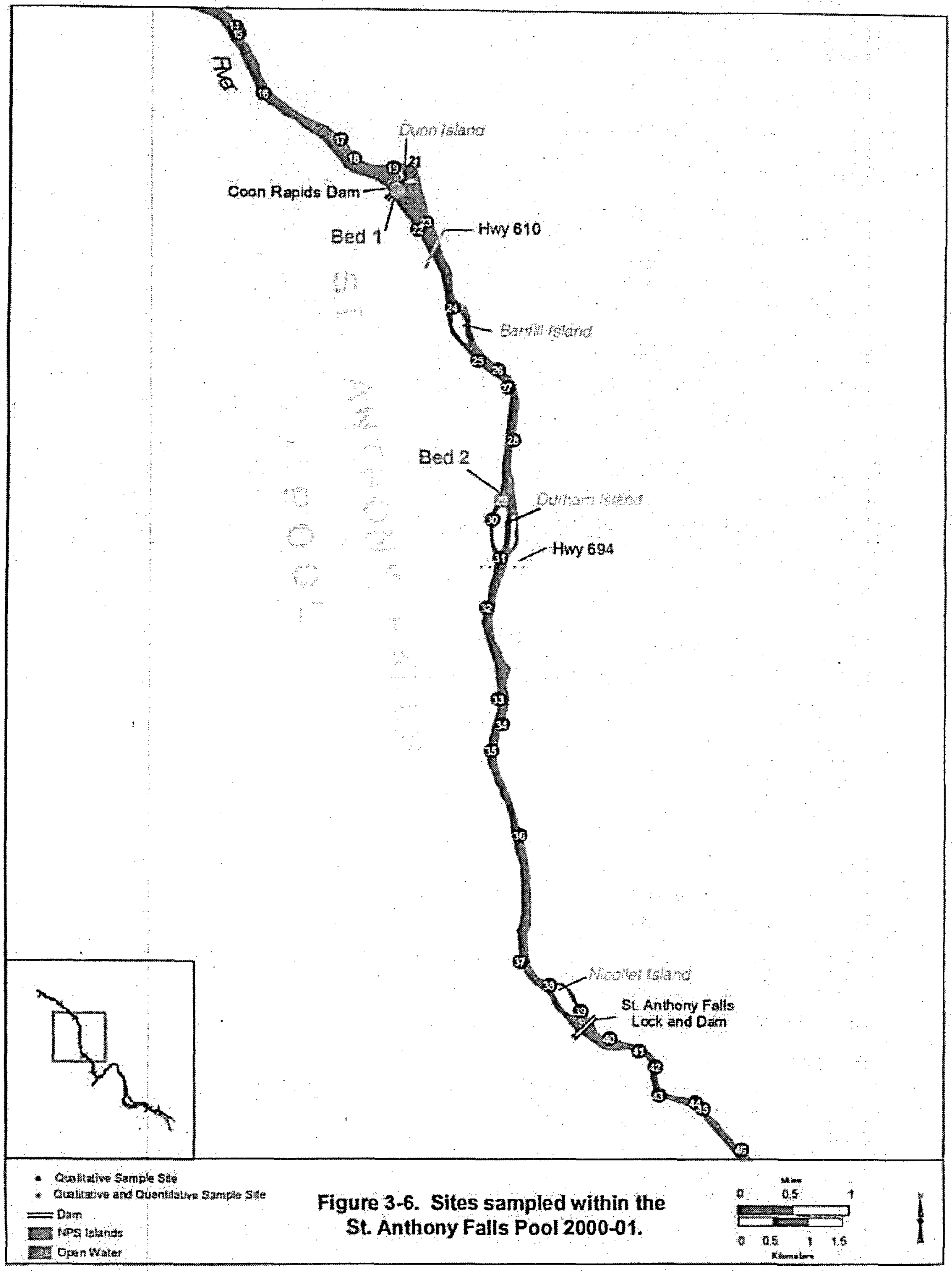


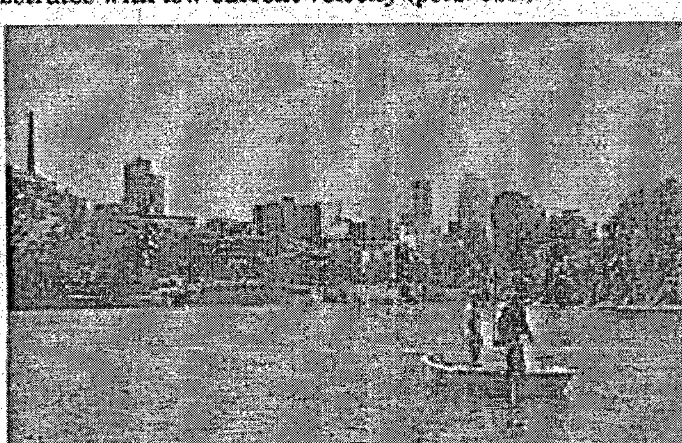
Figure 3-6. Sites sampled within the St. Anthony Falls Pool 2000-01.

3.1.3 Pool 1

Pool 1 supported a mussel community similar to the SAF Pool in species richness but mussels were slightly less abundant (see Figures 3-2 and 3-3). Relative abundance varied slightly in comparison with the SAF Pool. A total of 808 mussels of 15 species were collected at 14 sites and average CPUE was moderately low (48.2 mussels/hr) in Pool 1 (see Table 3-2). The community was dominated by *Q. quadrula* (29.3%), *A. plicata* (21.4%), and *F. flava* (18.6%) (see Table 3-2). Other abundant species (>5%) include *T. truncata* (12.3%) and *O. reflexa* (7.7%) and several species were fairly common including *Q. nodulata* (3.5%), one of two Minnesota endangered species found live within the MNRRA Corridor (see Table 3-2).

As with most other reaches, a relatively young community was found in Pool 1 (see Figure 3-5). Overall, 75% of the individuals collected were <11 years old and 93% and 80% of the species had individuals <11 and <6 years old, respectively. Six species had individuals that were all <11 years old including all 28 live *Q. nodulata* collected. As with the SAF Pool and most other MNRRA reaches, it appears mussels have recently reproduced here and/or have colonized Pool 1 probably from downstream reaches via fish infected with glochidia.

Unlike the CR and SAF pools, the most dense and species rich mussel communities were found in the middle and lower portion of Pool 1. Only Sites 46, 50, and 52 supported healthy populations in Pool 1 (Figure 3-7 and Appendix II). At all three sites, mussels were found along a sand bar or sand beach in 1-2.5m water depth in minimal flow. Site 46, located mid-pool, supported the highest number of species (12) and greatest density (135.8 mussels/hr (see Appendix II). Sites 50 and 52 were at the lower end of the pool and species richness (8 and 10, respectively) and abundance (76.7 and 74.0 mussels/hr, respectively) were similar between sites (see Figure 3-7 and Appendix II). All *Q. nodulata* were collected from the lower half of Pool 1 and one-half (14) of the individuals were collected from Sites 50 and 52 (see Appendix II and 2). This is not surprising given that *Q. nodulata* typically prefers softer substrates with low current velocity (pers. obs.).



Upper Pool 1, Site 42, downtown Minneapolis in the background (RM 853).

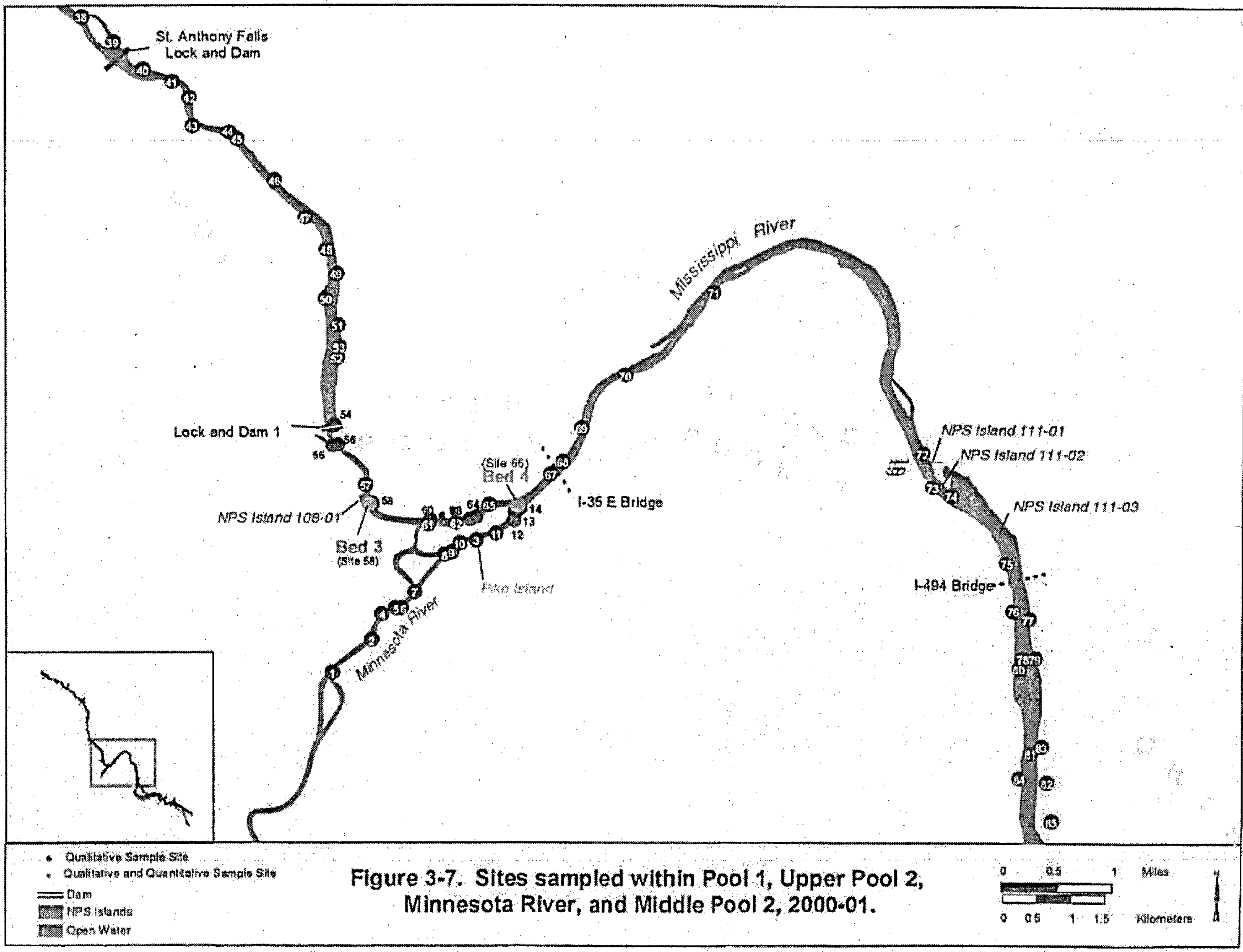


Figure 3-7. Sites sampled within Pool 1, Upper Pool 2, Minnesota River, and Middle Pool 2, 2000-01.

3.1.4 Upper Pool 2

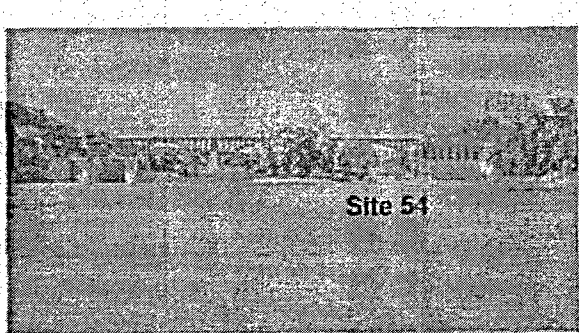
The Upper Pool 2 reach supported the most dense and one of the most species rich communities among the reaches in the study (see Figures 3-2 and 3-3). A total of 2,410 mussels of 18 live species were collected at 13 sites and average CPUE was 142.9 mussels/hr (see Table 3-2). The community was dominated by *T. truncata* (29.8%) and *A. plicata* (28.0%). *Obliquaria reflexa* (14.5%) and *Q. quadrula* (8.4%) were also relatively abundant (see Table 3-2). Most of the remaining species were uncommon (<5%) or rare (<1%) including three species listed for protection in Minnesota; *Q. nodulata* (2.6%) (endangered), *L. recta* (1.5%) (species of special concern), and *Alasmidointa marginata* (0.1%) (threatened) (see Table 3-2).

Young individuals again dominated the mussel community in Upper Pool 2 and most species were represented by young individuals. Overall, 70% of the individuals in the community were <11 years old (see Figure 3-5) and 78% of the species were represented by individuals <6 years old. However, all three *A. marginata* collected within the entire MNRRA Corridor were from this reach and all were old individuals (>15 years old) (see Figure 3-1). Given the low number of individuals collected and the lack of recent reproduction, the potential exists for this species to become extirpated from the corridor. Conversely, approximately 88% of the *Q. nodulata* collected in Upper Pool 2 were <11, 20% were <6 years of age.

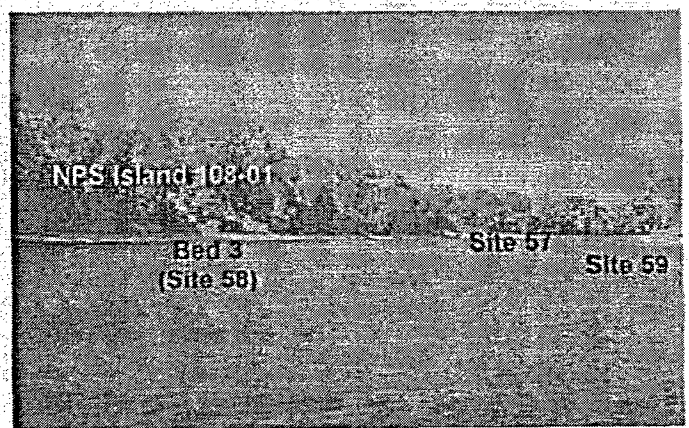
The Upper Pool 2 reach extends from immediately below Lock and Dam 1 to the lower end of Pike Island at the Mississippi River confluence with the Minnesota River (see Figure 3-7). Habitat in this reach appeared favorable for mussels with moderate flow and water depth from 1-4m. Substrate appeared stable, consisting of a consolidated mixture of sand, gravel, cobble, and boulder. Several sites harbored a dense and species rich mussel community including Sites; 54, 57-60, 62, 65, and 66 (see Figure 3-7). Catch per unit effort ranged from 114.5 to 336.0 mussels/hr among these sites (see Appendix II). Site 54 was adjacent to an unnamed island immediately downstream of Lock and Dam 1. Twelve species were collected here including *A. marginata* (threatened) and *L. recta* (special concern). Sites 58 and 66 were also sampled quantitatively because they supported the greatest number of species (15 and 14 respectively), included rare species, and had a high CPUE (see Appendix II).

Over 1,000 live mussels of 15 species were collected from Sites 57, 58, and 59 which were positioned close together near NPS Island 108-01 (see Figure 3-7 and Appendix II). *Quadrula nodulata* and *L. recta* were present at all three sites. Site 60 was across the Mississippi River from the head of Pike Island and immediately upstream of the Watergate Marina. Mussels were most abundant at this site (CPUE 336.0 mussels/hr) and 13 species were collected (see Appendix II). Site 66 was the exception in habitat type for this reach. This site was at the lower end of Pike Island in an eddy, current velocity was low, and substrate consisted of silt and sand. Site 66 supported the second highest mussel

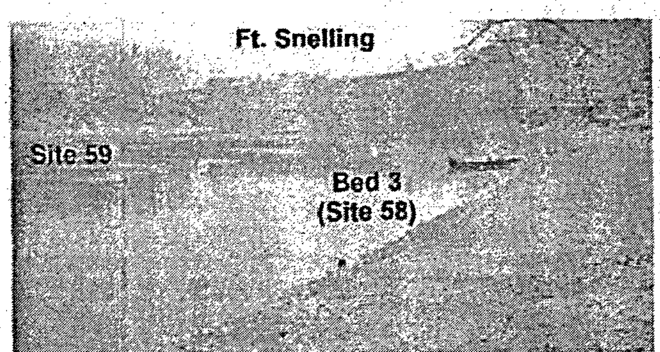
abundance (CPUE 287.3 mussels/hr) and number of species (14) in Upper Pool 2 (see Appendix II). Particularly noteworthy was the high number of *Q. nodulata* (39) collected at Site 66 (see Appendix II). *Quadrula nodulata* was collected live at eight of the 13 sites sampled in Upper Pool 2 but well over half (63%) were collected from Site 66 where it comprised nearly 8% of the mussel community (see Appendices I and II). As in Pool 1, *Q. nodulata's* high abundance at this site is not surprising given that the habitat found here is unique to Upper Pool 2 and seems favorable to this species (i.e., low flow and soft substrate). It's possible that Site 66 harbors a source population for *Q. nodulata* that facilitates its dispersal throughout Upper Pool 2 and lower Pool 1.



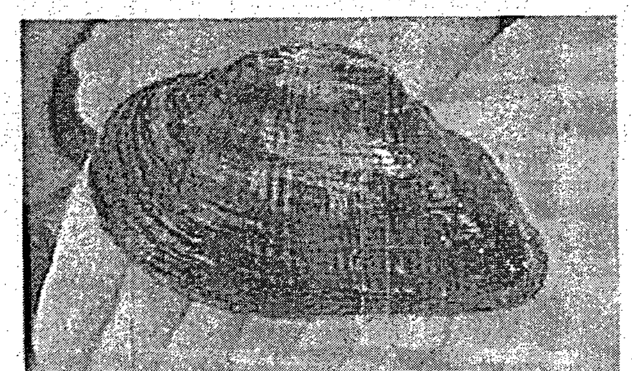
Lock and Dam 1 (Ford Dam), Site 54 is along an unnamed island and was a state listed species relocation area.



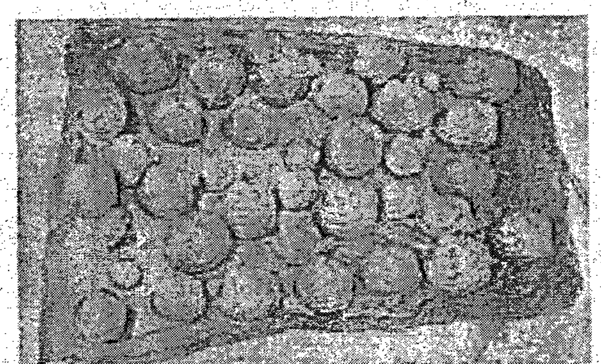
Looking upstream from Ft. Snelling, Bed 3 was a *L. higginsi* and state listed species relocation site (RM 846.2).



Looking downstream towards Ft. Snelling.



Very old (>15 years) *A. marginata* collected from Bed 3.



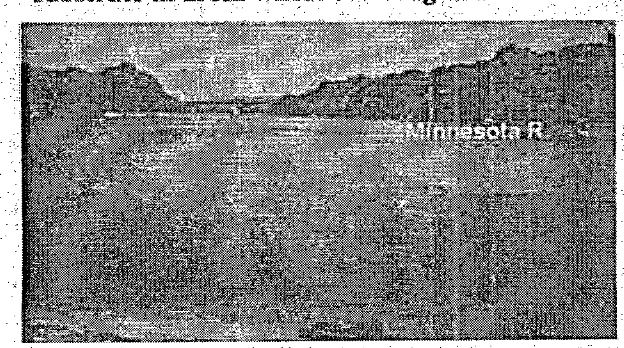
Healthy population of *Q. nodulata* collected near the base of Pike Island from Bed 4 (Site 66, RM 844.0).

3.1.5 Middle Pool 2

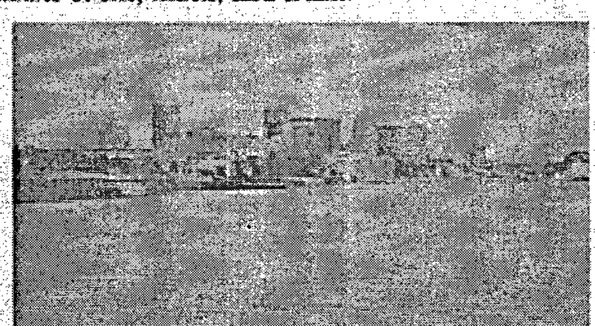
Although it supported 12 species, mussels were not abundant through most of the Middle Pool 2 reach. A total of 175 live mussels were found and average CPUE was 20.0 mussel/hr (see Appendix II). Mussels were sparse or absent from seven of the nine sites sampled (see Appendix II). Only one site, Site 68, supported a dense and species rich mussel community. This site was immediately downstream of the I-35E Bridge, approximately one mile below the Minnesota and Mississippi rivers confluence (see Figure 3-7 and Appendix II). A total of 138 mussels representing eight species were collected and CPUE was 184.0 mussels/hr at this site (see Appendix II). The community at this site was dominated by *A. plicata* (57.1%) and *O. reflexa* (20.0%). Also, included in the assemblage were four *Q. nodulata* (2.3%), the only site in this reach where this species was collected.

Only six live mussels were found in the approximate two mile stretch of river at the lower end of the reach where three NPS islands are located (NPS 111-01, 111-02, 111-03) (see Figure 3-7). Aquatic habitat was highly degraded in this area and substrate consisted primarily of silt and muck that appeared continually disturbed by barge prop blasts and mooring activities. Several barges were pushed up onto banks, and two sunken barges were observed.

Interestingly, this Middle Pool 2 reach once harbored at least 26 species. In addition to the 12 live species, we collected old shells of 14 additional species (see Table 3-2). The loss of species and lack of live mussels throughout the majority of the reach is probably a result of poor water quality and unstable degraded habitat. This reach is impacted directly by the Minnesota River, which has a long history of contributing considerable agricultural pollution (pesticides and herbicides) and erosional silt runoff (Bright et al. 1990) to the Mississippi River at the head of this reach. Although water quality in the Mississippi River has dramatically improved, it hasn't for the Minnesota River. Furthermore, most of this reach is within the city limits of St. Paul and loss of habitat via riverfront development, dredging, and industrial activities (i.e., barge loading facilities) have reduced and altered the aquatic habitat. The channel is rather constricted here, flow is often extreme and scouring in nature, and substrate in areas where scouring does not occur consists of silt, muck, and trash.



Looking downstream towards St. Paul from the base of Pike Island at the confluence of the Minnesota and Mississippi rivers.



Downtown St. Paul.

3.1.6 Lower Pool 2

The mussel community improves dramatically in the Lower Pool 2 reach compared to the reach immediately upstream. This reach is relatively long, extending 15 miles (24.1km) from the I-494 Bridge in South St. Paul downstream to Lock and Dam 2, and covers an extremely large surface area at the lower half of the reach (Figure 3-8). Forty sites were required to adequately sample this large area. A total of 3,208 mussels were collected representing 20 species and average CPUE was moderately high (87.1 mussels/hr) (see Table 3-2). The community was dominated by *O. reflexa* (38.2%) and *Q. quadrula* (20.8%). Three other species were also relatively abundant including; *T. truncata* (10.1%), *F. flava* (9.9%), and *A. plicata* (9.1%) (see Table 3-2). Several species were uncommon including five listed for protection in Minnesota; two endangered (*A. confragosus* [0.8%] and *Q. nodulata* [2.4%]), two threatened (*P. sintoxia* [<0.1%] and *Quadrula metanevra* [<0.1%]), and one species of special concern (*L. recta* [<0.1%]) (see Table 3-2). *Arcidens confragosus* was mainly present at the lower end of the reach, whereas *Q. nodulata* was distributed throughout Lower Pool 2.

The mussel community in Lower Pool 2 was the youngest of all Mississippi River reaches. Overall, 83% of the individuals in the community were <11 years old (see Figure 3-5) and all but one of the species were represented with individuals <11 years old. All but one individual of *A. confragosus* were <11 years old and 85% were <6 years old. All *Q. nodulata* collected were <11 years old and 60% were <6 years old.

Four areas within Lower Pool 2, slightly less than half of the 40 sites sampled, supported healthy mussel populations. Three of these areas were in the lower half of Lower Pool 2, one of which was also quantitatively sampled. In the upper portion of Lower Pool 2, Sites 79 and 81 supported dense and species rich mussel communities (see Figure 3-8). Site 79 was at the lower end of an unnamed island at Newport, MN; 214 mussels of 13 live species were collected and CPUE was 183.4 mussels/hr. Site 81 was approximately 1.5 miles (2.4km) downstream of Site 79, immediately above an unnamed island and below River Heights Marina. A total of 155 mussels of 11 species were collected at this site and CPUE was 132.9 mussels/hr (see Appendix II). *Quadrula nodulata* was collected at both sites.

The three high quality areas in the lower end of the reach were located as follows: 1) between the lower end of Lower Grey Cloud Island and Spring Lake (Sites 96-100), also quantitatively sampled, 2) along the old channel that is parallel to the left descending bank immediately above Lock and Dam 2 (Sites 105-106, 109, 111, 114), and 3) along the old channel paralleling the right descending bank immediately above Lock and Dam 2 (Sites 110, 112, 113, 115) (see Figure 3-8). Over 700 mussels of 18 species were collected from area one (Sites 96-100) and CPUE ranged from 54.0 to 507.0 mussels/hr (see Appendix II). Included in the assemblage were all five state listed species found in Lower Pool 2 (see Appendix II). The area along the left descending bank above Lock and Dam 2 harbored 12 species and CPUE ranged

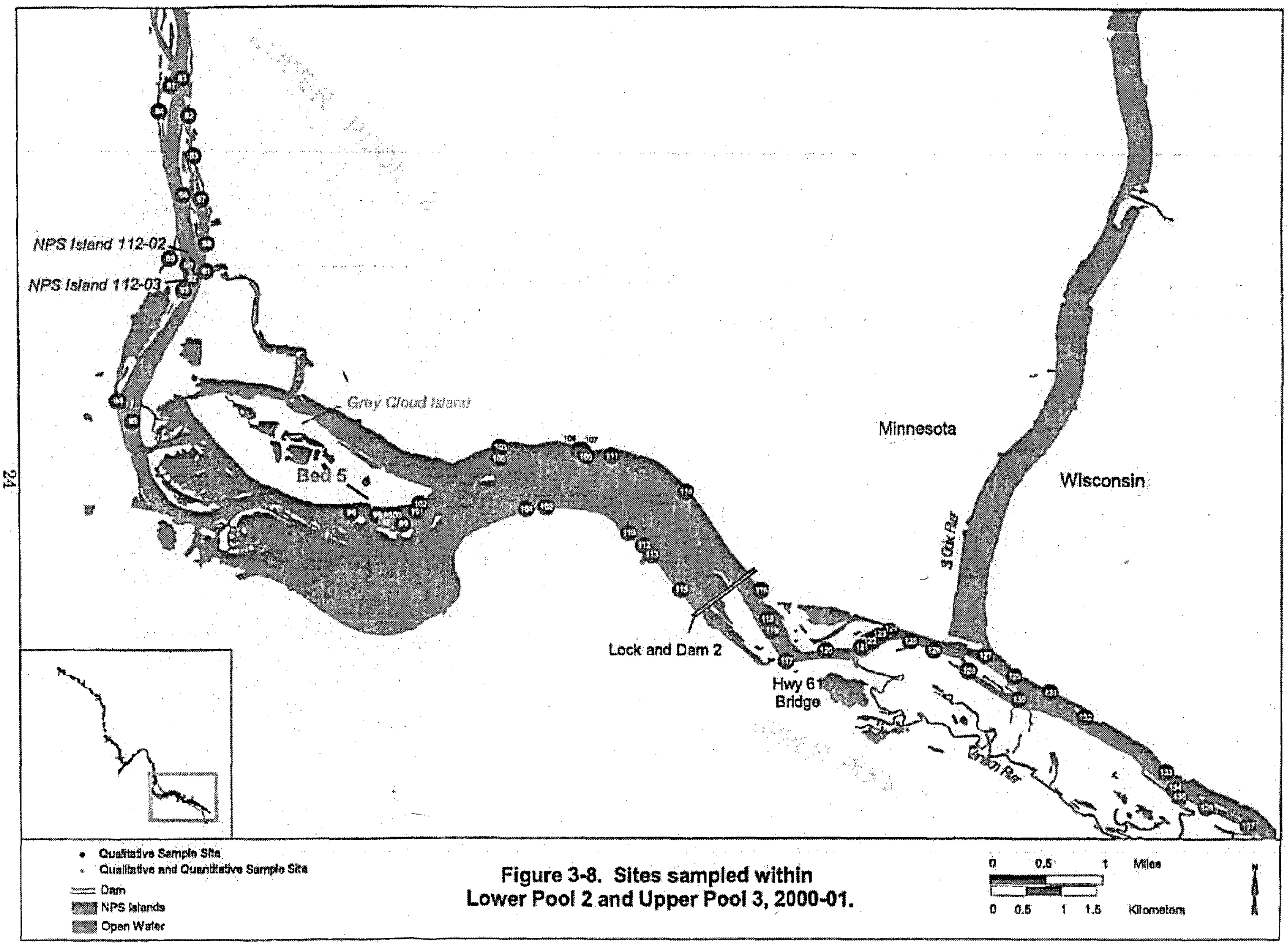
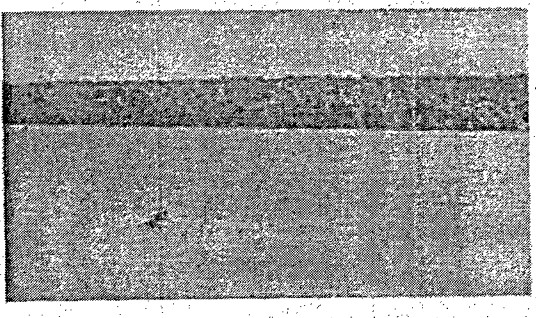


Figure 3-8. Sites sampled within Lower Pool 2 and Upper Pool 3, 2000-01.

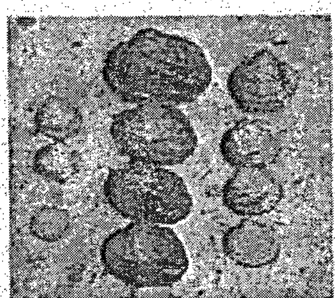
ranged from 116.7 to 159.6 mussels/hr (see Figure 3-8 and Appendix II). *Arcidens confragosus* and *Q. nodulata* were both collected from these sites. The area along the right descending bank above Lock and Dam 2 harbored 14 species and CPUE ranged from 62.7 to 188.0 mussel/hr (see Figure 3-8 and Appendix II) and both *A. confragosus* and *Q. nodulata* were present.

Two NPS Islands (112-02 and 112-03) are present within Lower Pool 2 (see Figure 3-8). The mussel community found at the three sites (90, 92, 93) sampled adjacent to these islands was fairly species rich but moderately populated. A total of 10 species were found including *Q. nodulata* and CPUE was <41 mussels/hr for all sites (see Appendix II).

Habitat within Lower Pool 2 was highly variable. In the upper portion, where the channel was more constricted, flow was moderate to fast and several islands and many wing dams were present. Substrate for the most part was silt and sand and mussels tended to occur along side channels or at the lower ends of islands where substrate was stable, being somewhat protected from erosive flows. These areas undoubtedly provide good fish habitat as well. Mussels also occurred in-between wing dams where flow was minimal and substrate stable. Habitat within the lower portion of the reach was typical of an impounded river. The navigation channel, guided by wing dams, winds through water-covered stump and debris fields. Substrate consisted primarily of silt and sand, and occasionally areas of the old riverbed were present which included cobble and boulder. Flow was minimal but wind and wave action resulting from the large surface area generally kept shallow areas silt free allowing mussels to survive. Flow however was moderate through the area adjacent to Lower Grey Cloud Island (Sites 96-100), and substrate consisted of clay and sand with some gravel and cobble. Most islands appeared to be dredge spoils and, as opposed to upstream, habitat around these islands was generally not favorable to mussels. Substrate was typically loose sand that apparently was slowly sloughing off from the human made islands that were nearly void of vegetation at the waters edge.

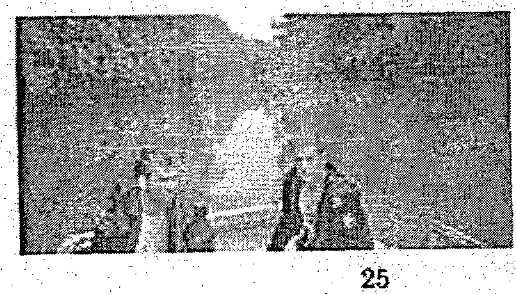


Lower portion of Lower Pool 2 (RM 819).



Q. nodulata , *A. confragosus* (center)

Side channel below Willie's Hidden Harbor, St. Paul Park, MN (RM 829).



Q. metanevra

3.1.7 Upper Pool 3

Upper Pool 3 was the most species rich reach in the study, and overall mussel abundance was second only to Upper Pool 2 (see Table 3-2). A total of 2,486 mussels of 23 species were collected and average CPUE was 128.3 mussel/hr. The community was dominated by *O. reflexa* (47.2%), *A. plicata* (25.0%), and *F. flava* (10.1%). The remaining species were uncommon or rare but include nine species listed for protection in Minnesota: 1) endangered - *Q. nodulata* (0.3%), *A. confragosus* (0.2%), 2) threatened - *Actinonaias ligamentina* (0.2%), *Ellipsaria lineoloata* (<0.1%), *Megalonaias nervosa* (0.1%), *Obovaria olivaria* (0.2%), *P. sintoxia* (0.2%), and 3) special concern - *Elliptio dilatata* (0.6%), *L. recta* (0.1%). Also noteworthy were the high number of additional species collected as empty shells. Most of the additional dead species collected were sub-fossil or long dead specimens indicating that historically at least 37 species were present within this reach (see Table 3-2). In this collection, two federally endangered species, *L. higginsi* and *Q. fragosa* and one species not previously recorded from the Upper Mississippi River above Lake Pepin, *Epioblasma triquetra*, were found as empty shells.

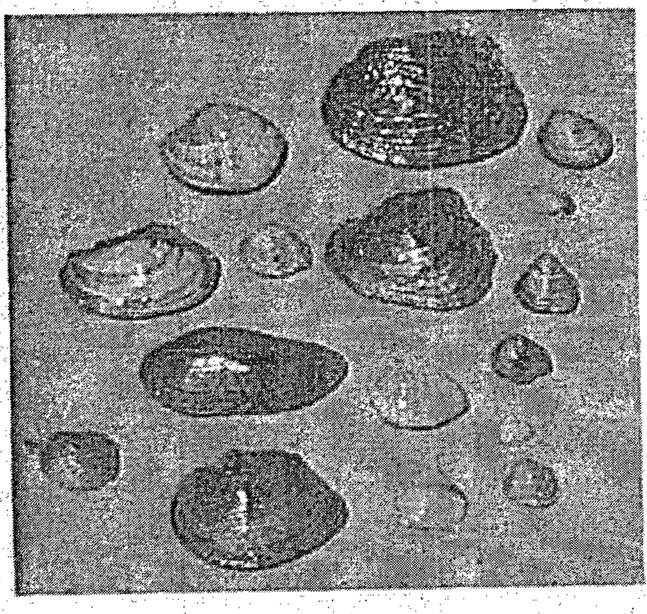
As with the other reaches within the MNRRA Corridor, the mussel community in Upper Pool 3 was relatively young. A total of 68% of the individuals were <11 years old (see Figure 3-4) and 87% and 74% of the species had individuals that were <11 and <6 years old, respectively. Comparatively, the mussel community of the lower St. Croix River, which empties into Upper Pool 3, shows a more typical age class structure of a healthy mussel community expected in a rather unaltered river (see Figure 3-5) in that many age classes are represented with older individuals dominating. Older individuals dominate the community, probably not because recruitment of young is low but because of increased survival due to the sustained quality of the system and the long-lived nature of mussels.

Although most of the 22 sites sampled had moderate species richness and density, six sites stand out as supporting very healthy mussel populations (Sites 121, 122, 129, 131, 135, 137). Sites 121 and 122 were very close together and between two wing dams downstream of the HWY 61 Bridge and immediately upstream the inlet to Conley Lake in Hastings, MN (see Figure 3-8). At these two sites, a total of 829 mussels of 18 species were collected and CPUE was >260 mussel/hour (see Appendix II). Included in the collections were *A. confragosus* (endangered), *E. lineolata* (threatened), *M. nervosa* (threatened), *O. olivaria* (threatened), and *L. recta* (special concern). At Site 121, along the bank there was evidence of a midden pile containing many sub-fossil or long dead specimens, probably discarded by humans, muskrats, or river otters. Among the species were *E. triquetra* (threatened), *Q. fragosa* (federally endangered), *Tritogonia verrucosa* (threatened), and *Plethobasus cyphyus* (endangered) (see Appendix II). Also of interest, many long dead shells were scattered along the exposed sand bar upstream at Site 118 near Hubs Bail Marina in Hastings, MN. Among the collection were empty shells of 17 species including *Cumberlandia monodonta* (threatened), *L. higginsi* (federally endangered), *Lampsilis teres* (endangered), and *Lasmigona costata* (special concern) among others (see Appendix II). These shells

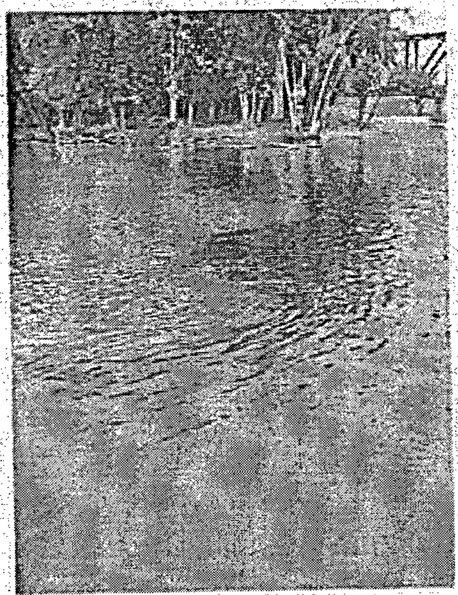
were probably deposited by high flows depositing during the 2001 flood, as the sand bar was not present in 2000.

The remaining sites were downstream the confluence with the St. Croix River and no doubt at least historically were favorably influenced by the superior water quality of the St. Croix River emptying into the Mississippi River. Sites 129 and 131 are along the left descending bank (Wisconsin bank) and are to some degree probably still influenced by the high quality effluent of the St. Croix River. Site 129 was located off a point immediately downstream of the Prescott, WI public boat launch and private marinas (see Figure 3-8). A total of 12 live species were collected including *A. ligamentina* (threatened), *M. nervosa* (threatened), *P. coccineum* (threatened), *E. dilatata* (special concern), and *L. recta* (special concern) (see Appendix II). Site 131 was located between two wing dams where about 400 live mussels of 14 species were collected and CPUE was 313.6 mussels/hr (see Appendix II). Sites 135 and 137 were along the right descending bank near the downstream border of the MNRRA Corridor (see Figure 3-8). Site 135 was at the inlet to Truedale Slough and downstream of a wing dam and Site 137 was situated along a side channel of an unnamed island and between two wing dams. Over 250 mussels were collected representing 11 species and CPUE was >120 mussels/hr for both sites combined (see Appendix II).

Habitat for the most part in Upper Pool 3 consisted of a run with moderate flow and substrate consisted primarily of silt and sand. However, substrate immediately below the St. Croix River at Site 129 consisted of a consolidated mixture of sand, gravel, cobble, and boulder. Mussels tended to be found where flow was often minimized, usually along the slopes just off the banks and/or in-between wing dams in sand.



Sixteen of the 17 species collected from Site 122 (*A. plicata* missing) (RM 813).



Mississippi (left) and St. Croix (right) river confluence, near Prescott, WI (RM 811.5).

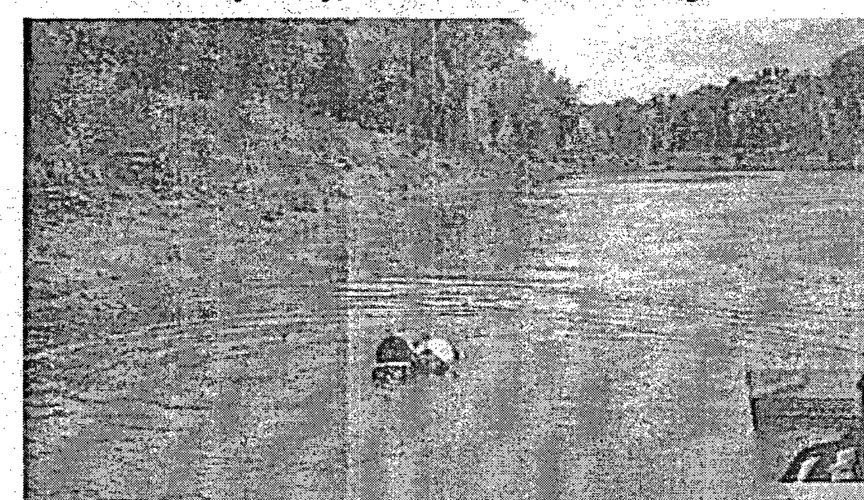
3.1.8 Minnesota River

Mussels were not abundant in the lower Minnesota River and the fauna was species poor compared to its historic complement of species and to the Mississippi River. Only 58 live mussels of nine species were collected at the 14 sites sampled and average CPUE was 6.4 mussels/hr (Table 3-3). *Leptodea fragilis* (36.2%) and *Potamilus ohiensis* (34.5%), species typical of soft substrates, were most abundant. An additional 13 species were collected as long dead specimens. Historically 30+ species occurred in this reach (Bright et. al. 1991) and the community very closely resembled that of the Mississippi River below St. Anthony Falls.

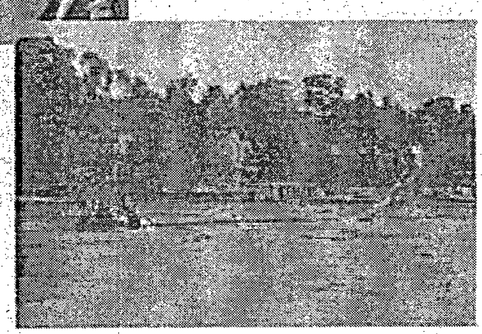
Most of the individuals collected were relatively young in this reach. Overall, 88% of the individuals were <11 years old (see Figure 3-4), one species was represented only by individuals >10 years old.

No sites in the Minnesota River supported a healthy mussel community. Eight of the 14 sites sampled contained <2 live mussels, only two sites contained >10 live mussels, and no site had >6 live species present (see Appendix II).

Habitat throughout this reach consisted of a run with variable flow. Substrate consisted of a layer of muck and silt mostly over sand but occasionally over gravel, cobble, and boulder. In many areas, the banks were sloughing into the river and many trees or dead falls existed along the river bottom. The river was extremely murky, brown in color, and full of algae.



Minnesota River (MN RM 3).



Dead falls along with a tremendous silt load and no doubt various agricultural pollutants entering the Mississippi River from the Minnesota River.

Table 3-3. Mussel species richness and relative abundance for the lower Minnesota and Rum rivers within MNRRA, 2000-01.

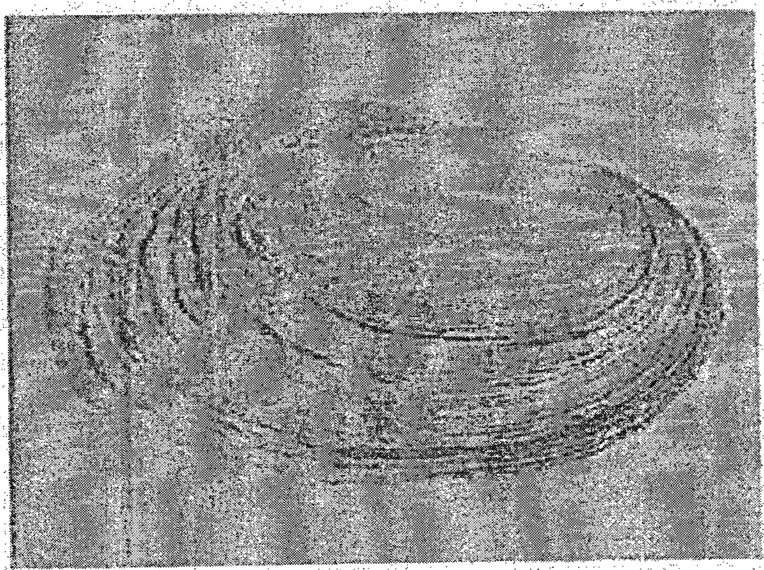
	Minnesota River		Rum River	
	No.	%	No.	%
*Actinonaias ligamentina**	D			
Amblema plicata	1	1.7		
*Arcidens confragosus**	D			
*Fusconaia ebena**	D			
Fusconaia flava	D			
Lampsilis cardium	1	1.7	4	16.0
Lampsilis siliquoidea	D		14	56.0
Lasmigona complanata	1	1.7		
*Lasmigona compressa**			1	4.0
Leptodea fragilis	21	36.2		
*Ligumia recta**	D		1	4.0
Obliquaria reflexa	D			
*Obovaria olivaria**	D			
*Pleurobema sintoxia**	D			
Potamilus alatus	7	12.1		
Potamilus ohiensis	20	34.5		
Pyganodon grandis	3	5.2	5	20.0
*Quadrula metanevra**	D			
*Quadrula nodulata**	D			
Quadrula pustulosa	D			
Quadrula quadrula	2	3.4		
Strophitus undulatus	D			
Truncilla truncata	2	3.4		
Total	58		25	
No. live species	9		5	
No. dead species	13		0	
Total species	22		5	
No. sites	14		1	
Ave time/site (min) ± stdev.	39.1 ± 19.4		60.0	
CPUE (no. live/hour) ± stdev.	6.4 ± 11.7		25.0	

*Listed species; D=Collected only as empty shell.

3.1.9 Rum River

Only one site was sampled on the RR reach from immediately below the spill over dam in Anoka, MN to its confluence with the Mississippi River at the CR Pool, a distance of a few hundred meters. A total of 25 live mussels were collected representing five species (see Table 3-3). The community at this site resembles the mussel community in the CR Pool (see Table 3-2 and 3-3), into which it empties, but with one exception. A single creek-heelsplitter (*Lasmigona compressa*), a species of special concern in Minnesota, was collected. This is the only record of this species in the MNRRA Corridor. This species typically inhabits headwaters of large rivers as well as smaller rivers and streams.

Habitat in the RR reach consisted primarily of a shallow run (<2m deep) with of a thick layer (0.5-1m) of loose shifting sand where mussels were absent. Mussels were only present near the river banks along a narrow seam of a consolidated mixture of sand, gravel, and cobble which appeared to be the original river bottom. The increased sediment load in this reach is probably due to increased upstream bank erosion from spring flooding that occurred in 2001. In addition, this spring flood event may have eroded sediment accumulations above the dam transporting them downstream into the sampling area.



L. compressa (photo courtesy Kevin S. Cummings INHS).

3.2 Quantitative Sampling

Beds 1, 2, 3, 4, and 5 correspond to qualitative Sites 20, 29, 58, 66, and 97, respectively. Beds 1 and 2 were located in the upper portion of the SAF Pool (see Figure 3-6), Beds 3 and 4 were located in Upper Pool 2 (see Figure 3-7), and Bed 5 was located in the lower portion of Lower Pool 2 (see Figure 3-8). Overall mussel density ranged from 0.8/m^2 at Bed 2 to 15.5/m^2 at Bed 3 (Table 3-4). Mussel density at Bed 3 was significantly greater than all other beds, density at Bed 2 was significantly less than all beds, and Beds 4 and 5 densities were significantly greater than Bed 1 (df=4, F=21.5, P<0.001). Beds 4 and 5 densities did not differ from each other (P=0.99), nor did Bed 1 differ from Bed 2 (P=0.95). Both. Below are results from each bed.

3.2.1 Bed 1 (Site 20)

This bed was located at the head of the SAF Pool about 300m below the Coon Rapids Dam along the right descending bank at the head of an unnamed island. Water depth was <1m in depth and habitat was a riffle/run with a sand and gravel substrate. Average mussel density was low (2.2/m^2) and a total of seven species were collected (see Table 3-4). Average age of mussels was 8.3 years (range 3-18) and 27.3% of the individuals were <6 years old (Table 3-5). Although density was rather low, this bed should be considered for future quantitative monitoring to provide trend data on a "marginal" mussel community. This community may provide an earlier warning to changes in water quality or habitat than higher density communities would.

3.2.2 Bed 2 (Site 29)

This bed was also located in the SAF Pool, along the side channel of Durnam Island. This area did not support a dense mussel community. Mussel density was 0.8/m^2 and only five live mussels of five different species were collected (see Table 3-4). Habitat within the area was a riffle/run and substrate was sand, gravel, and cobble. Because of the extremely low density and lack of species, this area should not be considered for future quantitative monitoring due to the considerable effort (i.e. high number of quantitative samples needed to detect change) required to obtain a statistically sound sample size.

3.2.3 Bed 3 (Site 58)

Mussel Bed 3 was located in Upper Pool 2 along NPS Island 108-01 (see Figure 3-7). State listed and the federally endangered *L. higginsi* were relocated to this bed from UMR Pools 11 and 14. Mussel density (15.5/m^2) and species richness (13) were highest here among the beds. *Obliquaria reflexa*, *A. plicata*, and *T. truncata* dominated the collection. Several species were rare including *Q. nodulata* and two species that had been relocated, *A. confragosus* and *Q. metanevra*. Individuals of relocated mussels were marked with a slash across the shell for future identification. The collection of only three relocated individuals of two species suggests that overall a relatively small number of mussels were relocated to the area and any impacts of increased density on the native community is probably not

Table 3-4. Mussel species density within Beds 1-5 from quantitative samples within the MNRRA Corridor, 2001.

	Mussel Bed																			
	1 (SAF Pool)				2 (SAF Pool)				3 (Upper Pool 2)				4 (Upper Pool 2)				5 (Lower pool 2)			
Species	No.	%	No./m²	2SE	No.	%	No./m²	2SE	No.	%	No./m²	2SE	No.	%	No./m²	2SE	No.	%	No./m²	2SE
Amblema plicata									38	24.5	3.8	0.4	55	50.9	5.2	0.4	1	1.4	0.1	0.1
Arcidens confragosus[1]									2	1.3	0.2	0.1								
Fusconaia flava									9	5.8	0.9	0.2	8	7.4	0.8	0.1	7	9.9	1.0	0.2
Lampsilis cardium	3	13.6	0.3	0.1	1	20.0	0.2	0.1	D				1	0.9	0.1	0.0				
Lampsilis siliquoidea	D				D															
Lasmigona costata	D																			
Leptodea fragilis	2	9.1	0.2	0.1					1	0.6	0.1	0.1	D				1	1.4	0.1	0.1
Ligumia recta	2	9.1	0.2	0.1	1	20.0	0.2	0.1	4	2.6	0.4	0.1								
Megalonaias nervosa[1]													1	0.9	0.1	0.0				
Obliquaria reflexa	4	18.2	0.4	0.1	1	20.0	0.2	0.1	44	28.4	4.4	0.4	17	15.7	1.6	0.2	26	36.6	3.6	0.5
Potamilus alatus	5	22.7	0.5	0.1					D				D							
Potamilus ohiensis													1	0.9	0.1	0.0	2	2.8	0.3	0.1
Pyganodon grandis									1	0.6	0.1	0.1					1	1.4	0.1	0.1
Quadrula metanevra[1]									1	0.6	0.1	0.1								
Quadrula nodulata									1	0.6	0.1	0.1	3	2.8	0.3	0.1	5	7.0	0.7	0.2
Quadrula pustulosa									4	2.6	0.4	0.1	6	5.6	0.6	0.1				
Quadrula quadrula	4	18.2	0.4	0.1	1	20.0	0.2	0.1	13	8.4	1.3	0.2	7	6.5	0.7	0.1	15	21.1	2.1	0.3
Strophitus undulatus	D								4	2.6	0.4	0.1	D				1	1.4	0.1	0.1
Truncilla donaciformis													D				D			
Truncilla truncata	2	9.1	0.2	0.1	1	20.0	0.2	0.1	33	21.3	3.3	0.3	9	8.3	0.9	0.1	12	16.9	1.7	0.2
Total	22		2.2	0.2	5		0.8	0.2	155		15.5	1.0	108		10.3	0.6	71		9.8	0.8
(n)	40				25				40				42				29			
No. live species	7				5				13				10				10			
Total species	10				6				15				14				11			
Zebra mussel density			0.0	0.0			0.0	0.0			0.0	0.0			0.0	0.0			0.1	0.1

2SE=2*Standard Error.

[1]Individuals were relocated from Mississippi River Pool 11.

Table 3-5. Mussel species age within Beds 1-5 from quantitative samples within the MNRRA Corridor, 2001.

	Mussel Bed																			
	1 (SAF Pool)				2 (SAF Pool)				3 (Upper Pool 2)				4 (Upper Pool 2)				5 (Lower pool 2)			
Species	(n)	Ave.	Min.	Max.	(n)	Ave.	Min.	Max.	(n)	Ave.	Min.	Max.	(n)	Ave.	Min.	Max.	(n)	Ave.	Min.	Max.
Amblema plicata									38	12.6	1	25	55	15.0	4	32	1	14.0	14	14
Fusconaia flava									9	10.2	5	19	8	9.3	3	20	7	7.6	2	18
Lampsilis cardium	3	5.0	3	7	1	11.0	11	11					1	4.0	4	4				
Lampsilis siliquoidea																				
Lasmigona costata																				
Leptodea fragilis	2	6.0	5	7					1	11.0	11	11					1	7.0	7	7
Ligumia recta	2	5.0	5	5	1	9.0	9	9	4	8.0	6	11								
Megalonaias nervosa													1	28.0	28	28				
Obliquaria reflexa	4	6.3	3	9	1	10.0	10	10	44	9.9	5	17	17	8.8	3	16	26	8.2	3	15
Potamilus alatus	5	11.6	7	18																
Potamilus ohiensis													1	2.0	2	2	1	2.0	2	2
Pyganodon grandis									1	7.0	7	7								
Quadrula nodulata									1	8.0	8	8	3	10.3	8	13	5	3.6	2	5
Quadrula pustulosa									4	10.5	5	16	6	12.5	3	17				
Quadrula quadrula	4	11.3	10	13	1	13.0	13	13	13	9.2	6	12	7	11.7	5	16	15	7.9	3	15
Strophitus undulatus									4	12.3	8	18					1	9.0	9	9
Truncilla donaciformis																				
Truncilla truncata	2	8.5	6	11	1	7.0	7	7	33	7.8	2	18	9	7.7	5	13	12	4.4	2	9
Total	22	8.3	3	18	5	10.0	7	13	152	10.1	1	25	108	12.4	2	32	69	7.1	2	18
% <4 years old		9.1				20.0				3.2				3.7				19.7		
% <6 years old		27.3				40.0				8.4				13.0				40.8		

measurable or non-existent. A total of 563 mussels of eight species were relocated to this bed in an area covering several hundred square meters. No relocated *L. higginsi* were collected in quantitative samples and no dead relocated mussels were collected.

Average age of the mussel community was 10.1 years (range 1 to 25), and 8.4% and 3.2% of the individuals were <6 and <4 years old, respectively (see Table 3-5).

Habitat in Bed 3 was a run with moderate to high flows and substrate consisted of a consolidated mixture of sand, gravel, cobble, and boulder. The bed lies immediately off the riverbank, along a slope to the river bottom and out into the navigation channel approximately 1/3 of the way across the river. Because this area harbors a relatively dense, species rich mussel community that supports rare native as well as relocated species, this area should be monitored in the future.

3.2.4 Bed 4 (Site 66)

Mussel Bed 4 was also in Upper Pool 2. This bed was at the lower end of Pike Island near the confluence with the Minnesota River and served as a state listed species only relocation site. Mussel density was 10.3/m^2 and a total of 10 species were collected (see Table 3-4). Mussel species composition and density were slightly different than at Bed 3. *Amblema plicata* accounted for >50% of the mussels collected. Particularly noteworthy at Bed 4 was the collection of a relocated *M. nervosa*. No dead relocated mussels were collected. *Quadrula nodulata* density was 0.3/m^2 (see Table 3-4).

Among all species, average age of mussels at Bed 4 was 12.4 years (range 2 to 32) and was slightly greater than at Bed 3. A total of 13.0% and 3.7% of the individuals were <6 and <4 years old, respectively (see Table 3-5). *Qudrula nodulata* age ranged from 8 to 13 years old.

The slight differences between Beds 3 and 4 mussel communities were probably related to habitat. Bed 4 was in an eddy where flow was minimal and substrate consists of sand and silt. As with Bed 3, this area harbors a relatively dense and species rich mussel community including rare native as well as relocated species. We therefore recommend it to be monitored in the future.

3.2.5 Bed 5 (Site 97)

Mussel Bed 5 was located in Lower Pool 2 between Lower Grey Cloud Island and Spring Lake and in the vicinity of qualitative Site 97 (see Figure 3-8). This bed's boundary was approximated and it was difficult to delineate because of its very large size. To account for the large size, three clusters of quantitative samples were collected at arbitrary locations within the bed.

Mussel density was 9.8/m^2 at Bed 5 consisting of 10 species (see Table 3-4). *Obliquaria reflexa*

dominated the collection and other abundant species included *Q. quadrula* and *T. truncata*. *Quadrula nodulata* density was 0.7/m^2, which was highest among the beds (see Table 3-4).
The mussel community at Bed 5 was the youngest among the beds (see Table 3-5). Overall average was 7.1 years (range 2 to 18) and 40.8% and 19.7% of the individuals were <6 and <4 years old, respectively. All *Q. nodulata* were <6 years old.

The mussel community within Bed 5 should be monitored in the future and a more thorough delineation of the bed boundaries should be done in order to better sample the community during future monitoring.

3.3 Zebra Mussels

Zebra mussels (*D. polymorpha*) were absent above Lock and Dam 1 (Pool 1, CR and SAF Pool, and the Rum River) and sparse from UMR Pools 2-3 and the lower MNR. It should be noted, however, that zebra mussels are likely present in Pool 1 and the lower SAF Pool and we simply did not observe any, as they have been observed within the lock chambers at St. Anthony Falls (U.S. Army Corps of Engineers, pers. comm.). During quantitative sampling, zebra mussels were only collected from Bed 5 in Lower Pool 2 where density was 0.1/m^2 (see Table 3-4). Throughout the MNRRA Corridor below Lock and Dam 1, where zebra mussels were observed in this study, a total of 89 (1%) 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 1 to 4). Zebra mussel infestation was greatest in Upper Pool 3 (2.6% native mussels infested) followed by lower MNR (1.7%), Lower Pool 2 (0.9%), Upper Pool 2 (<0.1%), and Middle Pool 2 (0%).

At this point it appears that zebra mussels are not reproducing since the zebra mussels observed were large (>15mm) isolated adult individuals. It may be that these individuals arrived on barges and other watercraft that transported them upriver into the MNRRA Corridor. Very few zebra mussels were observed attached to the substrate and no discernable difference in zebra mussel infestation was observed between 2000 and 2001.

3.4 Relocated mussels

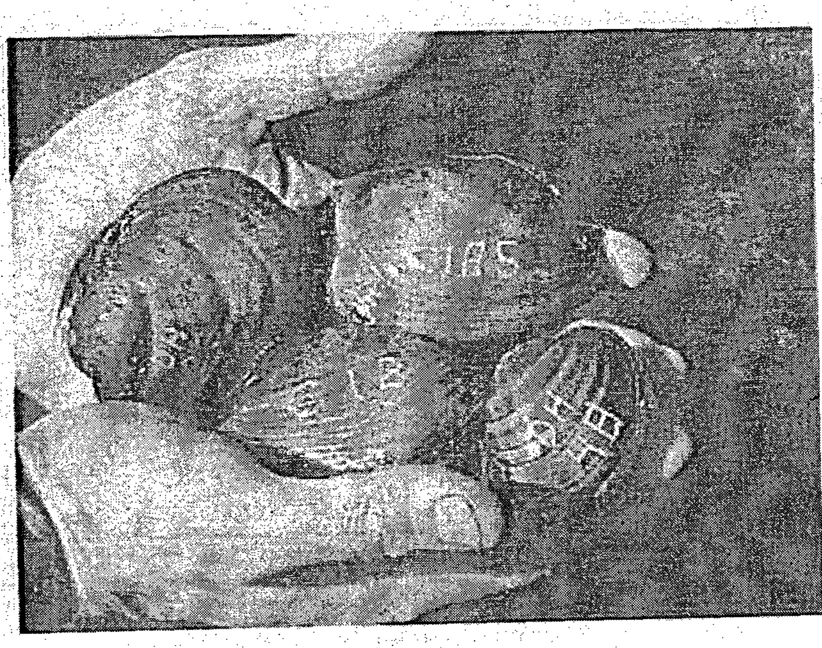
A total of 2,435 mussels of eight species were relocated by the USACE, FWS, and the natural resources departments of Minnesota, Wisconsin, Illinois, and Iowa from Mississippi River Pool 11 near Cassville, WI (2000) and Pool 14 near Cordova, IL (2001) to four areas within the MNRRA Corridor (Table 3-6) (Davis 2002). All species were listed for protection in Minnesota including the federally endangered *L. higginsi*. Mussels were placed at three sites within Upper Pool 2 (54, 58, 66) and one site in Upper Pool 3 (122) (see Table 3-6). State listed species were relocated to all four sites and *L. higginsi* were only relocated to Sites 58 and 122.

Table 3-6. Number of mussels relocated from Mississippi River Pools 11 and 14 and their destination within MNRRA, 2000 and 2001.

	Upper Pool 2				Upper Pool 3	
	Site 54	Site 58 (Bed 3)	Site 58 (Bed 3)	Site 66 (Bed 4)	Site 122	Total
Species	No.	No.	No.	No.	No.	No.
Arcidens confragosus		30		25	37	92
Ellipsaria lineolata	100	50		2	424	576
Elliptio dilatata		8				8
Lampsilis higginsi		99	271		101	471
Ligumia recta	60	20		59	400	539
Megalonaias nervosa	72	35		73	466	646
Pleurobema sintoxia		31			32	63
Quadrula metanevra		19			21	40
Total	232	292	271	159	1,481	2,435
No. species	3	8	1	4	7	8
Year relocated[1]	2000	2000	2001	2000, 2001	2000	

[1]All mussels relocated in 2000 were from Pool 11 and all relocated in 2001 were from Pool 14.

Relocated *L. higginsi*.



4.0 Discussion

This study provides important baseline data on the status of mussels within the MNRRA Corridor and should provide a benchmark for future reference. More specifically, the study provides information on the following:

- Current and historic species distributions throughout the corridor
- Mussel species richness and abundance (relative and CPUE) for individual sites, reaches, pools, and rivers throughout the corridor
- Age class structure of individual mussel species and mussel communities
- Identification of sites harboring healthy and poor mussel communities
- Description of the mussel communities associated with NPS Islands
- Specific site and bed locations.
- General aquatic habitat conditions throughout the corridor and their relation to the mussel fauna
- Mussel density, relative abundance, and age structure within five mussel beds
- Zebra mussel densities and estimates of colonization rates on native mussels

The mussel fauna of the UMR within the study area has improved dramatically since the 1970s. The mussel community was more species rich and mussels were more abundant in the Mississippi River below the Coon Rapids Dam (SAF Pool to Upper Pool 3) as compared to the CR Pool and the lower Minnesota River and Rum River. Upper Pool 3 supported the most species and greatest density of mussels followed by Pool 2 (all three sub-reaches combined) and the SAF Pool (see Table 3-2). However, within Pool 2, Upper Pool 2 (above the Minnesota River) mussel density was greater than Upper Pool 3 and species richness was nearly as high suggesting it is an exceptional habitat for mussels.

In addition, zebra mussels are extremely scarce, which is not the case below UMR Pool 4 where they are negatively impacting native mussel populations (Kelner and Davis 2002, MNDNR unpubl. data). Although zebra mussels have been present in the MNRRA Corridor for a decade, they apparently have not increased in abundance. Recently, zebra mussels have been reproducing in the Lake St. Croix portion of the St. Croix River (Kelner and Davis 2002), which could eventually impact Pool 3 by supplying larval zebra mussels.

For the most part the mussel fauna within the MNRRA Corridor was relatively young, indicating recent reproduction and recruitment of young individuals has occurred throughout the corridor. Older individuals are uncommon suggesting recolonization of formerly degraded habitat. Most species populations were dominated by individuals <11 years old (see Figure 3-1). It's our experience that age class distribution of a well-established species population is usually skewed toward older individuals

due to the lengthy survivorship of mussels (MNDNR unpubl. data). We found the age class distribution to be skewed towards younger individuals for nearly every species in this study, which supports Fuller's (1980) assertion that mussels were once nearly eliminated from the MNRRA Corridor. The relatively young mussel fauna may be a temporary condition. Given sufficient time coupled with sustained water quality, older individuals should become more dominant due to the long-lived nature of mussels. The mussel fauna of the St. Croix River has probably not changed much from historic conditions and older individuals dominate the community (see Figure 3-5), probably not because recruitment of young is low but because it has been consistent and survival rates of older individuals is high (MNDNR unpubl. data). Over time, age class structure within the MNRRA Corridor should look similar to that of the St. Croix River.

Four species within MNRRA were dominated by individuals >10 years old and were scarce, *A. ligamentina, E. dilatata, A. marginata,* and *M. nervosa*. It appears at this point, only *A. marginata* has potential to become extirpated from MNRRA. Three old (>15 years) individuals of this species were collected from Upper Pool 2 and may be a pre-impoundment remnant. This reach was the only area within MNRRA where Fuller (1980) found an assemblage of mussels and where this species might have been able to survive in low numbers. However, present habitat conditions are not ideal for this species in the UMR and it may be headed towards extirpation from MNRRA. This species is typical of smaller rivers and often associated with riffles (pers. obs.), which once extended from St. Anthony Falls to near the confluence with the Minnesota River (present day Pool 1 and Upper Pool 2), but since have been eliminated by impoundment. All *A. ligamentina* and *E. dilatata* were collected from sites immediately downstream of the St. Croix River along the Wisconsin bank in what we would identify as St. Croix waters. These two species are currently present in the St. Croix River (MNDNR unplubl. data) and are probably an extension of those populations. Apparently these species have not re-established themselves in the Mississippi River upstream of the St. Croix River where they once lived (as evidenced by the presence of long dead specimens), and it remains speculative if this species will. Only two *M. nervosa* were collected in Upper Pool 3 (one additional relocated individual was collected in Bed 4 [Upper Pool 2]). As with *A. ligamentina* and *E. dilatata,* this species may not have successfully re-colonized the UMR above the St. Croix River. However, with the addition (via relocation) of >600 individuals to Upper Pool 2 and Upper Pool 3, this species hopefully will naturally propagate within MNRRA, and its status should be considered for future monitoring.

It appears from this study that the Coon Rapids Dam serves as a faunal barrier to upstream migration of mussels via their host fish, much as the Falls at St. Anthony have done historically. The Coon Rapids Dam is a spillover and hydropower dam that is virtually impassable to fish and mussels. Only six mussel species were found in the CR Pool, and the lower portion of the pool supported few mussels. The mussel community of the CR Pool very closely resembles that of the Mississippi River drainage

above this pool. Upstream of the Twin Cities the mussel fauna of the CR Pool may have been decimated in the first half of the 1900s as the lower reaches were. Municipalities upstream of the CR Dam, such as St. Cloud, MN were notorious for polluting the Mississippi River and the mussel fauna may have suffered as a result. The relatively young mussel community present today supports this hypothesis. When conditions improved, the only means by which mussels could recolonize the CR Pool was from tributaries or headwaters of the Upper Mississippi River. The mussel fauna in the CR Pool is different from lower reaches of the Mississippi River and similar to the headwater Upper Mississippi River fauna in that the community is dominated by *L. cardium* (62.4%), *L. siliqouidea* (19.4%) and *L. recta* (14.8%). This is very similar to what has been documented in the tributaries above the CR Dam and in the Mississippi River at St. Cloud (MNDNR unpubl. data).

The SAF Pool supports a mussel fauna today that is more difficult to interpret. The mussel fauna bears some similarity to its historic or upstream assemblage, but also to that of the river below the historic barrier. Some mussels undoubtedly survived past pollution and have begun to thrive, explaining the young age and high numbers of *L. cardium*, *L. siliqouidea*, and *L. recta*. In addition, of the 16 species found, 10 are species not previously reported above the falls. Apparently these species have arrived as larvae attached to fish that have used navigation locks to travel around the Falls of St. Anthony, and/or perhaps fish stocking activities inadvertently introduced these species into the pool. Only two species found in Pool 1, *Q. nodulata* and *Q. pustulosa*, were not found in the SAF Pool.

Middle Pool 2 and the lower Minnesota River are similar in that they both lack the healthy mussel community that they supported historically. Both have degraded habitat and apparent poor water quality. Middle Pool 2's poor water quality is no doubt a result of the Minnesota River emptying into the Upper Mississippi River at the head of this reach but its altered habitat is probably the result of a combination of factors. Silt from the Minnesota River contributes most of the silt and muck found in Middle Pool 2. However, the constricted nature of the Upper Mississippi River at this reach coupled with the industrial and urban presence creates an unstable substrate and poor habitat for mussels. The Minnesota River has a long history of pollution and siltation from agricultural run-off and stream bank erosion throughout the drainage (Bright et. al. 1990). It appears that the mussel fauna in the Minnesota River, and to a lesser degree Middle Pool 2, will not improve unless these issues in the Minnesota River Basin are addressed.

Upper Pool 2, Lower Pool 2, and Upper Pool 3 appear to support the healthiest mussel communities within MNRRA. All areas support a relatively high number of species (>17) and abundance is also high (CPUE >87 mussels/hr). All (27) but one species collected within the MNRRA Corridor were collected from these reaches and density of the three mussel beds within these areas ranged from 9.8/m^2 to 15.5/m^2. All three areas support a young population of *Q. nodulata* and Lower Pool 2 and Upper Pool 3

support a young and fairly healthy population of *A. confragosus.*

How *Q. nodulata* and *A. confragosus* arrived is somewhat puzzling, but is probably not linked to the St. Croix River, which empties into Upper Pool 3. These two species are not present in the lower St. Croix River, which would serve as ideal refugia for most of the Mississippi River mussel species due to its sustained high water quality and currently healthy mussel populations. This leads to speculation on the origin of the remaining species that are recolonizing the MNRRA Corridor.

It's very probable that a certain number of mussel species were able to survive at very low numbers in protected patches during the decades of extreme pollution within the Mississippi River above Pool 4, and are once again reproducing. Alternatively, the Upper Mississippi River mussel fauna below Lake Pepin (Pool 4), which serves as a natural catch-basin for contaminants, may be the source of recolonizing fauna. Fish carrying larvae from these mussels could be bringing them upstream into the MNRRA Corridor. In conjunction with certain species able to survive within the MNRRA Corridor, species may have migrated from tributaries such as the St. Croix River. Regardless of origin, the current mussel fauna is approaching the historic mussel fauna in species composition. Whatever the mechanism of recolonization, this reach of the Mississippi River between the Twin Cities and Hastings, MN, once nearly a dead zone, may now constitute one of the most significant big river mussel refuges in the Midwestern United States, and its status should be monitored closely in the future.

5.0 Recommendations

This inventory was the first step in managing the mussel fauna within the MNRRA Corridor. We recommend several locations for future long term monitoring of the mussel fauna. Long term monitoring is essential to establish trends in the community structure. This will provide better knowledge for conservation planning for individual species, restoration of critical habitat, recovery of listed species, and for sustaining the mussel resources for future generations. We recommend the following:

- Monitor Beds 1, 3, 4, and 5 biannually with quantitative and qualitative samples.
- Better delineate the boundaries of Bed 5
- Continue to fill in inventory gaps with timed searches, especially in SAF Pool and Lower Pool 2.
- Add quantitative monitoring sites in the following reaches so most reaches contain at least one monitoring site and include relocation sites:
    - **CR Pool**
        - Site 4 at the base of NPS Island 101-01.
    - **SAF Pool**
        - Site 25 immediately below Banfill Island
        - Site 33 downstream of the I-694 Bridge.
    - **Pool 1**
        - Site 46 located mid pool.
    - **Upper Pool 2**
        - Site 54 is a state listed relocation site.
        - Site 60 across from the head of Pike Island. Hornbach (pers. comm., Biology Department, Macalaster College, St. Paul, MN) quantitatively sampled this site in 1996 and it would serve as a good comparison.
    - **Lower Pool 2**
        - Better delineate Bed 5 and search for another site to monitor
    - **Upper Pool 3**
        - Site 122 above St. Croix River (*L. higginsi* and state listed species relocation site)
        - Site 131 located between two wing dams downstream of the confluence with the St. Croix River.
        - Monitor additional sites above and below the St. Croix River in order to assess impacts of the St. Croix's influence especially since zebra mussels are reproducing in the St. Croix River.

In addition, Table 5-1 (page 41) is a summary table showing sites organized by reach that were outlined in the results that were exceptional with respect to supporting a relatively healthy mussel community. These sites, if not mentioned above should also be considered for future monitoring depending upon funding. Consult Figures 3-4, 3-6, 3-7, and 3-8, and Appendix III for specific site location and Appendix II for a species list and abundance for each site.

Table 5-1. Sites with comparatively healthy mussel communities within MNRRA, 2000-01.

	Mississippi River Pool (reach)					
CR	SAF	1	Upper 2	Middle 2	Lower 2	Upper 3
Site	Site	Site	Site	Site	Site	Site
4	(Bed 1) 20	46	54	68	79	121
12	21	50	57		81	122
	22	52	(Bed 3) 58		96	129
	25		59		(Bed 5) 97	131
	27		60		98	135
	(Bed 2) 29		62		99	137
	30		65		100	
	32		(Bed 4) 66		105	
	33				106	
					109	
					111	
					114	
					110	
					112	
					113	
					115	

6.0 Literature Cited

Bright, R., C. Gatenby, D. Olson and E. Plummer. 1990. A survey of mussels of the Minnesota River, 1989. Bell Museum of Natural History, University of Minnesota, St. Paul, MN., pp 1-36.

Dawley, C. (1947). Distribution of aquatic mollusks in Minnesota. *American Midland Naturalist* 38: 671-697.

Davis, M. 2002. Section 6 Grant Project Final Report, 2001: Emergency conservation relocation and reintroduction of Higgins' eye pearly mussel (Lampsilis higginsi) and other mussel species from zebra mussel affected area in the Upper Mississippi River. 17pp.

Fuller, S.L.H. 1980. Final report: Freshwater mussels (Mollusca: Bivalvia: Unionidae) of the Upper Mississippi River: obervations at selected sites within the 9-foot navigation channel project for the St. Paul District, United State Army Corps of Engineers, 1977-1979. Volume 1: Text. Academy of Natural Sciences of Philadelphia, Division of Limnology and Ecology, Philadelphia, PA. 175pp.

Graf, D. L. 1997. Distribution of unionoid (Bivalvia) faunas in Minnesota, USA. *Nautilus* 110: 45-54.

Havlik, M. E. and J. S. Sauer. 2000. Native freshwater mussels of the Upper Mississippi River System. Project Status Report 2000-04, Upper Midwest Environmental Sciences Center, U.S. Geological Service, La Crosse, Wisconsin. 2pp.

Kelner, D.E. and M. Davis. 2002. Final Report: Mussel (Bivalvia: Unionidae) surveys 2001: Lower St. Croix River from Stillwater, Minnesota (RM 23.7) to Prescott, Wisconsin (RM 1.7), Mississippi River Lock and Dam 3 tailwaters mussel bed mapping, Higgins' eye gravid female mussel collection. Prepared for U.S. Army Corps of Engineers, St. Paul District, St. Paul Minnesota. 45pp.

Miller, A. C. and B. S. Payne 1988. The need for quantitative sampling to characterize size demography and density of freshwater mussel communities. *American Malacological Bulletin* 6: 49-54.

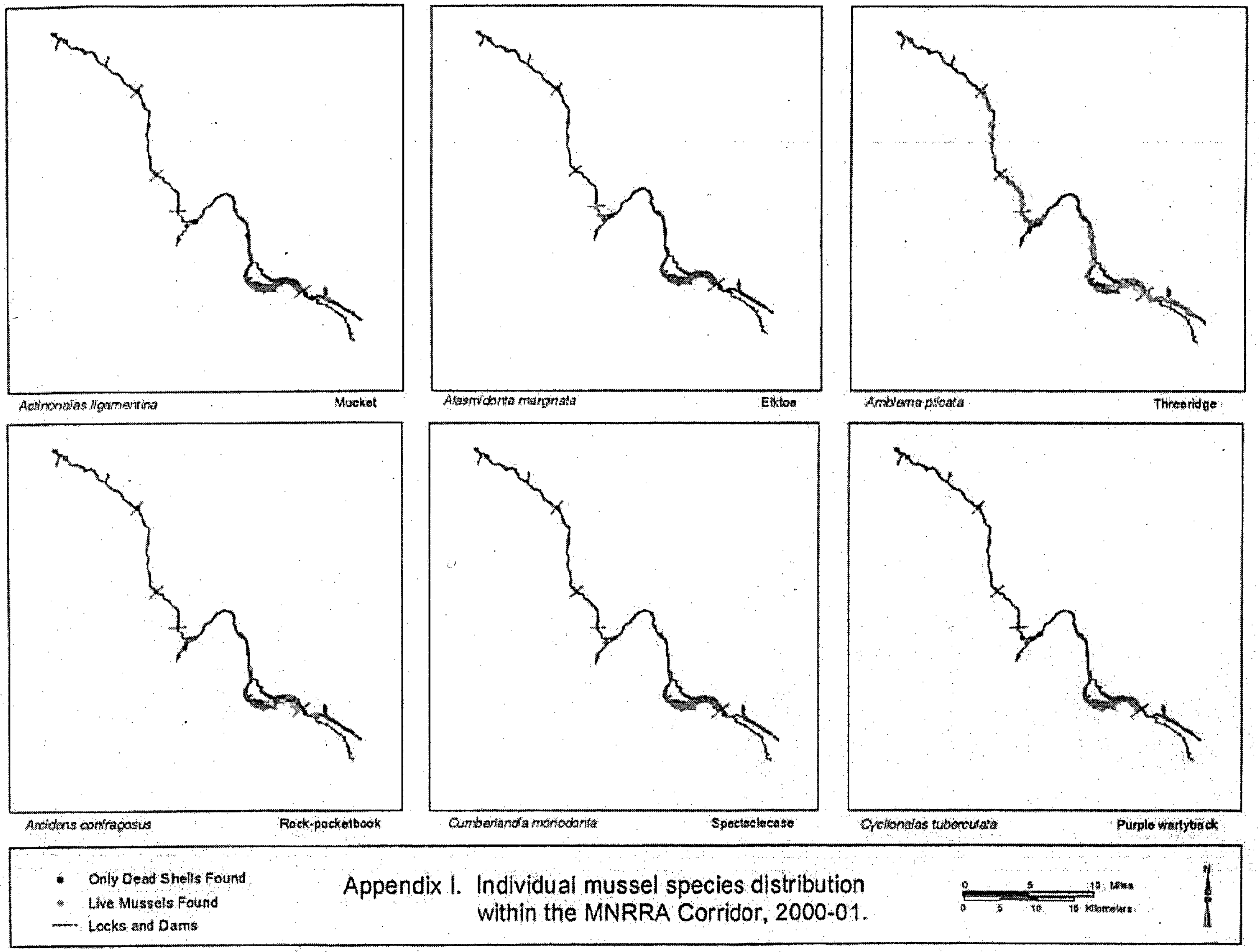
Neves, R. J. and S. N. Moyer. 1988. Evaluation of techniques for age determination of freshwater mussels (Unionidae). *American Malacological Bulletin* 6: 179-188.

7.0 Appendices

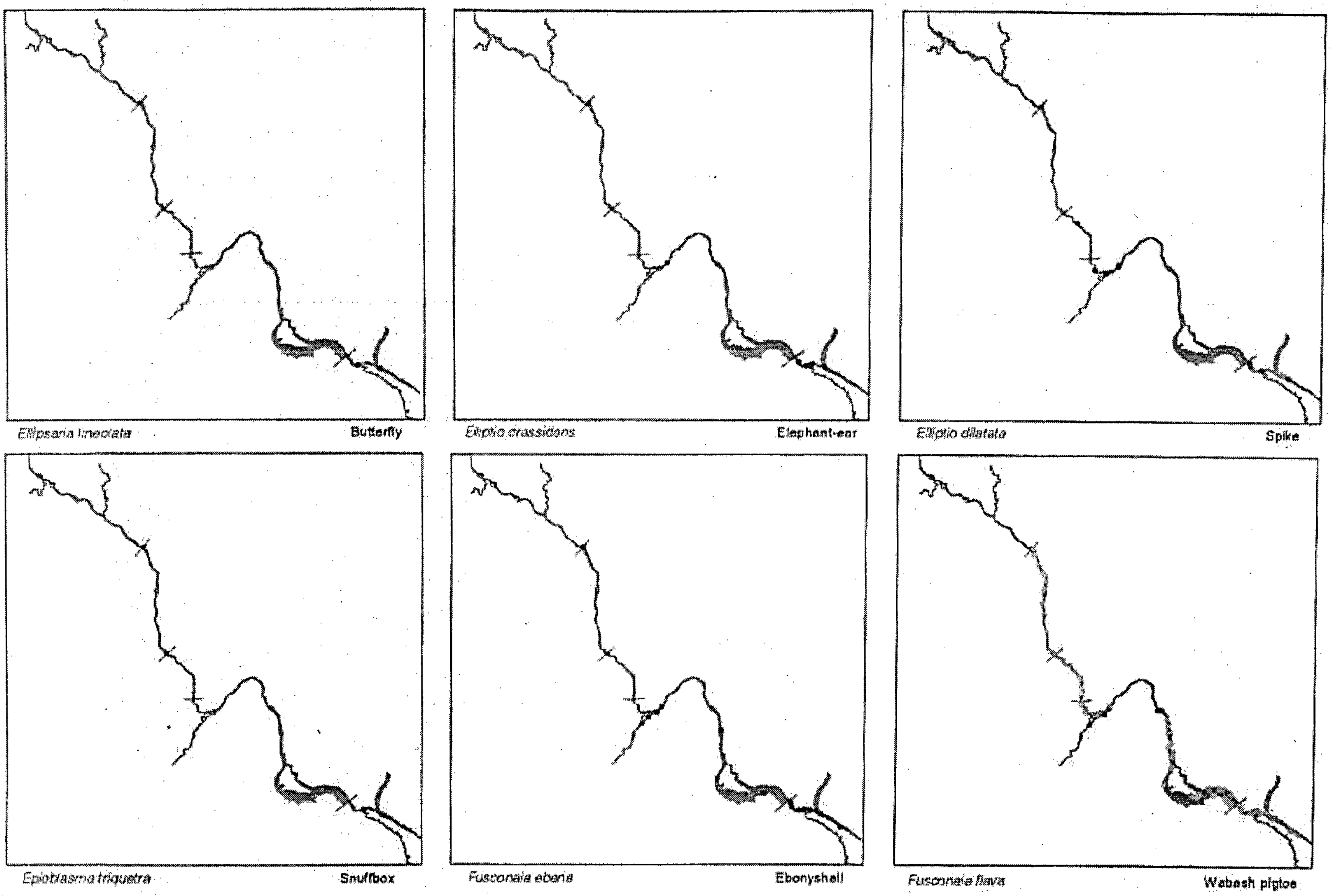
Appendix I. Individual mussel species distribution within the MNRRA Corridor, 2000-01.

Appendix II. Number live mussels and species collected at sites sampled within the MNRRA Corridor, 2000-01.

Appendix III. UTM coordinates (NAD 1983) for each site sampled.

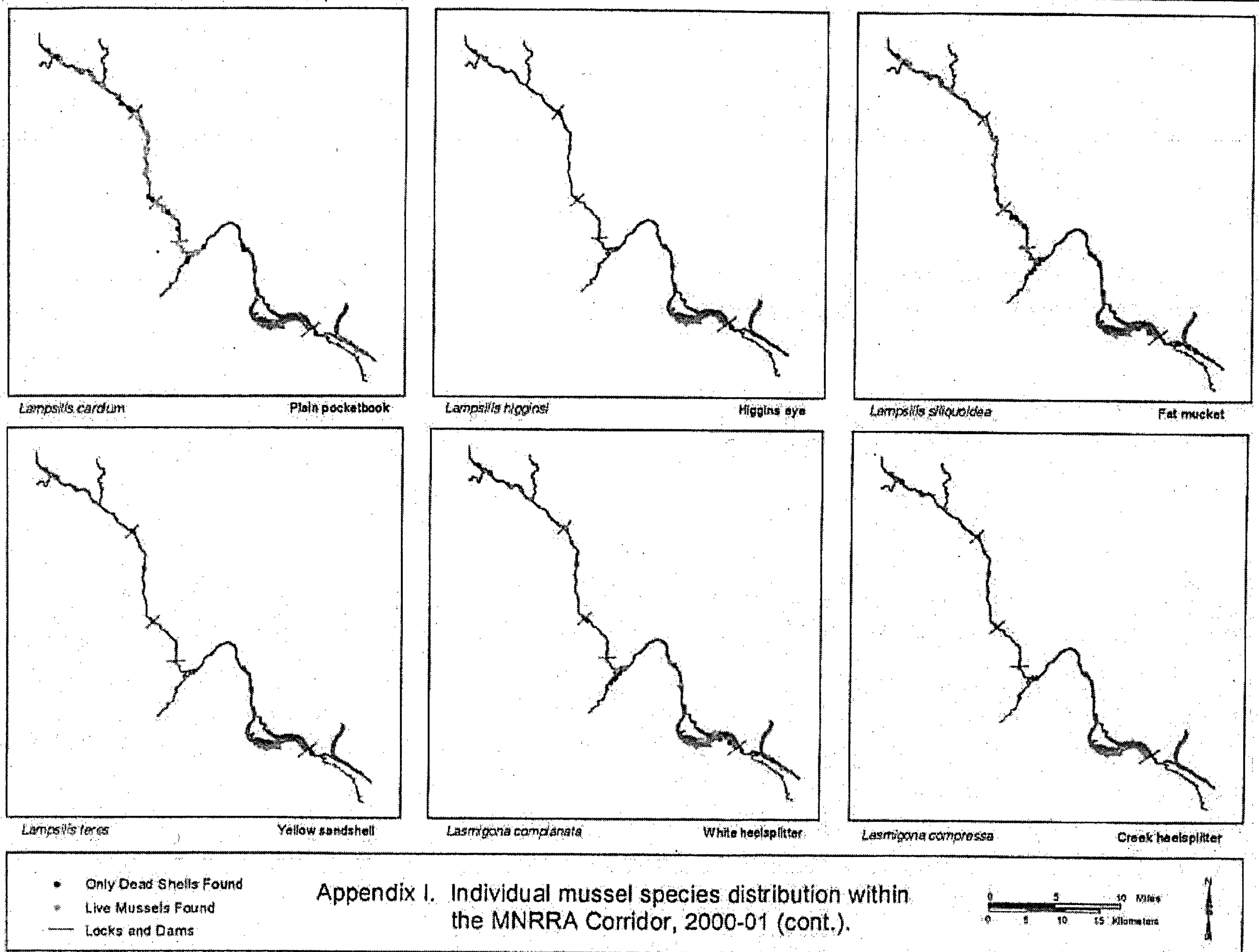


Appendix I. Individual mussel species distribution within the MNRRA Corridor, 2000-01.

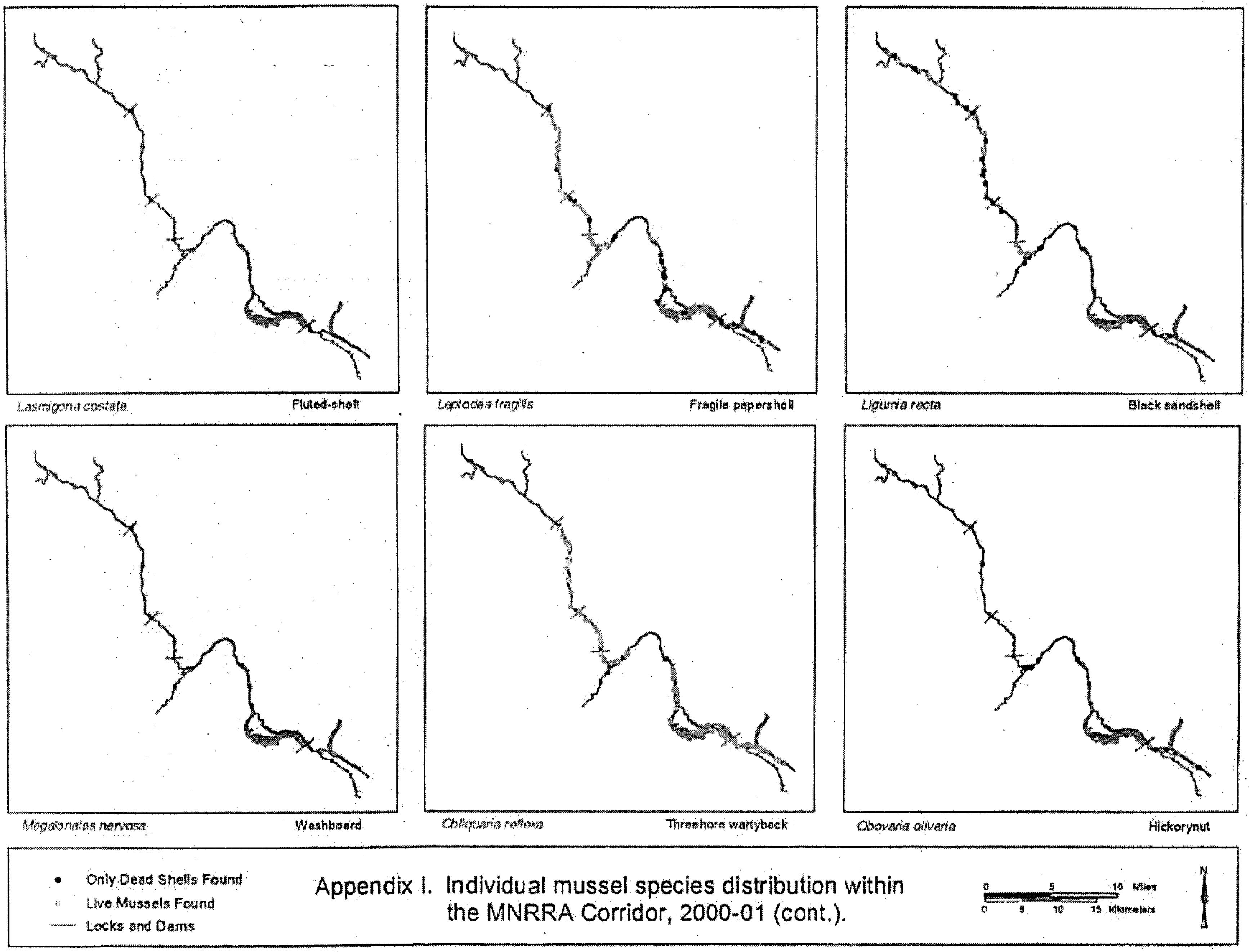


- Only Dead Shells Found
- Live Mussels Found
- Locks and Dams

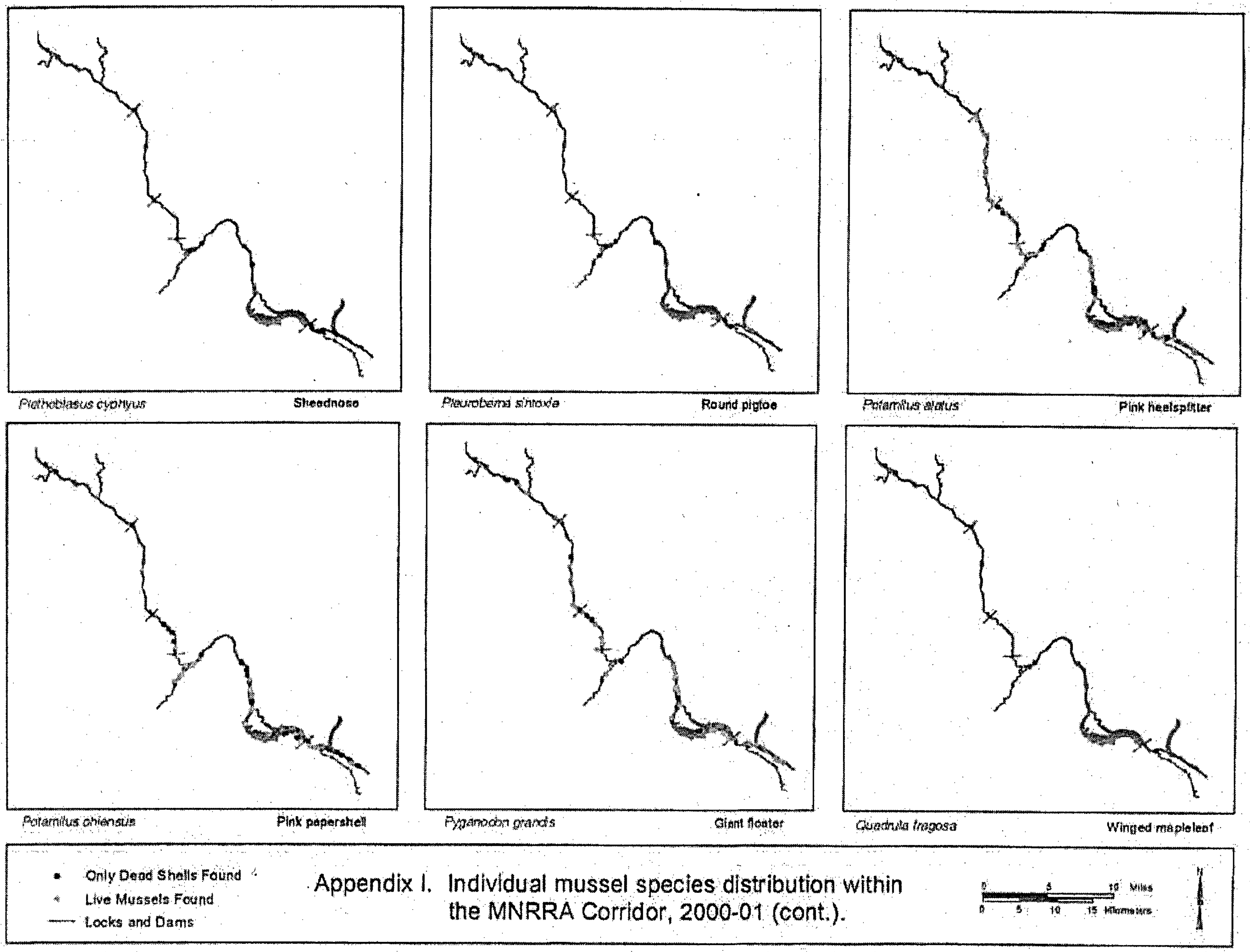
Appendix I. Individual mussel species distribution within the MNRRA Corridor, 2000-01 (cont.).



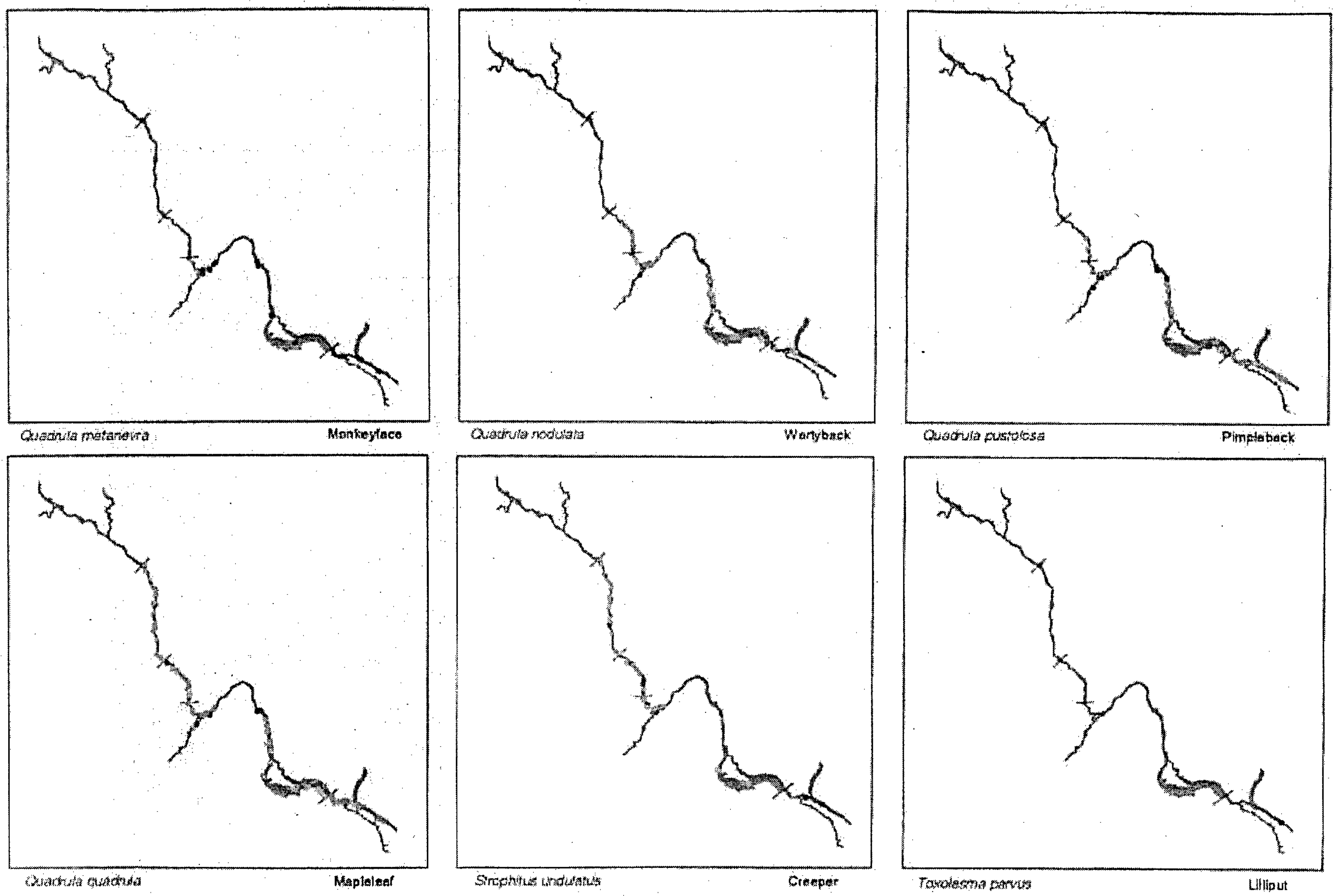
Appendix I. Individual mussel species distribution within the MNRRA Corridor, 2000-01 (cont.).



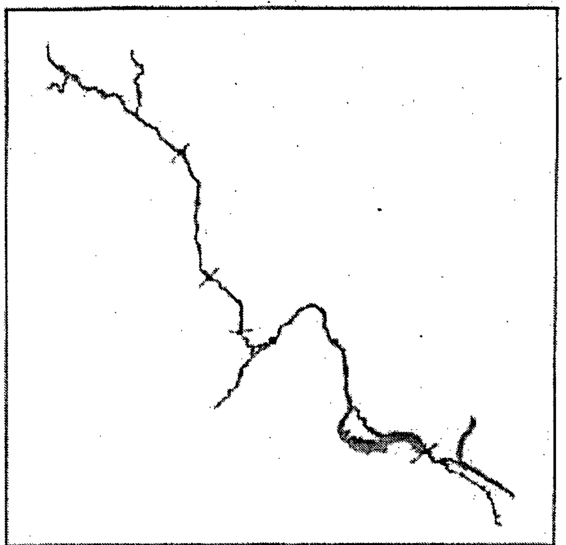
Appendix I. Individual mussel species distribution within the MNRRA Corridor, 2000-01 (cont.).



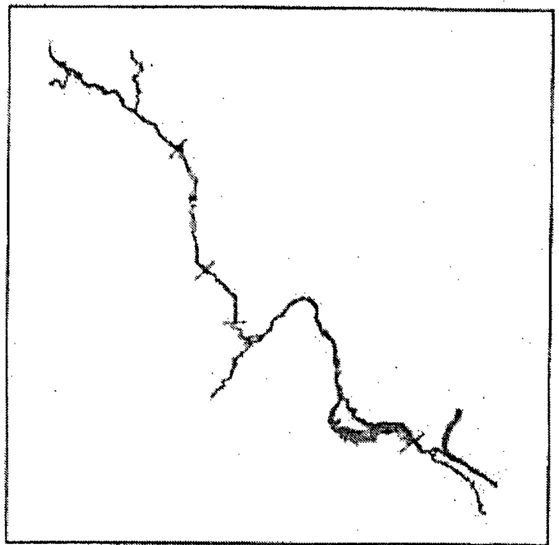
Appendix I. Individual mussel species distribution within the MNRRA Corridor, 2000-01 (cont.).



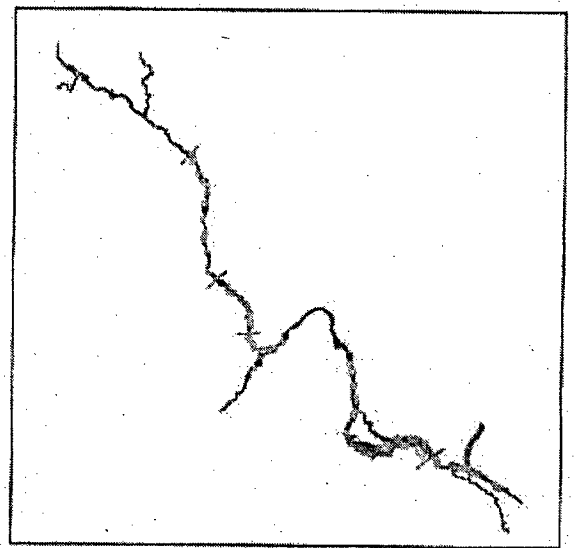
Appendix I. Individual mussel species distribution within the MNRRA Corridor, 2000-01 (cont.).



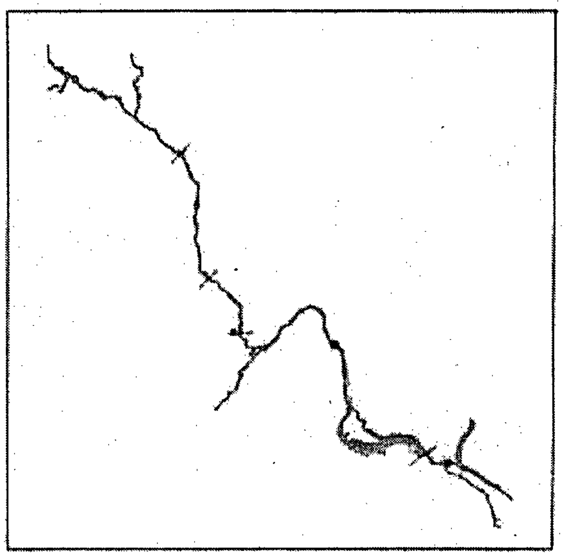
Tritogonia verrucosa **Pistolgrip**



Truncilla donaciformis **Fawnsfoot**



Truncilla truncata **Deertoe**



Utterbackia imbecillis **Paper pondshell**

- Only Dead Shells Found
- Live Mussels Found
- Locks and Dams

Appendix I. Individual mussel species distribution within the MNRRA Corridor, 2000-01 (cont.).

0 5 10 Miles
0 5 10 15 Kilometers

Appendix II. Number live mussels and species collected at sites sampled within the MNRRA Corridor, 2000-01.

	Coon Rapids Pool														
Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Actinonaias ligamentina															
Alasmidonta marginata															
Amblema plicata															
Arcidens confragosus															
Cumberlandia monodonta															
Cyclonaias tuberculata															
Ellipsaria lineolata															
Elliptio crassidens															
Elliptio dilatata															
Epioblasma triquetra															
Fusconaia ebena															
Fusconaia flava															
Lampsilis cardium	5	D	D	202	4	4	D	8	22	6	23	89	1	2	D
Lampsilis higginsi															
Lampsilis siliquoidea	6	2	D	8	3	3	D	10	10	4	14	48	3	2	1
Lampsilis teres															
Lasmigona complanata							1		1			2			
Lasmigona compressa															
Lasmigona costata															
Leptodea fragilis															
Ligumia recta	1	D	D	19	1	D	D	7	12	7	8	32		D	D
Megalonaias nervosa															
Obliquaria reflexa															
Obovaria olivaria															
Plethobasus cyphyus															
Pleurobema sintoxia															
Potamilus alatus												1			
Potamilus ohiensis															
Pyganodon grandis							1	D	D	1		3			
Quadrula fragosa															
Quadrula metanevra															
Quadrula nodulata															
Quadrula pustulosa															
Quadrula quadrula															
Strophitus undulatus															
Toxolasma parvus															
Tritogonia verrucosa															
Truncilla donaciformis															
Truncilla truncata															
Utterbackia imbecillis															
No. live	12	2	0	229	8	7	2	25	45	18	45	175	4	4	1
No. live species	3	1	0	3	3	2	2	3	4	4	3	6	2	2	1
Total species	3	3	3	3	3	3	5	4	5	4	3	6	2	3	3
CPUE (no. live/hr.)	14.4	1.5	0.0	152.7	4.8	10.5	2.0	16.7	24.5	10.8	22.5	105.0	2.0	8.0	2.0

Appendix II *(cont)*. Number live mussels and species collected at sites sampled within the MNRRA Corridor, 2000-01.

Species	Coon Rapids Pool				St. Anthony Falls Pool										
	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Actinonaias ligamentina															
Alasmidonta marginata															
Amblema plicata						2	6	1	2	1				14	4
Arcidens confragosus															
Cumberlandia monodonta															
Cyclonaias tuberculata															
Ellipsaria lineolata															
Elliptio crassidens															
Elliptio dilatata															
Epioblasma triquetra															
Fusconaia ebena															
Fusconaia flava						46	5	2	2	2		9	6	6	15
Lampsilis cardium	D	D	D		7		26	4	6	19	16	13	1	88	58
Lampsilis higginsi															
Lampsilis siliquoidea			3		3		5	3	1	8	D	5		22	11
Lampsilis teres															
Lasmigona complanata						1									
Lasmigona compressa															
Lasmigona costata															
Leptodea fragilis					4	D	9	11	1	30	6	27	6	20	9
Ligumia recta	D	D					5	4	1	5	4	7	D	34	25
Megalonaias nervosa															
Obliquaria reflexa						2	21		21	11	1	11	5	18	19
Obovaria olivaria															
Plethobasus cyphyus															
Pleurobema sintoxia						1									
Potamilus alatus					3	1	83	9	8	13	12	22	3	42	16
Potamilus ohiensis															
Pyganodon grandis			7			35									D
Quadrula fragosa															
Quadrula metanevra															
Quadrula nodulata															
Quadrula pustulosa															
Quadrula quadrula						113	16	2	7	11		11	7	16	29
Strophitus undulatus						1		5	2	26		15	5	14	1
Toxolasma parvus															
Tritogonia verrucosa															
Truncilla donaciformis							14			3		5		6	D
Truncilla truncata						2	3	6	18	135	D	53	24	78	39
Utterbackia imbecillis															
No. live	0	0	10	0	17	204	193	47	69	264	39	178	57	358	226
No. live species	0	0	2	0	4	10	11	10	11	12	5	11	8	12	11
Total species	2	2	3	0	4	11	11	10	11	12	7	11	9	12	13
CPUE (no. live/hr.)	0.0	0.0	3.0	0.0	8.5	204.0	82.7	23.5	51.8	211.2	52.0	92.9	42.8	119.3	96.9

Appendix II *(cont)*. Number live mussels and species collected at sites sampled within the MNRRA Corridor, 2000-01.

	St. Anthony Falls Pool									Pool 1					
Species	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
Actinonaias ligamentina															
Alasmidonta marginata															
Amblema plicata		1	1			3				1			2	6	13
Arcidens confragosus															
Cumberlandia monodonta															
Cyclonaias tuberculata															
Ellipsaria lineolata															
Elliptio crassidens															
Elliptio dilatata														D	
Epioblasma triquetra															
Fusconaia ebena															
Fusconaia flava		7	12			1		1	3			1	3	4	4
Lampsilis cardium	3	6	9	4	1	1	D	D	3	1		1	2	3	D
Lampsilis higginsi															
Lampsilis siliquoidea		2	1	2		D			2				D	D	D
Lampsilis teres															
Lasmigona complanata										D					
Lasmigona compressa															
Lasmigona costata															
Leptodea fragilis	3	20	12	8	D	10	1	1	4	D		D	5	1	1
Ligumia recta	2	D	2	D	D	D	D		D			1	D		
Megalonaias nervosa															
Obliquaria reflexa	1	5	4	7		5	2		5	1			6	1	
Obovaria olivaria															
Plethobasus cyphyus															
Pleurobema sintoxia															
Potamilus alatus	4	10	4	6	1	6	1	1	1	D		1	D	1	1
Potamilus ohiensis		2													D
Pyganodon grandis		1		1		1	2	1	D	1		D		1	D
Quadrula fragosa															
Quadrula metanevra															
Quadrula nodulata														1	
Quadrula pustulosa															
Quadrula quadrula		25	21	2	1	2	4	7	28	D		7	12	20	5
Strophitus undulatus	1	20	7	3	D	4		6	5			3	4	D	2
Toxolasma parvus															
Tritogonia verrucosa															
Truncilla donaciformis	2	1	1	1											
Truncilla truncata	D	93	63	15	1	1	4		8	D		19	32	7	6
Utterbackia imbecillis															
No. live	16	193	137	49	4	34	14	17	59	4	0	33	66	45	32
No. live species	7	13	12	10	4	10	6	6	9	4	0	7	8	10	7
Total species	8	14	12	11	7	12	8	7	11	9	0	9	11	13	11
CPUE (no. live/hr.)	13.7	105.3	117.4	42.0	2.7	14.6	10.5	17.0	39.3	4.0	0.0	36.0	66.0	38.6	29.5

Appendix II *(cont)*. Number live mussels and species collected at sites sampled within the MNRRA Corridor, 2000-01.

	Pool 1								Upper Pool 2						
Species	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
Actinonaias ligamentina															
Alasmidonta marginata									1				1		
Amblema plicata	56	16	2		16	22	11	28	30	2	2	11	112	52	166
Arcidens confragosus															
Cumberlandia monodonta															
Cyclonaias tuberculata													D		
Ellipsaria lineolata															
Elliptio crassidens															
Elliptio dilatata													D		
Epioblasma triquetra															
Fusconaia ebena															
Fusconaia flava	41	8	1		45	9	20	14	11		1	3	9	8	7
Lampsilis cardium	1				D				10	3		11	17	11	8
Lampsilis higginsi															
Lampsilis siliquoidea	1	D							1				2		
Lampsilis teres															
Lasmigona complanata															
Lasmigona compressa															
Lasmigona costata															
Leptodea fragilis	1	1	1	D					15	1	2	1	12	3	1
Ligumia recta									5	1		2	11	7	6
Megalonaias nervosa															
Obliquaria reflexa	37	3	3		1	1	8	1	16		1	12	80	53	31
Obovaria olivaria															
Plethobasus cyphyus															
Pleurobema sintoxia															
Potamilus alatus	2	1				D			1		2		2	8	3
Potamilus ohiensis	D	D			D		1								1
Pyganodon grandis	3				1		2	4							
Quadrula fragosa															
Quadrula metanevra															
Quadrula nodulata	5		4		7		7	4				3	2	3	4
Quadrula pustulosa		1			1		2						9	2	10
Quadrula quadrula	45	14	8		43	1	55	27	56			17	34	16	11
Strophitus undulatus	3	2		D	D		2		17	2		D	14	5	10
Toxolasma parvus															
Tritogonia verrucosa															
Truncilla donaciformis										1			10		
Truncilla truncata	20	7	1	1	1	1	3	1	83	2	5	26	289	61	106
Utterbackia imbecillis															
No. live	215	53	20	1	115	34	111	79	246	12	13	86	604	229	364
No. live species	12	9	7	1	8	5	10	7	12	7	6	9	15	12	13
Total species	13	11	7	3	11	6	10	7	12	7	6	10	17	12	13
CPUE (no. live/hr.)	135.8	35.3	15.0	0.8	76.7	51.0	74.0	39.5	123.0	9.6	13.0	129.0	170.5	114.5	336.0

Appendix II *(cont)*. Number live mussels and species collected at sites sampled within the MNRRA Corridor, 2000-01.

Species	Upper Pool 2							Middle Pool 2							
	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75
Actinonaias ligamentina															
Alasmidonta marginata	1	D													
Amblema plicata	10	24	10	1	73	182	2	88				2			8
Arcidens confragosus															
Cumberlandia monodonta															
Cyclonaias tuberculata				D			D	D							
Ellipsaria lineolata															
Elliptio crassidens							D								
Elliptio dilatata		D					D	D							
Epioblasma triquetra															
Fusconaia ebena							D								
Fusconaia flava		5	2		7	28	D	6					D		5
Lampsilis cardium	1	1	1		6	2		D				D	D		
Lampsilis higginsi															
Lampsilis siliquoidea	1	D										D			D
Lampsilis teres															
Lasmigona complanata	1				1	2						1			
Lasmigona compressa															
Lasmigona costata															
Leptodea fragilis	1	3			4	2		D	D			3			
Ligumia recta	3		2				D	D							
Megalonaias nervosa															
Obliquaria reflexa	10	10	3	1	15	117	D	29	1				D		5
Obovaria olivaria		D						D				D			
Plethobasus cyphyus		D						D							
Pleurobema sintoxia		D					D						D		
Potamilus alatus	1	D	1	1	1	3	2	D	D			D			1
Potamilus ohiensis					2	5		1	D					D	D
Pyganodon grandis						2									2
Quadrula fragosa							D								
Quadrula metanevra		D					D	D				D	D		
Quadrula nodulata		2	1		8	39		4							
Quadrula pustulosa			1		4	24		3				D	D		D
Quadrula quadrula	3	6	2		8	49	1	6					D		4
Strophitus undulatus	2	3	1	1	2	2									
Toxolasma parvus															
Tritogonia verrucosa							D								
Truncilla donaciformis		4		1											
Truncilla truncata	17	51	14	1	8	56		1	D			D	D		D
Utterbackia imbecillis														D	
No. live	51	109	38	6	139	513	5	138	1	0	0	6	0	0	25
No. live species	12	10	11	6	13	14	3	8	1	0	0	3	0	0	6
Total species	12	18	11	7	13	14	14	17	5	0	0	10	8	2	10
CPUE (no. live/hr.)	51.0	118.9	61.6	24.0	139.0	287.3	3.8	184.0	1.0	0.0	0.0	6.0	0.0	0.0	12.5

Appendix II *(cont)*. Number live mussels and species collected at sites sampled within the MNRRA Corridor, 2000-01.

	Lower Pool 2														
Species	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
Actinonaias ligamentina			D												
Alasmidonta marginata															
Amblema plicata	3	2	1	39	4	17	2	4	7	2	8	4		1	
Arcidens confragosus										1					
Cumberlandia monodonta															
Cyclonaias tuberculata															
Ellipsaria lineolata															
Elliptio crassidens															
Elliptio dilatata															
Epioblasma triquetra															
Fusconaia ebena				D											
Fusconaia flava	5			29	4	27		2	6	7	5	8			
Lampsilis cardium				1											
Lampsilis higginsi															
Lampsilis siliquoidea										D					
Lampsilis teres															
Lasmigona complanata				1	2							D			
Lasmigona compressa															
Lasmigona costata															
Leptodea fragilis	D		1	2	D	1	D	D		D	1				
Ligumia recta															
Megalonaias nervosa															
Obliquaria reflexa	15	8	8	110	13	60	6	15	1	14	35	3			1
Obovaria olivaria															
Plethobasus cyphyus				D											
Pleurobema sintoxia															
Potamilus alatus		1	D	2	2	1		1		D	1	D			
Potamilus ohiensis	D			5		1	2	2		2	1	D			
Pyganodon grandis	2	1	4	3	8	9	16	2	4	1		D			D
Quadrula fragosa															
Quadrula metanevra															D
Quadrula nodulata	3			5	2	4	2		2	3	4	1			
Quadrula pustulosa	1			3	4	8			2	2		1			
Quadrula quadrula	3		2	7	1	26	2	4	8	11	1	1			
Strophitus undulatus		1													
Toxolasma parvus															
Tritogonia verrucosa															
Truncilla donaciformis								1							
Truncilla truncata	1		1	7	3	1		1		1		1			1
Utterbackia imbecillis								1				1			
No. live	33	13	17	214	43	155	30	33	30	44	56	20	0	1	2
No. live species	8	5	6	13	10	11	6	10	7	10	8	8	0	1	2
Total species	10	5	8	15	11	11	7	11	7	13	8	12	0	1	4
CPUE (no. live/hr.)	79.2	13.0	11.3	183.4	34.4	132.9	40.0	19.8	32.7	52.8	30.5	40.0	0.0	1.0	1.3

Appendix II *(cont)*. Number live mussels and species collected at sites sampled within the MNRRA Corridor, 2000-01.

	Lower Pool 2														
Species	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105
Actinonaias ligamentina															
Alasmidonta marginata															
Amblema plicata		1	1	1	1	9	14	1	8	6	1	4	1	3	13
Arcidens confragosus						1	2		1					1	
Cumberlandia monodonta															
Cyclonaias tuberculata															
Ellipsaria lineolata															
Elliptio crassidens															
Elliptio dilatata															
Epioblasma triquetra															
Fusconaia ebena							D							D	
Fusconaia flava		9	1		3	8	38	4	16	17	1	3	4	1	7
Lampsilis cardium		1				1									
Lampsilis higginsi															
Lampsilis siliquoidea														D	
Lampsilis teres															
Lasmigona complanata						1	3						1		
Lasmigona compressa															
Lasmigona costata															
Leptodea fragilis	D		D	D		3	2	D	1		D		1	3	1
Ligumia recta							1	D							
Megalonaias nervosa															
Obliquaria reflexa	7	17	22	5	15	47	109	14	42	61	25	7	17	8	117
Obovaria olivaria															
Plethobasus cyphyus															
Pleurobema sintoxia															
Potamilus alatus		1			1		1	D		1	D		1	D	
Potamilus ohiensis	1	2	2	1	2	1	D	1			D		1	D	2
Pyganodon grandis	3		D	1	D		3	D			D	2	8	1	2
Quadrula fragosa															
Quadrula metanevra						1			D		D				
Quadrula nodulata		1	1		8	1	17	1	3	2	4				
Quadrula pustulosa		2			2	1	2		1	3	1			D	2
Quadrula quadrula		2	2	10	4	42	102	5	38	34	3	9	21	12	14
Strophitus undulatus				1	2	1			1						
Toxolasma parvus															
Tritogonia verrucosa															
Truncilla donaciformis							1								
Truncilla truncata		3	3		5	11	22	1	15	8	2	1	36	3	17
Utterbackia imbecillis															
Total	11	39	32	19	43	128	317	27	126	132	37	26	91	32	175
No. live species	3	10	7	6	10	14	14	7	10	8	7	6	10	8	9
Total species	4	10	9	7	11	14	16	11	11	8	12	6	10	13	9
CPUE (no. live/hr.)	66.0	31.2	40.9	25.3	34.4	144.9	271.7	54.0	504.0	264.0	74.0	260.0	107.1	54.9	116.7

Appendix II *(cont)*. Number live mussels and species collected at sites sampled within the MNRRA Corridor, 2000-01.

Species	Lower Pool 2											Upper Pool 3				
	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	121
Actinonaias ligamentina													D		D	
Alasmidonta marginata													D			D
Amblema plicata	1		2	1	34	2	57	22	6	10	21	1	2	2	17	35
Arcidens confragosus	2	1	1	1	3	4	2	3	1	2			D			2
Cumberlandia monodonta													D			
Cyclonaias tuberculata																
Ellipsaria lineolata															D	
Elliptio crassidens													D		D	D
Elliptio dilatata											D		D			D
Epioblasma triquetra																D
Fusconaia ebena			D								D		D		D	D
Fusconaia flava	9	2	2	3	50	5	8	22	3	7	3		1	7	7	18
Lampsilis cardium						2							1	D		4
Lampsilis higginsi													D			
Lampsilis siliquoidea			D	D	D		D									D
Lampsilis teres													D			
Lasmigona complanata			D			D	D						D			
Lasmigona compressa																
Lasmigona costata													D			
Leptodea fragilis	5		3		D	3	D	D			D		D	D	D	D
Ligumia recta			D										D			D
Megalonaias nervosa																
Obliquaria reflexa	32	2	11	36	99	80	49	50	56	7	38	1	57	18	62	161
Obovaria olivaria			D										2		D	
Plethobasus cyphyus											D		D		D	D
Pleurobema sintoxia			D					1			D				D	
Potamilus alatus			D		D	4		1	D	D	2		D		1	8
Potamilus ohiensis	3	1	D	4	2	8	D	D	1	1	1		2	1	2	8
Pyganodon grandis	4		4	4	4	6	7	8	10	2	3			D		10
Quadrula fragosa																D
Quadrula metanevra											D		D		D	D
Quadrula nodulata	5		D	3	1	1		2	2				D	2		
Quadrula pustulosa	1	1	D	1	1	1					1		6		1	8
Quadrula quadrula	37	12	13	15	54	39	36	52	29	17	3	1	1		3	14
Strophitus undulatus																
Toxolasma parvus																
Tritogonia verrucosa																D
Truncilla donaciformis			D		1											
Truncilla truncata	34	9	9	10	22	35	13	27	21	1	3		2	1		18
Utterbackia imbecillis							1									
No. live	133	28	45	78	271	190	173	188	129	47	75	3	74	31	93	286
No. live species	11	7	8	10	11	13	8	10	9	8	9	3	9	6	7	11
Total species	11	7	19	11	14	14	12	12	10	9	15	3	26	9	16	23
CPUE (no. live/hr.)	159.6	186.7	33.8	117.0	147.8	126.7	148.3	188.0	129.0	62.7	48.0	22.5	88.8	41.3	93.0	376.0

Appendix II *(cont)*. Number live mussels and species collected at sites sampled within the MNRRA Corridor, 2000-01.

	Upper Pool 3															
Species	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137
Actinonaias ligamentina						1		5								
Alasmidonta marginata																
Amblema plicata	89	5	1	9	22	26	1	40		192	33	27	2	52	9	36
Arcidens confragosus		2														
Cumberlandia monodonta																
Cyclonaias tuberculata																
Ellipsaria lineolata	1							D								
Elliptio crassidens	D	D				D										
Elliptio dilatata						1		12		1	D					
Epioblasma triquetra																
Fusconaia ebena	D				D	D		D					D			
Fusconaia flava	46	2	1	3	14	5		6	1	86	9	14	3	15	2	9
Lampsilis cardium	5					1		7		4	1	4	1	1		2
Lampsilis higginsi																
Lampsilis siliquoidea	1			D	D			D		1	D					
Lampsilis teres																
Lasmigona complanata					D					2	D			1		1
Lasmigona compressa																
Lasmigona costata																
Leptodea fragilis	2	1	D		D	1					D	D		D	2	
Ligumia recta	1				D			1								
Megalonaias nervosa	1							1								
Obliquaria reflexa	323	29	10	59	70	49	31	10	2	55	8	44	21	63	13	29
Obovaria olivaria	1				D		1			1					1	D
Plethobasus cyphyus	D					D										
Pleurobema sintoxia								1		4						
Potamilus alatus	20	1		D	2	1				1		1	1	1		
Potamilus ohiensis	4	1	2	1	D		D	1		D	D	D	1	1	3	D
Pyganodon grandis	7	2	1	1	3	2				8	2	6	3	7	2	3
Quadrula fragosa																
Quadrula metaneura						D		D					D			
Quadrula nodulata					1		3					1				
Quadrula pustulosa	6				3		2	2		26	11	3	2	8	2	4
Quadrula quadrula	17	1			7	3	1	1	2	5				6	1	1
Strophitus undulatus					D						D					
Toxolasma parvus																D
Tritogonia verrucosa																
Truncilla donaciformis																
Truncilla truncata	18	1			4	6	1		2	6		1	1	2	3	
Utterbackia imbecillis	1			D												
No. live	543	45	15	73	126	96	40	87	7	392	64	101	35	177	38	85
No. live species	17	10	5	5	9	11	7	12	4	14	6	9	9	11	10	8
Total species	20	11	6	8	17	15	8	16	4	15	12	11	11	12	10	11
CPUE (no. live/hr.)	265.3	67.5	22.5	146.0	84.0	115.2	80.0	65.3	26.3	313.6	65.1	121.2	70.0	124.9	57.0	127.5

Appendix II *(cont)*. Number live mussels and species collected at sites sampled within the MNRRA Corridor, 2000-01.

Species	Minnesota River														Rum River
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	1
Actinonaias ligamentina												D			
Alasmidonta marginata															
Amblema plicata						D	D		D		D	D		1	
Arcidens confragosus						D									
Cumberlandia monodonta															
Cyclonaias tuberculata															
Ellipsaria lineolata															
Elliptio crassidens															
Elliptio dilatata															
Epioblasma triquetra															
Fusconaia ebena						D			D			D			
Fusconaia flava						D						D			
Lampsilis cardium						D	D				1				4
Lampsilis higginsi															
Lampsilis siliquoidea		D				D			D						14
Lampsilis teres															
Lasmigona complanata		D			1	D	D		D						
Lasmigona compressa															1
Lasmigona costata															
Leptodea fragilis	2	5			4	4	1		1		3	D		1	
Ligumia recta						D			D						1
Megalonaias nervosa															
Obliquaria reflexa						D									
Obovaria olivaria											D				
Plethobasus cyphyus															
Pleurobema sintoxia					D										
Potamilus alatus		3				3						D		1	
Potamilus ohiensis	1	1		1	2	7					1			7	
Pyganodon grandis		3										D			5
Quadrula fragosa															
Quadrula metanevra									D			D			
Quadrula nodulata						D									
Quadrula pustulosa		D							D						
Quadrula quadrula		1			1	D						D			
Strophitus undulatus									D						
Toxolasma parvus															
Tritogonia verrucosa															
Truncilla donaciformis															
Truncilla truncata		2			D	D									
Utterbackia imbecillis															
No. live	3	15	0	1	8	14	1	0	1	0	5	0	0	10	25
No. live species	2	6	0	1	4	3	1	0	1	0	3	0	0	4	5
Total species	2	9	0	1	6	15	4	0	9	0	5	9	0	4	5
CPUE (no. live/hr.)	6.0	30.0	0.0	6.0	6.9	35.0	1.3	0.0	1.0	0.0	10.7	0.0	0.0	20.0	25.0

Appendix III. UTM coordinates (NAD 1983) for each site sampled.

Reach	Site	East	North
Coon Rapids Pool	1	459081	5010507
	2	460308	5010149
	3	460137	5009960
	4	460977	5009685
	5	461036	5008918
	6	464165	5007475
	7	464973	5007033
	8	465220	5007145
	9	466824	5006425
	10	467258	5005912
	11	467216	5005535
	12	468613	5004588
	13	469274	5004060
	14	472148	5002174
	15	472208	5002060
	16	472716	5000817
	17	474385	4999838
	18	474669	4999442
	19	475485	4999250
St. Anthony Falls Pool	20	475577	4998740
	21	475844	4999150
	22	476018	4997943
	23	476200	4998100
	24	476783	4996287
	25	477346	4995174
	26	477776	4994992
	27	477972	4994622
	28	478097	4993509
	29	477853	4992239
	30	477668	4991812
	31	477847	4991018
	32	477544	4989918
	33	477812	4987986
	34	477886	4987441
	35	477669	4986890
	36	478257	4985080
	37	478288	4982420
	38	478906	4981929
	39	479566	4981388
Pool 1	40	480185	4980808
	41	480799	4980544
	42	481158	4980214
	43	481220	4979602
	44	482004	4979451
	45	482161	4979334
	46	482973	4978450
Pool 1	47	483619	4977657
	48	484068	4976959
	49	484273	4976449
	50	484055	4975914
	51	484304	4975357
	52	484291	4974666
	53	484332	4974896
Upper Pool 2	54	484226	4973231
	55	484206	4972804
	56	484289	4972808
	57	484901	4971966
	58	484981	4971546
	59	485043	4971567
	60	486246	4971202
	61	486219	4971115
	62	486804	4971149
	63	487095	4971226
	64	487222	4971284
	65	487514	4971547
	66	488103	4971520
Middle Pool 2	67	488819	4972192
	68	489076	4972459
	69	489467	4973187
	70	490398	4974303
	71	492268	4976060
	72	496722	4972652
	73	496939	4971931
	74	497340	4971759
	75	498526	4970327
Lower Pool 2	76	498668	4969311
	77	498994	4969145
	78	498884	4968318
	79	499129	4968313
	80	498795	4968108
	81	499056	4966313
	82	499409	4965704
	83	499286	4966464
	84	498823	4965793
	85	499515	4964885
	86	499305	4964110
	87	499657	4964012
	88	499771	4963116
	89	499033	4962825
	90	499395	4962689
	91	499749	4962561
	92	499466	4962414

Appendix III. UTM coordinates (NAD 1983) for each site sampled.

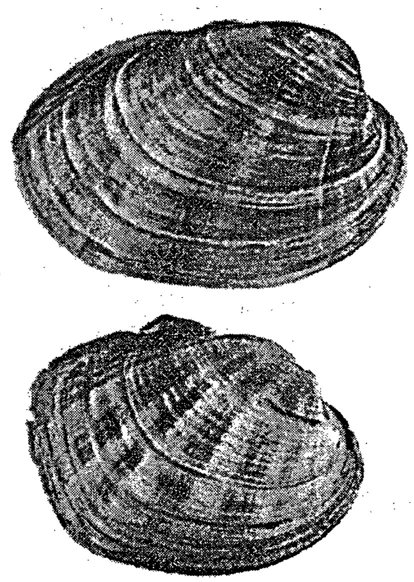
Reach	Site	East	North	Reach	Site	East	North
Lower Pool 2	93	499305	4962187	Minnesota River	1	484209	4967999
	94	497982	4959959		2	485028	4968681
	95	498260	4959541		3	487232	4970792
	96	502663	4957707		4	485255	4969232
	97	503376	4957542		5	485535	4969349
	98	503182	4957653		6	485637	4969352
	99	503701	4957468		7	485938	4969700
	100	503539	4957649		8	486571	4970481
	101	503975	4957719		9	486705	4970535
	102	504049	4957874		10	486891	4970727
	103	505685	4959020		11	487656	4970922
	104	506215	4957770		12	488036	4971215
	105	505657	4958786		13	488059	4971376
	106	507277	4958960		14	488157	4971481
	107	507352	4958960	Rum River	1	469314	5004373
	108	506618	4957815				
	109	507418	4958853				
	110	508279	4957294				
	111	507931	4958852				
	112	508587	4957044				
	113	508740	4956850				
	114	509422	4958131				
Upper Pool 3	115	509327	4956154				
	116	510937	4956147				
	117	511454	4954721				
	118	511076	4955562				
	119	511157	4955330				
	120	512255	4954928				
	121	512966	4954998				
	122	513187	4955106				
	123	513332	4955219				
	124	513545	4955316				
	125	513947	4955119				
	126	514412	4954942				
	127	515451	4954824				
	128	515125	4954521				
	129	516040	4954419				
	130	516138	4953960				
	131	516778	4954094				
	132	517478	4953596				
	133	519087	4952497				
	134	519265	4952149				
	135	519357	4952017				
	136	519899	4951801				
	137	520736	4951434				

Higgins Eye Pearlymussel
(*Lampsilis higginsii*)
Recovery Plan: First Revision

May 2004

Original Approved: July 29, 1983

♂



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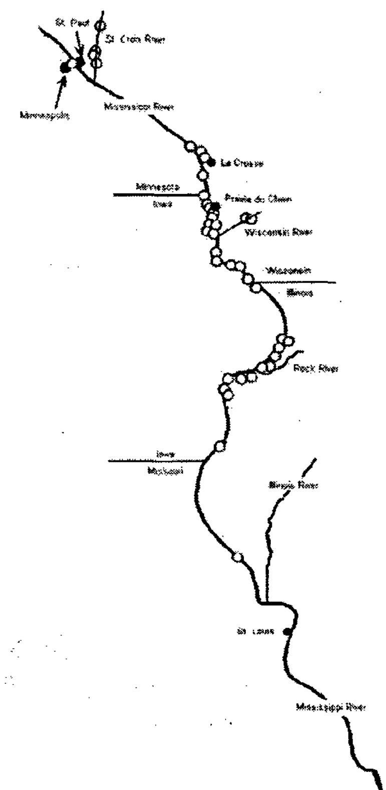

U.S. Department of Interior
U.S. Fish and Wildlife Service
Great Lakes/Big Rivers Region
Ft. Snelling, Minnesota

Higgins Eye Pearlymussel (*Lampsilis higginsii*) Recovery Plan: First Revision

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DISCLAIMER

Recovery plans delineate reasonable actions which are believed to be required to recover and/or protect listed species. Plans are published by the U.S. Fish and Wildlife Service (USFWS), sometimes prepared with the assistance of recovery teams, contractors, state agencies, and others. Objectives will be attained and any necessary funds made available subject to budgetary and other constraints affecting the parties involved, as well as the need to address other priorities. Recovery plans do not necessarily represent the views nor the official positions or approval of any individuals or agencies involved in the plan formulation, other than the USFWS. They represent the official position of the USFWS only after they have been signed by the Regional Director or Director as approved. Approved recovery plans are subject to modification as dictated by new findings, changes in species status, and the completion of recovery tasks.

Literature citation: U.S. Fish and Wildlife Service. 2004. Higgins Eye Pearlymussel (*Lampsilis higginsii*) Recovery Plan: First Revision. Ft. Snelling, Minnesota. 126 pp.

Recovery plans can be downloaded from USFWS website: http://endangered.fws.gov.

ACKNOWLEDGMENTS

The Higgins Eye Pearlymussel Recovery Team would like to acknowledge the following individuals for their contributions to the development of this plan: Chuck Kjos and Gerald Bade of the USFWS for overseeing the plan development process; Dr. Teresa Newton of the National Fisheries Research Lab, La Crosse, Wisconsin, and Dave Warburton USFWS Twin Cities Field Office, Minnesota for development of the section dealing with contaminants; and Mark Farr, U.S. Army Corps of Engineers, St. Paul, Minnesota for additional editing and critical review, for updating the information on the status of zebra mussels within the Higgins Eye's range, and for providing a summary of the endangered species consultation between the USFWS and the Corps of Engineers on Operation and Maintenance of the Navigation Channel on the Upper Mississippi River System. Cover photos are used courtesy of the Illinois Natural History Survey.

EXECUTIVE SUMMARY

Current Species Status

This species is currently listed as endangered. Studies before 1993 indicate healthy populations of *Lampsilis higginsii* in the Upper Mississippi River drainage, with no apparent significant declines in its distribution or abundance. In fact, information since completion of the first recovery plan in 1983 has extended its known range by 180 river miles.

There was concern, however, that a major flood in 1993, as well as an infestation of the non-native zebra mussel (*Dreissena polymorpha*), may pose serious threats to the continued existence of this species. In response to these threats and information, the recovery team was constituted to review the status of the species and to revise the initial recovery plan if necessary. The team commissioned a review of all research conducted on the species since 1980, as well as a survey of all sites designated as Essential Habitat Areas in the 1983 recovery plan. During the development of this revised recovery plan, new information suggesting a significant impact of zebra mussels on *Lampsilis higginsii* came forward and the team believes there is now a significant risk that the distribution and abundance of this species will be severely compromised.

The initial Higgins Eye Pearlymussel Recovery Plan listed seven locations as primary habitats (called Essential Habitat Areas in this document) and nine locations as potential secondary habitats. This revised plan identifies ten Essential Habitat Areas -- six in the Mississippi River between river miles 489 (Sylvan Slough) and 656 (Whiskey Rock), one in the Wisconsin River (Orion), and three in the St. Croix River, which empties into the Mississippi River at river mile 811. The term "Essential Habitat Area" is intended to identify those areas that the Service and its partners have found to be of utmost importance to the conservation of the species. Cawley (1996) indicated that since 1980, all seven of the Essential Habitat Areas in the initial Higgins Eye Pearlymussel Recovery Plan had been sampled. In addition, six of the nine secondary habitats had been sampled. *L. higginsii* also occurs elsewhere in the Mississippi River, and this revised plan recommends that surveys be conducted in several specific areas to better describe other potentially important habitats.

Since zebra mussels invaded the Mississippi River in the early 1990's, three of the Essential Habitat Areas, East Channel (Prairie du Chien), Harpers Slough, and Cordova have become severely infested with zebra mussels; only one Essential Habitat Area, Interstate Park (St. Croix River) is entirely free of zebra mussels. There are currently no effective methods to control established populations of zebra mussels of the scale and nature necessary to nullify their threat to *L. higginsii* in the Mississippi River. Since 2000, *L. higginsii* has been reintroduced into four rivers from which it had been extirpated, but it is too soon to determine whether these efforts have resulted in the successful reestablishment of the species there.

Habitat Requirements and Limiting Factors

Lampsilis higginsii is characterized as a large river species occupying stable substrates that vary from sand to boulders, but not firmly packed clay, flocculent silt, organic material, bedrock, concrete or unstable sand. Water velocities should be less than 1 m/second during periods of low discharge. They are usually found in mussel beds that contain at least 15 other species at densities greater than .01 individual/m^2. In the Mississippi River, the density of all mussels in the bed typically exceeds 10/m^2.

The ten identified Essential Habitat Areas are: The Mississippi River at Lansing, Iowa (Whiskey Rock); near Harper's Ferry, Iowa (Harper's Slough); the main and east channel areas at Prairie du Chien, Wisconsin; near Guttenberg, Iowa (McMillan Island); Cordova, Illinois; Moline, Illinois (Sylvan Slough); the St. Croix River at Prescott, Wisconsin, at Hudson, Wisconsin, and near Taylor's Falls, Minnesota (Interstate Park); and the Wisconsin River near Muscoda, Wisconsin (Orion mussel assemblage). Zebra mussels have severely degraded the mussel communities at a few of these areas to the degree that they may no longer support dense and diverse mussel beds. Each of these areas, however, demonstrated its importance to the conservation of *Lampsilis higginsii* before zebra mussel infestation and zebra mussels are the only factor that has, at least temporarily, degraded their ability to support stable or growing populations of *Lampsilis higginsii*. Therefore, we will retain each of these areas as Essential Habitat Areas at this time due to their historical importance to the species and the uncertainty regarding their potential to recover from the effects of zebra mussels. The Service's Twin Cities Field Office will retain an up-to-date list of Essential Habitat Areas. There are no numeric criteria for areas to be added or removed from this list. Any Essential Habitat Areas used as part of the basis for a decision to reclassify or delist the species, however, must meet specific numeric criteria (see Recovery Criteria).

Recovery Strategy

This revised recovery plan continues the approach of the previous recovery plan for *L. higginsii* by focusing recovery on the conservation of the species at identified Essential Habitat Areas. In the 1983 recovery plan, Essential Habitat Areas were specific areas throughout the historical range of *L. higginsii* that supported dense and diverse mussel beds where *L. higginsii* was successfully reproducing. This revised recovery plan identifies three additional "Essential Habitat Areas" (Orion, WI, Prescott, WI, and Interstate Park, MN/WI). The plan recommends the development of a uniform protocol for collecting information on populations of *L. higginsii*. Use of this protocol will allow for ongoing evaluation of the list of Essential Habitat Areas and progress towards recovery.

The highest priority recovery actions for *L. higginsii* are primarily intended to address the severe impacts and threats posed by zebra mussels. Of the ten Essential Habitat Areas designated in this revised plan, zebra mussels have had severe impacts on the mussel communities at Harpers

Slough, Prairie du Chien, and Cordova and are imminent threats at the Prescott, and Hudson, WI areas. The Prairie du Chien Essential Habitat Area may have contained the largest population of *L. higginsii* before its severe infestation by zebra mussels, but Miller and Payne (2001) found nearly 10,000 zebra mussels/m^2 in this area in 2000.

The removal of zebra mussels in a manner and scale necessary to benefit *L. higginsii* is evidently not currently feasible. Therefore, the plan focuses on developing methods to prevent new infestations, monitoring zebra mussels at Essential Habitat Areas, and developing and implementing contingency plans to alleviate impacts to infested populations. Based on recent activities, the latter may consist largely of removing *L. higginsii* from areas where zebra mussels pose an imminent risk to the persistence of the population and releasing them into suitable habitats within their historical range where zebra mussels are not an imminent threat. Since 2000, workers have removed 471 adult *L. higginsii* from areas near Cassville, WI and Cordova, IL on the Upper Mississippi River and relocated them into Pools 2 and 3 near Minneapolis, MN and Hastings, MN, respectively (Table 1). Cleaning fouled adults *in situ* and artificial propagation and release (Table 1) are also currently being implemented in an attempt to alleviate the effects of zebra mussels on the conservation of *L. higginsii.*

Although zebra mussels are currently the most important threat to *L. higginsii*, construction activities, environmental contaminants, and poor water quality may also pose significant threats. Therefore, the Corps and other agencies must continue to assess and limit the potential impacts of their actions on *L. higginsii.* The plan also outlines tasks needed to improve our understanding of the potential importance that contaminants play in the conservation of *L. higginsii* and calls on the U.S. Coast Guard, Environmental Protection Agency, and other agencies to take actions to minimize the potential impacts of toxic spills.

Interagency partnerships will be key to the recovery of *L. higginsii.* In addition to the USFWS, the Implementation Table identifies five other federal agencies and four states as being responsible for various aspects of the recovery of the species. The U.S. Army Corps of Engineers, for example, is called on to implement several of the tasks. The Corps' implementation of the 2000 Biological Opinion on continued operation and maintenance and operation of the 9-foot navigation channel has resulted in the formation of the Mussel Coordination Team (MCT). This MCT has assisted the Corps with the implementation of extensive relocation and reintroduction of *L. higginsii* since 2000 (Table 1). These activities, although necessary to avoid jeopardizing the species, are leading to the development and refinement of techniques for propagating *L. higginsii* and other mussel species.

Recovery Goals and Recovery Criteria

The goal of the recovery plan is the recovery of Higgins eye to levels where its protection under the Act is no longer necessary and it may be removed from the Federal list of Endangered and Threatened Wildlife (50 CFR 17.11). This plan also contains an intermediate goal of reclassifying the species from Endangered to Threatened.

Essential Habitat Areas

Essential Habitat Areas used to support the reclassification or delisting of *L. higginsii* (see below) must meet the following criteria.

1. *L. higginsii* constitute at least 0.25% of the mussel community and the mussel habitat appears to be stable and supports a dense and diverse mussel community; or,

2. *L. higginsii* are found, but constitute <0.25% of the community, the mussel habitat appears to be stable and supports a dense and diverse mussel community, and zebra mussel densities are $< 0.5/m^2$.

For each definition, "dense and diverse" mussel communities are those that:

- include a total mussel density of $> 10/m^2$ (Mississippi River) or $> 2/m^2$ (other rivers); and,
- contain at least 15 other mussel species, each at densities greater than 0.01 individual/m^2.

Intermediate Goal (Reclassification of *Lampsilis higginsii* to Threatened Status)

Criteria for Intermediate Goal (Goal 1: Reclassification)

1. *Lampsilis higginsii* may be considered for reclassification from Endangered to Threatened when at least five identified Essential Habitat Areas contain reproducing, self-sustaining populations of *L. higginsii* that are not threatened by zebra mussels. The five Essential Habitat Areas must meet the above criteria and must include the Prairie du Chien Essential Habitat Area and at least one Essential Habitat Area each in the St. Croix River and in Mississippi River Pool 14.

    a. *L. higginsii* populations will be considered to be "reproducing" if there is evidence that they include a sufficient number of strong juvenile year classes.[1]

    b. Populations will be considered to be "self-sustaining" if they have maintained stable or increasing population densities for at least twenty years.[2] *L. higginsii* populations will be considered stable or increasing if:

---

[1] Task 1.2.2 details the questions that the Service must answer to determine the number of strong juvenile year classes sufficient to allow for stable or increasing populations of *L. higginsii*.

[2] For all analyses of trends use a significance level $(\alpha) \leq 0.2$ and power ≥ 0.9.

i. total mussel density in each of the identified Essential Habitat Areas is stable or increasing for at least twenty years (significance level (α) ≤ 0.2 and power ≥ 0.9);

ii. and, in each of the identified Essential Habitat Areas *L. higginsii* comprises at least 0.25% of the mussel community in Mississippi River sites or, in other rivers, are consistently present throughout the twenty year period.

The Service will develop standardized sampling protocols (Task 1.2.1) to evaluate the status of populations relative to these criteria.

c. This criterion will be met if zebra mussels are not present in locations where they or their offspring are likely to adversely affect *L. higginsii* populations in any of the five identified Essential Habitat Areas. The Service will make this determination by evaluating zebra mussel densities in the source areas and identified Essential Habitat Areas, the distances between the zebra mussel populations and identified Essential Habitat Areas, water velocities, larval development times, and any other relevant information.

2. Complete the following tasks to determine if water quality criteria for the Final Goal (Delisting) are necessary to ensure the conservation of *L. higginsii* and, if so, to develop measurable water quality criteria for the Final Goal.

   a. Develop a freshwater mussel toxicity database for sediment and water quality parameters to define *L. higginsii* habitat quality goals. (7 sub-tasks)

   b. Characterize specific sediment and water quality parameters in *L. higginsii* Essential Habitat Areas and reestablishment areas. (1 sub-task)

3. Harvest of freshwater mussels is prohibited by law or regulation in Essential Habitat Areas. This applies to all Essential Habitat Areas, not just the five identified for criterion 1.

Criteria for Final Goal (Delisting)

1. Delisting *L. higginsii* requires that populations of *L. higginsii* in at least five Essential Habitat Areas are reproducing, self-sustaining, not threatened by zebra mussels, and are sufficiently secure to assure long-term viability of the species. The five Essential Habitat Areas must meet the above criteria and must include the Prairie du Chien Essential Habitat Area and at least one Essential Habitat Area each in the St. Croix River and in Mississippi River Pool 14. "Reproducing" and "self-sustaining" are defined above under the Intermediate Goal (Reclassification).

Populations at the identified Essential Habitat Areas will be "sufficiently secure to assure long-term viability of the species" if each of the following four conditions is met:

a. The Service can identify no activities that are likely to take place in the foreseeable future that will result in a change in the predominant substrate conditions within each identified Essential Habitat Area to shifting, unstable sands, silt, cobble, boulder, or artificial substrates (*e.g.*, concrete) to the extent that such changes would appreciably reduce the likelihood of conserving the Higgins eye population in the Essential Habitat Area.

b. The Service can identify no activities that are likely to take place in the foreseeable future that will result in water quality characteristics (*e.g.*, harmful concentrations of un-ionized ammonia) in Essential Habitat Areas that have been shown to cause detrimental effects to *L. higginsii* or to sympatric or surrogate species to the extent that such effects would appreciably reduce the likelihood of conserving the Higgins eye population in the Essential Habitat Area.

c. There is no indication that construction of barge loading or off-loading sites, boat harbors, highway bridges, or fleeting areas or dredging of access channels is likely to occur in the foreseeable future within the identified Essential Habitat Areas to the extent that such activities would appreciably reduce the likelihood of conserving the Higgins eye population in the Essential Habitat Area.

d. Measures that provide for review of federally funded, permitted, or planned activities in or near *L. higginsii* habitat pursuant to the Fish and Wildlife Coordination Act and Clean Water Act are in place.

e. This criterion will be met if zebra mussels are not present in locations where they or their offspring are likely to adversely affect *L. higginsii* populations in any of the five identified Essential Habitat Areas. The Service will make this determination by evaluating zebra mussel densities in the source areas and identified Essential Habitat Areas, the distances between the zebra mussel populations and identified Essential Habitat Areas, water velocities, larval development times, and any other relevant information.

2. The use of double hull barges or other actions have alleviated the threat of spills to each of the identified Essential Habitat Areas.

3. *L. higginsii* habitat information and protective responses to conserve each of the identified Essential Habitat Areas have been incorporated into all applicable spill contingency planning efforts.

4. Water quality criteria may be added to the criteria for the Final Goal (Delisting) upon completion of the tasks referred to under the Criteria for the Intermediate Goal (Reclassification) (see 2a-b above and Tasks 1.5.1 and 1.5.2).

Actions Needed: The recovery plan is organized around two main objectives: 1) Preserving *L. higginsii* and its Essential Habitat Areas and 2) Enhancing the abundance and viability of *L. higginsii* in areas where it currently exists and restoring populations within its historical range.

1) Preserving the current populations of *L. higginsii* and its Essential Habitat Areas requires the following actions:

A. Limit the impact of the exotic bivalve, the zebra mussel, *Dreissena polymorpha.*
B. Develop uniform protocols for collecting and maintaining information on *L. higginsii* populations.
C. Confirm and modify the list of Essential Habitat Areas.
D. Limit construction in areas of essential *L. higginsii* habitat. Mitigation, including translocation, may be an acceptable alternative in limited instances.
E. Continue to examine the relationship between water quality, especially contaminants, and *L. higginsii* populations in Essential Habitat Areas.
F. Develop plans to reduce the shipment of toxic materials near *L. higginsii* habitat and develop response plans for any spills that may occur.
G. Review current regulations and develop additional regulation of mussel harvest in the upper Mississippi River drainage to reduce impacts on *L. higginsii.*
H. Develop materials to educate the public on the nature of endangered mussels and *L. higginsii,* in particular.

2) Enhancing and restoring populations of *L. higginsii* within its historic range requires the following actions:

A. Identify and rank potential sites of existing *L. higginsii* populations for enhancement.
B. Increase the number of *L. higginsii* at enhancement sites to current levels found in Essential Habitat Areas or to numbers appropriate for the local habitat.
C. Determine the feasibility of reestablishing *L. higginsii* into historic habitats, particularly streams that are at lower risk for zebra mussel colonization, and carry out reintroduction using the best available methods.
D. Examine the taxonomic validity of *L. higginsii* especially since *L. abrupt* is found in noncontiguous geographic areas.

Several specific actions are recommended for immediate implementation to ensure the survival of the *L. higginsii.*

A. Limit the impact of the exotic bivalve, the zebra mussel, *Dreissena polymorpha.*

B. Develop uniform protocols for collecting and maintaining information on *L. higginsii* populations.

C. Confirm and modify the locations listed in the initial recovery plan as Essential Habitat Areas.

D. Require the use of double hull barges.

Estimated Cost of Recovery for Fiscal Years 2005-2007 (in $1000s): Costs for fiscal years 2008-2055 will be determined on at least an annual basis by the USFWS and cooperating agencies.

Fiscal Year	Task 1.1	Task 1.2	Task 1.3	Task 1.4	Task 1.5	Task 1.6	Task 1.7	Task 1.8	**Total**
2005	100	160	290	50	745	40	0	10	**1395**
2006	120	160	280	50	745	40	0	0	**1395**
2007	70	110	270	50	470	40	0	0	**1010**
Total	**290**	**430**	**840**	**150**	**1960**	**120**	**0**	**10**	**3800**

The total costs for Years 1 - 3 do not include the cost of two tasks (1.4.1 and 1.4.2) which could not be determined at this time.

Date of Recovery: 2055, if recovery criteria are met and if fully funded.

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I. INTRODUCTION

The Higgins eye pearlymussel (*Lampsilis higginsii*, Lea 1857) was federally listed as an endangered species June 14, 1976 (41 FR 24064). The first Federal recovery plan was approved on July 29, 1983. Revision of the 1983 plan began in 1994, in the wake of the large flood of 1993. There was concern that the flooding may have significantly impacted *L. higginsii*. This revision is part of the Service's ongoing revision of recovery plans, and it supersedes the initial 1983 recovery plan.

Description of *Lampsilis higginsii*

Taxonomy and Systematics

Phylum: Mollusca
Class: Bivalvia
Order: Unionoida
Family: Unionidae
Genus: *Lampsilis*
Species: *higginsii* (Lea 1857)

The type locality for *L. higginsii* is the Mississippi River at Muscatine, Iowa (USFWS 1983). The original species name given was *higginsii*, but many references, including the original listing document, gives the spelling as *higginsi*. Turgeon *et al.* (1998) indicate that the proper name is *Lampsilis higginsii* with the common name for the species being the Higgins Eye. This species belongs to a morphologically variable, geographically widespread genus. Most malacologists agree that *L. higginsii* is a valid species. There was some early confusion between *L. higginsii* and the morphologically similar *L. abrupt* (the pink mucket pearly mussel -- also on the Federal Endangered and Threatened Species list). *Lampsilis abrupt* is distributed further to the south, and *L. higginsii* is found only in the Upper Mississippi River Basin (Oesch 1984). Johnson (1980) discusses the similarities and differences between *L. abrupt* and *L. higginsii* but there is still some controversy surrounding the taxonomic status of these species.

Morphological Description

Baker (1928) provided a general description of the shell morphology. Baker stated that the shell was: "Oval or elliptical, somewhat inflated, solid, with gaping anterior base; beaks placed forward of the center of the dorsal margin, much elevated, swollen, their sculpture consisting of a few feeble ridges slightly looped; anterior end broadly rounded; posterior end truncated in the female, bluntly pointed in the male; ventral and dorsal margins slightly curved, almost parallel; posterior ridge rounded, but well marked; surface shining, marked by irregular growth lines which are better developed at rest periods where they are usually dark colored; epidermis olive or yellowish-green with faint green rays. Hinge massive; pseudocardinals erect, triangular or pyramidal, divergent, serrated, two in the left and one in the right valve, with sometimes indications of additional denticles on either side of the single right pseudocardinal; interdentium narrow, flat;

laterals short, thick, slightly curved, almost smooth; cavity of the beaks deep, containing the dorsal muscle scars; anterior adductor scar deeply excavated, posterior scar distinct; nacre silvery-white, iridescent, often tinged with pink."

This species exhibits marked sexual dimorphism with the posterior end in the females sharply truncated with a post-basal swelling. The posterior end in the males is more roundly pointed. A number of species can be confused with *L. higginsii*. Those cited as most similar are *Obovaria olivaria, L. cardium, L. siliquoidea, L. abrupt* and *Actinonaias ligamentina* (Baker 1928; Cummings and Mayer 1992). Although nothing has been published specifically on the internal anatomy of *L. higginsii*, Baker (1928) indicates it is most likely similar to that of other lampsilines.

Historical and Present Distributions

In the initial Higgins Eye Pearlymussel Recovery Plan (USFWS 1983), the historic distribution of *L. higginsii* before 1965 was given as the main stem of the Mississippi River from just north of St. Louis, Missouri, to just south of St. Paul, Minnesota; in the Illinois, Sangamon, and Rock Rivers in Illinois; in the Iowa, Cedar, and Wapsipinicon Rivers in Iowa; in the Wisconsin and St. Croix rivers in Wisconsin; and, in the Minnesota River in Minnesota (based on Havlik 1980). A questionable report of this species in the lower Ohio River was also given (Havlik 1980). The initial plan also indicated a great reduction in the range of *L. higginsii* based on studies from 1965 through 1981 (Larsen and Holzer 1978; Mathiak 1979; Perry 1979; Havlik 1980; Fuller 1980; Thiel *et al.* 1980; Thiel 1981; Ecological Analysts 1981a).

Since the 1983 Recovery Plan, a number of studies have provided new information on the distribution and abundance of *L. higginsii*. A study by Cawley (1996) commissioned by the USFWS for the current recovery team provided a review of the information on *L. higginsii* distribution from 1980-1996. Cawley (1996) noted that 510 specimens of *L. higginsii* had been collected since 1980. Cawley (1996) extended the reported range of *L. higginsii* 98 miles to the south and 82 miles to the north based on the collection of dead specimens. Figure 1 (see Section V) summarizes the distributional data before 1965, from 1965-1980 and 1981-1996 based on the 1983 Recovery Plan and Cawley's (1996) study. Thiel (1981) stated that Pool 10 of the Mississippi River supported the largest population of *L. higginsii*. The area in the East Channel of the Mississippi River, by Prairie du Chien, Wisconsin, was considered to be the most productive *L. higginsii* habitat in the Mississippi River system. Cawley's (1996) review supports this assessment. Since Cawley's (1996) review, however, zebra mussels (*Dreissena polymorpha*) have drastically reduced the population of *L. higginsii* at Prairie du Chien.

Based on Cawley's (1996) review, it appears that there has been recruitment of *L. higginsii* (individuals <30 mm in shell length) in locations surveyed since 1980. The age distribution indicated that there were more middle-age mussels (35-85 mm shell length) than young. Miller and Payne (1988) indicated that some mussel species display infrequent, but fairly strong, recruitment and that there can be substantial variability in recruitment among closely located sites.

Given that Cawley's (1996) review included a wide variety of sites examined over a number of years, the actual size distribution of *L. higginsii* populations is unknown at this time.

As mentioned above, one reason for examining the current status of *L. higginsii* was the Great Flood of 1993. Clarke and Loter (1992, 1993, 1994, 1995) have been monitoring the population of *L. higginsii* at Prairie du Chien, Wisconsin, since 1990 as part of a study designed to examine the impacts of barge traffic on mussels. Based on their results, it appears that the flood caused no significant change in the number of *L. higginsii* found, while recruitment of some other mussel species was reduced in 1994. Recruitment varied among years (Miller and Payne 1991, 1992, 1993, 1994, 1995a,b, 1996a, 1997), and thus a cause-effect relationship cannot necessarily be inferred from Clark and Loter's (1995) work. Mussel communities may have been slightly relocated due to the flood.

This recovery team commissioned four studies, funded by the Service, to examine *L. higginsii* populations. The major objective of these studies was to examine what impact, if any, the 1993 floods in the Upper Mississippi River and its tributaries had on *L. higginsii*. These studies were conducted by Davis and Hart (1995), Heath (1995), Hornbach *et al.* (1995) and Miller and Payne (1996b). Differences in methods among these studies may not allow for statistical comparisons among populations.

Heath (1995, 2003) sampled quantitatively and qualitatively for *L. higginsii* and other mussel species at the Orion mussel aggregation in the Wisconsin River in 1988, 1995, and 2002. During each of these three years he counted living and dead mussels present within randomly placed quadrats and supplemented these samples with qualitative collections within the mussel aggregation. *L. higginsii* comprised 0.21% and 0.08% of the live mussels counted in 1988 and 1995, respectively, but no living *L. higginsii* were found during sampling in 2002 (Heath 1995, 2003). Heath (1995) estimated that there were 2,273 *L. higginsii* within the aggregation in 1988. Total mussel densities in the aggregation decreased significantly between 1988 and 2002; sample means were 6.05/m^2 in 1988 and 1.34/m^2 in 2002. Species richness may have also decreased since 1988. Among the initial 600 mussels collected each year, there were 23 species in both 1988 and 1995, but only 21 species in 2002.

Hornbach *et al.* (1995) examined *L. higginsii* populations in the St. Croix River and estimated populations to be 4,000 mussels at Franconia, 4,000 to 10,000 mussels at Prescott, Minnesota, and 238,000 to 260,000 mussels at Hudson, Wisconsin (all listed as Essential Habitat Areas in the initial recovery plan). Doolittle and Heath (1997), Heath (*in litt.* 1998), and Heath *et al.* (1999) collected almost 90 *L. higginsii* from 1987-1999 in the area of the St. Croix river, extending upstream of Franconia, MN to the Interstate Park Area (Taylor's Falls, MN) - about 3 river miles. They estimate *L. higginsii* population densities of approximately 0.01 individuals/m^2. In 2000, mean density estimates of *L. higginsii* at Interstate Park and Hudson were 0.01 and 0.09, respectively (Heath *et al.* 2001); these estimates did not reflect a statistically significant change in abundance at either site. Estimates of population size were 9,224 (95% CI = 4,192 - 14,255) at Hudson and 4,212 (95% CI = 358 - 7,886).

Miller and Payne (1996b) estimated that there were 40,000 m^2 of suitable habitat for *L. higginsii* at McMillan Island in Pool 10 of the Mississippi River near Guttenberg, Iowa, (an area designated as Essential Habitat Areas in the 1983 Recovery Plan) which contained an estimated 5,320 individuals. A more recent report contained revised estimates of both suitable habitat (860,994 m^2) and potential population size (662,965 individuals), although the authors suggest cautious interpretation of these crude estimates due to high levels of variability among the data (Miller and Payne 2001).

Davis and Hart (1995) examined an area downstream of Lock and Dam No. 6 on the Mississippi River near Trempealeau, Wisconsin, to determine whether this area should be classified as essential for *L. higginsii*. They found two live and two dead *L. higginsii* in the area. Although they did not estimate overall population size of *L. higginsii*, they indicated that because this area harbored many other mussel species at high densities, it has potential as an important area for *L. higginsii*. Unfortunately, at the four sites they examined, from 9 to 44% of all unionids were infested with zebra mussels.

Recent Reintroductions

Since 2000, state and federal conservation agencies have cooperated to reintroduce *Lampsilis higginsii* into areas that it occupied historically, but from which it had been extirpated. This work has largely been a result of a consultation between USFWS and the U.S. Army Corps of Engineers (Corps) under section 7(a)(2) of the Endangered Species Act (Act) on the effects to *Lampsilis higginsii* of the Corps' operation and maintenance of a nine-foot navigation channel on the Upper Mississippi River (see below). In 2000 and 2001, biologists relocated 471 adult *Lampsilis higginsii* from the Mississippi River at Cassville, WI and Cordova, IL, where zebra mussels posed an imminent risk, to two sites in Pools 2 and 3 of the Mississippi River where zebra mussel densities are below threatening levels. Davis (2003) examined 59 relocated females at these two sites in 2002 and found that about one-third were gravid. Of the 63 *L. higginsii* recovered in 2002 (59 females, 4 males), only one was found dead, although several had abnormal growth patterns exhibited by "exaggerated growth arrest lines and in-turning along the ventral margin of the shell" (Davis 2003). These mussels appeared to have resumed normal growth patterns in 2003 (M. Davis, Minnesota Department of Natural Resources, pers. comm., 2003).

Workers are also releasing fish artificially infested with *L. higginsii* glochidia and hatchery-propagated juveniles into its historical range and into its current range in an effort to reintroduce the species and refine propagation techniques, respectively (Table 1). To produce glochidia or juveniles for release, gravid females have been collected from the Hudson Essential Habitat Area in the St. Croix River or from relocated *L. higginsii* in Pool 2 (Cordova origin). At Genoa National Fish Hatchery, workers remove glochidia and either place them in water containing suitable fish-hosts or pipette glochidia directly onto the gills. Workers hold the fish at the hatchery for three weeks before releasing them or placing them in cages at the release site (Table 1, Gordon 2002). The hatchery has typically retained about 5% of the infested fish to monitor the success of glochidial transformation, provide juveniles for hatchery propagation trials, and for

direct juvenile releases (Table 1, Gordon 2002). Propagation is discussed further below under "Conservation Measures."

Essential Habitat Areas

The initial Higgins Eye Pearlymussel Recovery Plan (USFWS 1983) listed seven locations as primary habitats (called Essential Habitat Areas in this document) and nine locations as potential secondary habitats (Table 2 - see Section IV). Essential Habitat Areas were selected based on:

1) historic and current distribution data (at the writing of the recovery plan);
2) the nature of the data available for each site, *e.g.*, presence of live *L. higginsii*, presence of both sexes, presence of juveniles, numerical abundance of *L. higginsii*, etc.; and,
3) the nature of the associated fauna (*L. higginsii* has often been reported from diverse and dense mussel beds - Nelson and Freitag 1980).

The Essential Habitat Areas described in this Recovery Plan are those areas capable of supporting reproducing populations of *L. higginsii* and are of utmost importance to the conservation of the species. Cawley (1996) indicated that since 1980, all seven of the Essential Habitat Areas in the initial Higgins Eye Pearlymussel Recovery Plan had been sampled. In addition, six of the nine secondary habitats had been sampled.

The Service will maintain a list of Essential Habitat Areas. This list will initially contain the areas described in this plan (Fig. 2), but the Service will revise this list if data indicate that one or more areas are no longer of utmost importance to the conservation of *L. higginsii* or if additional Essential Habitat Areas are identified. The following criteria will be used as a guideline to identify new Essential Habitat Areas and for an ongoing evaluation of identified Essential Habitat Areas. As stated above, any Essential Habitat Area that is one of the five on which either a reclassification or delisting decision is based must meet these criteria:

1. *L. higginsii* constitute at least 0.25% of the mussel community and the mussel habitat appears to be stable and supports a dense and diverse mussel community; or,

2. *L. higginsii* are found, but constitute <0.25% of the community, the mussel habitat appears to be stable and supports a dense and diverse mussel community, and zebra mussel densities are < $0.5/m^2$.

For each definition, "dense and diverse" mussel communities are those that:

- include a total mussel density of > $10/m^2$ (Mississippi River) or > $2/m^2$ (other rivers); and,
- contain at least 15 other mussel species, each at densities greater than 0.01 individual/m^2.

Zebra mussels have severely degraded the native mussel communities at a few of the Essential Habitat Areas to the degree that they may no longer meet the definition above. These sites, however, demonstrated their importance to the conservation of *L. higginsii* until zebra mussels invaded the Upper Mississippi River in the 1990s and zebra mussels are likely the sole reason that they no longer meet the Essential Habitat criteria. Moreover, it is unclear how long zebra mussels will continue to suppress native mussel communities at these sites. Therefore, the Service will retain each of these as Essential Habitat Areas until data are sufficient to determine that one or more no longer possesses and is unlikely to recover the physical and biological features that are essential to the conservation of *L. higginsii.* The USFWS's Twin Cities Field Office will retain an updated list of Essential Habitat Areas for this species and should make this list available on the world wide web.

Critical Habitat

Critical habitat is not currently designated for the Higgins eye. If following the completion of this plan the Service finds that it is prudent and determinable to designate critical habitat for this species, the Service will prepare a critical habitat proposal at such time as our available resources and other listing priorities under the Act allow. This proposal will be based on essential habitat features needed to ensure the conservation and recovery of the species, many of which have been documented in the below Habitat Characteristics section of this Recovery Plan.

Biology, Ecology and Life History

Reproduction

Major aspects of the unionid reproductive cycle have been well described. Males release sperm into the water, often in packets known as volvocoid bodies (Fuller 1974) that are taken in through the incurrent siphon by the female. Fertilization occurs and zygotes are brooded in the water tubes of the gills by the female. In the genus *Lampsilis*, the marsupia that contain the glochidia, are kidney-shaped, occupying the posterior portion of the outer gills. Female unionids can produce up to a million eggs a year (Burky 1983). The zygotes develop into larvae (glochidia) that are released into the water column in various ways. In the genus *Lampsilis,* the edge of the mantle of the female develops into a ribbon-like flap in front of the branchial opening. This flap has been described as "minnow-like" in appearance, often having a dark "eye-spot," and thus it has been suggested to be important in attracting fish hosts (Baker 1928). The glochidia attach to a fish host, where they remain for approximately three weeks (at water temperatures of 20-22°C) (D. Waller, U.S. Geological Survey, pers. comm.) as they transform into juveniles. They then drop off their fish host, develop a byssal thread, which may assist in dispersal, and upon settling on suitable habitat, use the byssal thread as a means of attachment, to prevent being swept away in water currents.

Lampsilis higginsii is a long-term brooder (bradytictic). This means that they spawn in the summer and larvae are retained in the marsupia through the winter until they are released the following spring/summer. Glochidial release has been reported during June and July (Waller and

Holland-Bartels 1988) and May and September (Surber 1912). Glochidia of *L. higginsii* are morphologically similar to those of several other species of lampsilines in the Upper Mississippi River. Waller and Mitchell (1988) have shown that *Lampsilis higginsii* glochidia can be differentiated from *L. cardium, L. siliquoidea,* and *Ligumia recta* by electron microscopy; they could not be differentiated by light microscopy or morphometric measures.

Table 3 (see Section IV) identifies the known hosts for *L. higginsii.* Early studies indicated that the sauger (*Stizostedion canadense*) and freshwater drum (*Aplodinotus grunniens*) were fish hosts for glochidia of *L. higginsii* (Surber 1912; Wilson 1916; Coker *et al.* 1921). These identifications were based on examination of natural infestations, but field identifications are not robust (Waller and Holland-Bartels 1988; Waller and Mitchell 1988); Hove and Kapuscinski (2002), however, confirmed sauger as a suitable host. Based on laboratory infestations of fish with *L. higginsii* glochidia, Waller and Holland-Bartels (1988) indicated that four species of fish were suitable hosts: largemouth bass (*Micropterus salmoides*), smallmouth bass (*M. dolomieu*), walleye (*Stizostedion vitreum vitreum*) and yellow perch (*Perca flavescens*). There was some transformation of glochidia to juveniles on green sunfish (*Lepomis cyanellus*), whereas two species, bluegill (*Lepomis macrochirus*) and northern pike (*Esox lucius*), were considered marginal hosts, because each produced only one juvenile. The common carp (*Cyprinus carpio*) and fathead minnow (*Pimephales promelas*) were unsuitable hosts. Studies by Waller and Holland-Bartels (1988) and Waller and Mitchell (1988) supported those by Sylvester *et al.* (1984) that walleye and largemouth bass were hosts for *L. higginsii,* but Sylvester *et al.* (1984) indicated that the green sunfish and bluegill were not suitable hosts. Hove and Kapuscinski (2002) confirmed largemouth bass as suitable hosts and found that sauger and black crappie also facilitated metamorphosis of *L. higginsii* glochidia. In general, Waller and Holland-Bartels (1988) indicate that percids and centrarchids are suitable hosts, whereas cyprinids, ictalurids and catostomids are unsuitable. Neves and Widlak (1988) also indicated that members of the subfamily Lampsilinae were more likely to be found on centrarchids and percids than on cyprinids and cottids.

Feeding

Among the few published studies on unionid feeding mechanisms are recent studies by Tankersley and Dimock (1992, 1993a, 1993b) who used endoscopic techniques to examine feeding in *Pyganodon cataracta.* There have been no studies focusing specifically on *L. higginsii* but generally unionids are filter-feeders, removing small suspended food particles from the water column utilizing the large lamellibranch gills as feeding organs. Feeding rate in bivalves is known to be greatly influenced by temperature, food concentration, food particle size and body size (Jørgensen 1975; Winter 1978).

Habitat

Lampsilis higginsii has been characterized as a large river mussel species (USFWS 1983). Davis and Hart (1995) indicated that it was found in the more "riverine" portion of Pool 7 and in the

tailwater reaches of other Mississippi River navigation pools. Wilcox *et al.* (1993) proposed the following decision criteria for estimating the likelihood of occurrence of *L. higginsii*:

- Substrate: Substrate not firmly packed clay, flocculent silt, organic material, bedrock, concrete or unstable moving sand;

- Current velocity: Current velocities less than 1 m/s during periods of low discharge;

- Mussel relative abundance: If 2,000 or more mussels are sampled and no *L. higginsii* are found, then it is unlikely to be present;

- Density: Density of all mussels should exceed $10/m^2$, and any rare species (including *L. higginsii*) should occur at densities greater than 0.01 individuals/m^2;

- Species Richness: Species richness (number of species) should exceed 15 when as few as 250 individuals have been collected.

Additional information regarding habitat characteristics is given below.

Substrate

Strayer (1983, 1993), Vannote and Minshall (1982), and others have suggested substrate stability may be important in determining the presence of freshwater mussel communities. It is the permanence of the populations in substrate that appears to be most important in constituting a mussel "bed". At smaller spatial scales however, such as within mussel beds, substrate difference provided little predictive power (Holland-Bartels 1990; Strayer and Ralley 1993). Heath (1995) found no correlation between overall mussel density and substrate size in the Wisconsin River where *L. higginsii* was found. Hornbach *et al.* (1995) have indicated that substrate size does influence mussel density, although accounting for only a small proportion of the variability in mussel density. Mussels also apparently help to stabilize the substrate of the river in some areas (Watters 1994a).

Lampsilis higginsii has been found in various substrates from sand to boulders, but not in areas of unstable shifting coarse sands. Sylvester *et al.* (1984) found that burrowing times for *L. higginsii* were similar in clay, silt and sand, but longer in pebble-gravel substrate. *Lampsilis higginsii* were not present in rock substrate. Miller and Payne (1996b) considered substratum that was free of plants and consisted of stable, gravelly sand as suitable for *L. higginsii.* Miller and Payne (1996b) noted that immediately downriver of wingdams, mussel diversity was high and new species were found at a more rapid rate on the wingdam than in gravelly sand. *Lampsilis higginsii* was found immediately below the wingdam at McMillan Island and has been collected on wingdams near Prairie du Chien. The distribution of mussels is at least partially mediated by the distribution of their host-fish. Therefore, the distribution of mussels in relation to wing dams and other habitat features may be influenced by the relative distribution of their host fishes in relation to these features. *L. higginsii* is found in substrate that consists of coarse sand and gravel, but not in

either finer (silt) or coarser (cobble) substrates (D. Hornbach, Macalester College, St. Paul, MN, pers. comm. 2004). Cawley (1996) indicated that *L. higginsii* were most common in sand/gravel substrate. *L. higginsii* does not only occur in areas where the river bottom is free of rooted plants. Divers have recently found significant numbers of *L. higginsii* in substrates with rooted plants in the "littoral areas of river channels" at Cassville, WI and Cordova, IL (M. Davis, pers. comm., 2003).

Stream Flow/Current/Hydrologic Variability

DiMaio and Corkum (1995) indicated certain species of mussels may be more readily found in different hydrologic conditions. *L. higginsii* may be primarily adapted to large river habitats with moderate current, such as the East channel of the Mississippi River near Prairie du Chien, Wisconsin (Andrew Miller, U.S. Army Corps of Engineers - Waterways Experiment Station,pers. comm.).

Water Quality

The effects of water quality, including inorganic and organic contaminants, are not well understood in freshwater mussels. Because of the scarcity of information in this area, most of the available data are not specific to *L. higginsii*; however, these data provide an indication of the relative effects of various water quality measures on unionids. Although this section will not be specific to *L. higginsii*, attempts will be made to reference studies on the genus *Lampsilis* or to species in the same subfamily (Lampsilinae).

In the Upper Mississippi River basin, sedimentation and toxic contaminants have been suggested as the major threats to biotic resources (Wiener *et al.* 1984). As benthic filter-feeding organisms, freshwater mussels are exposed to contaminants dissolved in water, associated with suspended particles, and deposited in bottom sediments. Thus, freshwater mussels can bioaccumulate contaminants to concentrations that exceed those in contaminated water or sediments. This section is organized into two parts: (1) existing water and sediment quality at *L. higginsii* locations where reproduction is occurring and (2) water and sediment quality measures most likely to adversely affect freshwater mussels.

The majority of the available data on mussels and contaminants concerns tissue residue studies (reviewed by Havlik and Marking 1987, Naimo 1995). Although these studies document existing contaminant burdens (*e.g.*, 100 mg of cadmium per gram dry tissue weight), there is little consistency in how the samples are obtained for analysis. For example, factors such as sex, age, season, reproductive status, and feeding status can all substantially alter the results of these studies. More importantly, there is little available information on what effects these residue concentrations have on the individual. For example, information on the highest tissue residue concentration that a mussel can tolerate without an adverse biological effect (lower growth rates, poorer reproduction, etc.) is largely unknown. These types of data are usually inferred from examining residue data from heavily contaminated systems and assuming that these mussels are being adversely affected.

Water and sediment quality at locations where L. higginsii are reproducing

Long-term persistence of *L. higginsii* in the Essential Habitat Areas identified in this plan indicates a history of successful reproduction in these areas. Based on the presence of reproducing populations, except where severely affected by zebra mussels, water and sediment quality are presumed to be presently not adversely affecting the survival of *L. higginsii* in the Essential Habitat Areas. Due to their limited mobility, however, freshwater mussels cannot actively avoid contaminated areas. Therefore, existing conditions at a given location should not necessarily be viewed as optimal or beneficial. Rather, these data should be viewed as ranges of physico-chemical values that allow survival or some level of reproduction of *L. higginsii* at the present time. Even though population size may be stable or even increasing at some sites, poor water or sediment quality could still be limiting population growth (*e.g.*, fecundity, juvenile survival, or growth rates could be negatively affected without causing a net population decline).

An assessment of water and sediment quality near reproducing populations of *L. higginsii* suggests that *L. higginsii* exist at locations with relatively good water and sediment quality (Tables 4 and 5 - see Section IV). It has been suggested that unionids require water with a hardness of at least 20 to 40 mg $CaCO_3$/L (Clarke and Berg 1959, Harman 1969) and an alkalinity of at least 15 mg $CaCO_3$/L (Harman 1970, Pennak 1978); hardness and alkalinity in the St. Croix and the Upper Mississippi rivers exceed these levels.

Few data exist on the concentrations of most contaminants thought to adversely affect freshwater mussels. Nevertheless, the presence of reproducing *L. higginsii* populations and the diversity and abundance of many other unionid species at Essential Habitat Areas, at least before zebra mussel invasions, suggests water quality is not limiting unionid survival and reproduction. Furthermore, because many inorganic and organic contaminants that enter aquatic systems associate with fine sediments (*i.e.*, silts and clays), the greatest likelihood for adverse effects from these contaminants should be in depositional areas with fine sediments.

The existing data for *L. higginsii*, however, suggests that the species is not generally found in areas with a relatively significant amount of sediment deposition (see habitat characteristics section). Thus, *L. higginsii* are generally not located in areas where concentrations of heavy metals and organic contaminants are most likely to reach toxic levels.

Water and sediment quality factors likely to affect unionids

Siltation, Eutrophication, and Ammonia -- High total suspended solids is often cited as a factor affecting the quality of freshwater mussel habitat. Aldridge *et al.* (1987) found intermittent exposure of freshwater mussels (*Quadrula quadrula*, *Pleurobema beadleanum*, and *Fusconaia cerina*) to 600 to 750 mg/L of suspended solids adversely affected feeding rate, oxygen uptake, and excretion. Concentrations of suspended solids of this magnitude, however, are not expected to occur in either the St. Croix or Upper Mississippi Rivers; Dawson *et al.* (1984) found concentrations in these two rivers that ranged from 1 to 54 mg/L and from 1 to 120 mg/L, respectively.

Recently, the effects of un-ionized ammonia (NH_3) on unionids have been evaluated. Augspurger *et al.* (2003) reviewed thirty acute (24-96 hour) median lethal concentrations (LC50s) covering ten species in eight unionid genera and three life history stages. These values indicate that unionids are sensitive to ammonia relative to fish and other vertebrates. They reported that "(G)enus mean acute values ranged from 2.56 to 8.97 mg/L total ammonia as N, normalized to pH 8." LC50s for juvenile unionids are typically "substantially less than the acute national water-quality criteria" (Newton 2003), which is 8.40 mg N/L at pH = 8.0 when salmonids are absent (U.S. Environmental Protection Agency 1999). Augspurger *et al.* (2003) proposed interim criteria for maximum and continuous concentrations of ammonia that may be necessary to protect unionids from acute and chronic exposures, respectively. They acknowledged, however, that it is difficult to calculate criteria for chronic exposures due to the paucity of data on long-term exposure and sub-lethal effects (Augspurger *et al.* 2003).

Ammonia sources "include industrial, municipal, and agricultural wastewaters", precipitation, and natural processes (Newton 2003). Concentrations of 30 μg NH_3/L are frequently observed in sediment pore water in the Upper Mississippi River during summer (Frazier *et al.* 1996). Concentrations in pore water in the St. Croix River in 2001 ranged from 0.3 to 140.8 μg NH_3-N/L (Bartsch *et al.* 2003). Because concentrations of NH_3 are related to temperature and pH, elevated concentrations can occur in riverine systems during low flow periods. Concentrations of NH_3 are also related to particle size, however, with finer sediments containing elevated concentrations of NH_3 (Frazier *et al.* 1996). Thus, the greatest threat to unionids from NH_3 is likely to occur in fine sediments during low flow periods.

Although recent data suggest that mussels are generally more sensitive to ammonia than fishes, effects of ammonia on host fishes is also important for the conservation of *L. higginsii*. Mean acute levels of ammonia for two marginal host species (green sunfish and bluegill, Table 3) and three suitable host species (largemouth bass, smallmouth bass, and walleye, Table 3) ranged from 20 to 35 mg NH_3-N/L (at pH = 8, U.S. EPA, unpubl. data summary).

Inorganic and Organic Contaminants -- An assessment of the available data in the Upper Mississippi River basin suggests contamination of riverine sediments with elevated concentrations of pesticides, heavy metals (Cd, Cu, Hg, and Zn), polychlorinated biphenyls (PCBs), and ammonia may pose the greatest harm to benthic invertebrates (Naimo *et al.* 1992a; 1992b; Steingraeber *et al.* 1994; Frazier *et al.* 1996).

Many contaminants, particularly toxic metals, that enter aquatic systems are adsorbed onto suspended particles and subsequently accumulate in surficial sediments (Tessier and Campbell 1987). Toxic concentrations of dissolved metals are uncommon in oxic surface waters. In the Mississippi River, for example, more than 90% of the trace metal load is associated with particles (Trefry *et al.* 1986). Thus, these metals can be accumulated by, and directly affect, filter-feeding benthic organisms such as freshwater mussels. Recently, studies have focused on sediment pore water because it is well known that concentrations of inorganic and organic contaminants in pore water can greatly exceed concentrations in overlying surface water. Yeager *et al.* (1994) demonstrated that although juvenile *Villosa iris* burrowed less than 1 cm into the sediment, they

were not exposed to the overlying water. Thus, although freshwater mussels, in general, can be exposed to metals dissolved in water, associated with suspended particles, and deposited in bottom sediments, juvenile mussels are most likely exposed to elevated metal concentrations found in association with sediment or pore water.

The effects of heavy metals on freshwater mussels, particularly cadmium (Cd), copper (Cu), mercury (Hg), and zinc (Zn), have been studied more than other contaminants because they are widespread, persistent, potentially toxic, and because many freshwater ecosystems are contaminated with these metals, as a result of human activities (Naimo 1995). Laboratory-based acute toxicity values for juvenile mussels, range from 44-388 μg Cu/L (Keller and Zam 1991; Jacobson *et al.* 1993), 211-588 μg Zn/L (Keller and Zam 1991; McCann 1993), 107-345 μg Cd/L (Keller and Zam 1991; Lasee 1991). Cherry *et al.* (2002) found mean acute values ranging from 37-4030 μg Cu/L among eight mussel species using water from Clinch River, Virginia; *Lampsilis fasciola* had the lowest species mean acute value (37, st. dev.=12.6). Concentrations of total Cd, Cu, Hg, and Zn in surface waters of the St. Croix River at St. Croix Falls, Wisconsin, are well below concentrations thought to be harmful to freshwater mussels (Table 5 - see Section IV). Similarly, in the reach of the Upper Mississippi River between Coon Rapids, Minnesota (River Mile 870) and Red Wing, Minnesota (River Mile 800), concentrations of total Cd, Cu, and Zn in surface waters are also below concentrations thought to be detrimental to mussels (ranges, Cd: 0.8-2.0 μg/L, Cu: 5.2-6.8 μg/L, and Zn: 20-30 μg/L; Boyer 1984).

Virtually nothing is known about the sublethal impacts in mussels to long-term exposure to metals at low concentration. Although laboratory toxicity tests provide tolerance limits, few of these tests have used environmentally realistic exposure concentrations. For example, total concentrations of Cd, Cu, Hg, and Zn in many oxic surface waters are in the ng/L range, yet many toxicity studies have exposed mussels to concentrations in the μg/L or even mg/L range (reviewed in Naimo 1995). Sublethal effects are frequently observed at concentrations only one-half the lethal concentrations, which indicates freshwater mussels become stressed at metal concentrations much lower than those reported in acute toxicity tests. For example, Jacobson *et al.* (1993) determined the 24-h LC_{50} for juvenile *Villosa iris* was 83 μg Cu/L, but the 24-h EC_{50} (percent gaped and dead or ungaped) was 27 μg Cu/L. In addition, Lasee (1991) determined that 0-d old juvenile *Lampsilis cardium* were killed at concentrations of 141 μg Cd/L, but significant reductions in ciliary activity, a surrogate for feeding intensity, were evident at concentrations of 90 μg Cd/L.

Comparatively less is known about both acute and sublethal effects of organic contaminants on freshwater mussels. Keller (1993) exposed juvenile *Utterbackia imbecillis* to eight organic compounds in laboratory tests and found pentachlorophenol was the most toxic (48-h LC_{50} = 0.6 mg/L) and methanol (48-h LC_{50} = 37.0 mg/L) was the least toxic. Mussels were insensitive to the herbicide Hydrothol-191 (96-h LC_{50} = 4.9 mg/L) and two chlorinated pesticides (chlordane, 96-h LC_{50} = 0.9 mg/L and toxaphene, 96-h LC_{50} = 0.7 mg/L), relative to *Ceriodaphnia dubia*, an organism commonly tested in laboratory studies (Keller 1993). Furthermore, juvenile *Utterbackia imbecillis* and *Villosa villosa* were insensitive to malathion, a commonly used organophosphorus insecticide (Keller and Ruessler 1997).

Although there are fewer data on the effects of organic contaminants to unionid mussels, the available data suggest some compounds in the Upper Mississippi River have the potential to harm *L. higginsii* and to degrade entire benthic invertebrate communities. For example, zebra mussels have been shown to bioaccumulate substantial quantities of PCBs in the Upper Mississippi River (M.R. Bartsch, U.S. Geological Survey - Upper Midwest Environmental Sciences Center, pers. comm.). In addition, a survey of PCBs in emergent mayflies identified two zones of concern regarding PCB contamination of riverine sediments--Pools 2 through 6 and Pool 15 of the Upper Mississippi River (Steingraeber *et al.* 1994).

In the Mississippi River, suspended sediments can transport substantial quantities of organochlorine pesticides such as PCBs, DDT and its metabolites (DDE and DDD), aldrin, and dieldrin. For example, during 1988 to 1993, suspended sediments in the Mississippi River transported between 410 and 37,000 grams per day of total PCBs (Rostad 1997). Because unionids can filter large volumes of water (range, 60 to 490 mL/individual/hour; Stanczykowska *et al.* 1976), the potential exists for unionids to obtain a substantial contaminant mass through inhalation of suspended particles.

Contaminants may also affect mussels via the fish that serve as hosts for the juveniles. Recently, it has been shown that exposure to fish containing elevated body burdens of DDE, toxaphene, or atrazine during transformation reduced the survival of juvenile mussels (N. J. Kernaghan, Florida Caribbean Science Center, pers. comm.). Thus, studies on *L. higginsii* should also examine contaminant body burdens in their fish hosts.

Water Quality Data Gaps

1. The biological effects of contaminant residues on freshwater mussels are largely unknown (*i.e.*, can a mussel accumulate 100 mg/g of contaminant "X" without deleterious effects to reproduction, feeding, and survival?).

2. One serious constraint in evaluating the effects of contaminants on the various life stages of freshwater mussels is the lack of basic information required for laboratory toxicity studies: nutritional requirements, culture methods, and realistic exposure concentrations--all of these likely affect the susceptibility of mussels to contaminant exposure. Furthermore, the lack of data on nutritional requirements and culture methods for species at risk, such as *L. higginsii*, jeopardizes species-specific studies.

3. Comparative data on modes of uptake in freshwater mussels are needed to more fully evaluate contaminant effects, design contaminant monitoring programs, and to develop water-quality criteria that adequately protect freshwater mussels. The relative significance of contaminant uptake from food sources, surface water, pore water, and sediments as routes of exposure is not documented.

4. The existing data on the most sensitive life history stage (*i.e.*, glochidium, juvenile, adult) are conflicting. More information is needed to determine which life history stage and sex

is the most sensitive or to determine if this sensitivity is contaminant-specific. These data will help guide and standardize field and laboratory toxicity tests for unionids.

Community Associations

Lampsilis higginsii is often found in dense and diverse mussel beds. Cawley's (1996) review indicated that on average 20.7 species of mussels were found at sites where *L. higginsii* have been collected (range 2 - 36 species). Havlik (1983) commented on the common occurrence of *L. higginsii* with either *Obovaria olivaria* or *Megalonaias nervosa.* Duncan and Thiel (1983) and Davis and Hart (1995) also reported a close relationship between the presence of *O. olivaria* and *L. higginsii*. Miller and Payne (1996b), however, found no positive relationship between the presence of *M. nervosa* and *L. higginsii.* Heath (1995) noted that four species (*Amblema plicata, Quadrula pustulosa, Fusconaia flava* and *L. cardium*) are very common at all known *L. higginsii* sites. Others have reported that at most *L. higginsii* sites, *L. higginsii* accounted for approximately 0.5% of the community (Fuller 1980; Thiel 1981; Holland-Bartels 1990; Miller and Payne 1991, 1992, 1993, 1994; Hornbach *et al.* 1995; Miller and Payne 1995a, 1995b, 1996a, 1997). In some areas *L. higginsii* may account for up to approximately 2.75% of the community (A. Miller *unpubl. data*), whereas in some marginal areas it may make up a smaller proportion of the mussel community. Hornbach *et al.* (1995) hypothesized that populations in marginal habitat areas are maintained by fish-mediated transport of glochidia from other populations.

Non-human Predators

The natural predators of adult mussels include a variety of aquatic and semi-aquatic animals: *Ondatra zibethicus* (muskrats) (Apgar 1887; Evermann and Clark 1920; Van Cleave 1940; Errington 1941; Takos 1947; Pennak 1978; Hanson *et al.* 1989; Convey *et al.* 1989; Neves and Odom 1989; Lacki *et al.* 1990), *Lutra canadensis* (river otters) (Morejohn 1969; Toweill 1974; Pennak 1978), *Mephitis mephitis* (striped skunk) (Hazard 1982), *Mustela vison* (mink) (Pennak 1978), turtles (Pennak 1978), *Cryptobranchus* (hell benders) (Pennak 1978), fish (McMahon 1991; Williams *et al.* 1993) and *Procyon lotor* (raccoon) (Evermann and Clark 1920; Hazard 1982). Tyrrell and Hornbach (1998) found differences in the sizes of mussels taken from the middens and adjacent river samples indicating that small mammals are size-specific mussel predators in the St. Croix and Mississippi Rivers. Their conclusions are supported by previous findings in similar studies. Convey *et al.* (1989), Hanson *et al.* (1989) and Jokela and Mutikainen (1995) found that mussels in midden piles were longer on average, than the mussel population in the adjoining body of water. Tyrrell and Hornbach (1998) also found differences in species composition, richness and diversity between mussels collected from middens and adjacent river sites, revealing species-specific selection by small mammal predators. This result was supported by the findings of Neves and Odom (1989) and Watters (1995), who found that muskrats exhibited preferences for some mussel species over others. Davis and Hart (1995) found 2 freshly consumed *L. higginsii*, both females, in muskrat middens in Pool 7 of the Mississippi River.

If populations of *L. higginsii* continue to decline in the mainstem of the Mississippi River, it is possible that predation, especially in smaller river systems such as the St. Croix and Wisconsin rivers may become a more important threat to *L. higginsii*.

Genetics

There have been relatively few studies that address the genetic structure and diversity of unionid populations. Many of the studies that have been conducted have been structured to examine evolutionary relationships among species (*e.g.* Davis and Fuller, 1981; Davis *et al.* 1981; Davis 1984; Lydeard *et al.* 1996). Kat (1983) and Stiven and Alderman (1992) focused their studies on *Lampsilis* species, but neither included *L. higginsii*. As in most genetic studies on unionids, these studies focused on species and subspecies identification - *i.e.*,determining the "status" of various taxonomic groups. Few studies have been designed to examine the degree of genetic variability both among and within populations of unionids. These types of studies are imperative if conservation efforts, including relocation projects, are to be successful in maintaining the genetic diversity of mussel species (Villella *et al.* 1997). One study by Berg *et al.* (1997) indicated that large river species and small stream species may differ in their "within" and "among"-population genetic variability. A large river species was found to have a high level of within-population genetic variability and a low level of among-population variability. Berg *et al.* (1997) claimed that large river populations may be considered a single large metapopulation, and thus preservation of several populations in big rivers will conserve most of a taxon's genetic diversity. While their study is intriguing, it is based on only a single species of mussel (*Quadrula quadrula*).

Data from mitochondrial DNA analysis from four populations of *L. higginsii* in the St. Croix (Hudson) and Mississippi Rivers [Whiskey Rock (IA), Cassville, WI, and Cordova, IL] indicate a high degree of genetic variability within populations with no site-specific haplotypes (genes or sets of genes that are inherited together, Bonnie Bowen, Dept. Animal Ecology, Iowa State University, Ames, Iowa *in litt.* 1999, 2002, and 2003). *L. higginsii* seems to possess a high degree of genetic variability relative to other endangered species (B. Bowen *in litt.* 2002 and 2003). Biologists planning and implementing artificial propagation and reintroduction of *L. higginsii* must be careful to ensure that reintroduced populations reflect the genetic variability found in natural populations.

Reasons for listing

The major reasons for listing *L. higginsii* were the decrease in both abundance and range of the species. As stated in the initial recovery plan (USFWS 1983), the Higgins eye pearlymussel was never abundant and Coker (1919) indicated that it was becoming increasingly rare even at the end of the 1800s. The fact that there were few records of live specimens from the early 1900s until the enactment of the Endangered Species Act in 1973 was a major factor in its listing in 1976.

Since the initial listing of the species, a variety of authors have noted declines in mussel populations within the range of *L. higginsii*. Thiel (1987) reported mid-1980's die-offs of mussels in the Mississippi River that were most noticeable in areas of *L. higginsii* occurrence. Blodgett

and Sparks (1987a) noted a decline in the unionid community near the Sylvan Slough Essential Habitat Area and Havlik (1987) noted a die-off near Prairie du Chien, Wisconsin, another Essential Habitat Area. Havlik (1987) also indicated an "unusual" number of fresh-dead *L. higginsii* at this site in 1985. Few papers presented at a workshop examining die-offs (Neves 1987) gave concrete reasons for the cause of the die-off, however Scholla *et al.* (1987) indicated that a gram-negative rod bacterium, which forms yellow colonies was associated with "sick" mussels from the Tennessee River. Research on mussel pathogens (bacterial, viral and protozoan) and their effects on population levels has not been conducted.

Present Threats

Zebra Mussels and other Invasive Species (see Tasks under 1.1 and 2.3 in the step-down outline)

Zebra Mussels -- The introduction of the zebra mussel to North America has negatively affected populations of native mussels (Unionidae) (Mackie 1991; Hunter and Bailey 1992; Strayer 1999). Unionid mussels evolved in the absence of any major fouling organisms and have no mechanisms for dealing with their deleterious effects. Zebra mussels have the potential to impact unionids both directly, by actual attachment, and indirectly, through competition for food or changes in water quality (Descy *et al.* 2003; Makarewicz *et al.* 2000). The relative amount of stress caused by zebra mussel attachment may be species and sex specific. For example, members of the subfamily Ambleminae, which are short-term brooders, are less stressed by zebra mussel colonization than are long-term brooders, such as the Lampsilinae (Haag *et al.* 1993). Sexual differences within a species also exist, with colonized males being less stressed than colonized females (Haag *et al.* 1993). These studies suggest that zebra mussel introduction could drastically alter unionid mussel community structure and overall biodiversity by affecting the fitness of community members unequally.

One way that zebra mussels effect unionids is through direct attachment to their shells. Zebra mussels can colonize all species and may reduce both population size and species richness of unionids (Mackie 1991). Observations by Hebert *et al.* (1989) and laboratory studies by Lewandowski (1976) showed that zebra mussel attachment rates were higher on live unionids than on dead unionids or rocks, although recent studies by Toczylowski and Hunter (1996) indicated that this preference may not be exhibited in the field. In 1989, on Great Lake gravel substrates, one third of the zebra mussels were attached to unionids, while the rest were attached to the gravel (Hebert *et al.* 1989). Unionid shells may provide substrate for zebra mussels in areas that they would otherwise be unable to colonize. Hebert *et al.* (1989) note that zebra mussels are most often found in locations with gravel substrate, but can also be found on sand and silt substrate if hard objects, such as unionids, are available. In the Great Lakes and in Polish lakes, up to 90% of the unionid population had attached zebra mussels (Lewandowski 1976; Hebert *et al.* 1989); although even severe infestations may not cause immediate 100% mortality of unionids in the Great Lakes, reductions in unionid densities to levels <5% of the pre-zebra mussel colonization levels have been documented and the long-term viability of the remnant populations is unclear (Schloesser 1997). Haag *et al.* (1993) examined unionids in Lake Erie and found an

average of 216 zebra mussels attached to each unionid. Individual unionids have been found encrusted with over 10,000 zebra mussels (Hebert *et al.* 1991).

The direct attachment of zebra mussels may affect unionids in several ways. Unionid locomotion may be impaired by the attached zebra mussel biomass. Zebra mussel biomass often exceeds that of the underlying host unionid (Lewandowski 1976; Mackie 1991). Tucker (1994) indicated that habitat alteration, with zebra mussels forming a "pavement" over gravel bars, prevented unionids from burrowing. Zebra mussels may interfere with siphon extension or prevent valve closure and opening, resulting in inhibition of feeding, respiration or excretion. Wiktor (1963) reported that zebra mussels can over-grow *Unio spp.* and *Anodonta spp.*, resulting in "suffocation." Prevention of valve closure may increase the susceptibility of unionids to diseases, parasites, and predation. Zebra mussels can also cause shell deformation of unionid shells, especially near the siphons (Lewandowski 1976). These deformations may also contribute to inhibition of physiological functions.

Indirect effects of zebra mussels on unionids include potential competition for food and changes in water quality. Zebra mussels, as filter-feeding organisms, have the potential to strip the water of food and nutrients. The enormous influence of zebra mussels on the phytoplankton dynamics of aquatic systems has been estimated by a number of authors. Stanczykowska *et al.* (1976) calculated that filter feeders, especially zebra mussels, consumed 8% of the primary production per year in a Polish lake. Lewandowski (1983) concluded that a population of zebra mussels in another lake in Poland can filter 213 x 10^6 m^3 of water per year. Reeders *et al.* (1989) indicated that the zebra mussel populations in Lakes Ijsselmeer and Markermeer in the Netherlands had the capacity to filter these lakes once or twice a month, greatly reducing phytoplankton biomass. Descy *et al.* (2003) found that high zebra mussel densities on the River Moselle in western Europe resulted in the loss of "virtually all small zooplankton in the summer." In addition, excretion of ammonium by zebra mussels may lead to increases in ambient concentrations of ammonia (Lavrentyev *et al.* 2000; Makarewicz *et* al. 2000).

Zebra mussels may also be affecting unionid mussel populations by filtering their glochidia. MacIsaac *et al.* (1991) indicated that although mussels preferred algal foods smaller than 50 μm, they can ingest particles at least up to 400 μm in length. McMahon (1991) indicated that unionid glochidia range in size from 50-400 μm, with most less than 200 um. Consequently, it is possible that zebra mussels consume unionid glochidia.

There are no studies that adequately quantify competition for food among freshwater mussels. Based on theoretical considerations, Levinton (1972) claimed it unlikely that there is competition for food among filter-feeding organisms. A number of studies in marine systems (*e.g.* Wildish and Kristmanson 1984, Fréchette *et al.* 1989), however, indicate that food supply to bivalves may be limited and that competition for food may be an important factor in controlling bivalve growth. Certainly, the potential for competition for food resources between zebra mussels and unionids is great. Strayer *et al.* (1996) and Caraco *et al.* (1997) have implicated a reduction of phytoplankton abundance in the Hudson River to the introduction of zebra mussels to this system;

this may also explain subsequent reductions in unionid density, even though the number of zebra mussels attached per unionid is quite low.

Zebra mussels have clearly had major impacts on North American unionids (Strayer 1999). Strayer and Smith (1996) have shown that unionid density fell by 56%, recruitment of young-of-the-year unionids fell by 90%, and condition of unionids fell by 20-50%, 4 years after the introduction of zebra mussels into the Hudson River. Similarly, Ricciardi (1996) found significant declines in unionid density and physiological condition in the St. Lawrence River 3-5 years after the introduction of zebra mussels.

All current populations of *Lampsilis higginsii* are under the potential threat of being colonized by zebra mussels; only one of the current Essential Habitat Areas, Interstate Park in the St. Croix River, is entirely free of zebra mussels. Tucker *et al.* (1993) reported the widespread colonization of unionids by zebra mussels in the upper Mississippi River. Clarke and Loter (1995) found nearly a ten-fold increase in zebra mussel densities from 1993 to 1994 at Prairie du Chien. Cope *et al.* (1996) summarized the status of zebra mussels in the upper Mississippi River and indicated that densities ranged from 1-11,000 zebra mussels/m^2 on the locks and dams in this stretch of the river. Ricciardi *et al.* (1995b) indicated that severe unionid mortality (>90%) is expected when zebra mussel density reach 6000/m^2 with infestation rates of 100 zebra mussels/unionid.

Zebra mussels have had a substantial impact on the mussel community at Prairie du Chien, WI, one of the Essential Habitat Areas (Miller and Payne 2001). Quantitative and qualitative samples for freshwater bivalves have been collected in the east channel of the Mississippi River at Prairie du Chien by the U.S. Army Engineer Waterways Experiment Station since 1984 (A. Miller, pers. comm.). The first zebra mussels in quantitative samples were taken in 1993, averaging 2 individuals/m^2. Zebra mussel density increased to over 10,000 individuals/m^2 in 1996. Although zebra mussel densities decreased and varied from 1996 to 2000, mean density estimates typically exceeded 1,000 individuals/m^2. Coincident with these densities of live zebra mussels, shell material from dead zebra mussels had increased to a depth of approximately 50 cm in some areas. Additionally, divers reported substantial hydrogen sulfide production associated with dead zebra mussels and other organic debris.

Impacts of zebra mussels on reproduction in some areas occupied by *L. higginsii* has been profound. From 1984 to 1994, evidence of recent recruitment for native mussels in the East Channel at Prairie du Chien was highly variable, but obviously unaffected by zebra mussels (A. Miller, *unpubl. data*). The percentage of live unionids less than 30 mm total shell length during this period ranged from 10.7% in 1984 to a maximum of 41.5% in 1993. The percentage of species showing at least some evidence of recent recruitment ranged from a low of 36.8% in 1992 to a high of 75% in 1987. In 1996, when zebra mussel density was at its maximum, juvenile native mussels were present, but the percentage of recent native mussel recruits decreased to 0.0% in 1999 and 2000. Thus, zebra mussel densities in 1996 and 1997 virtually eliminated recruitment of native species by 1999.

Mean density of all unionids in the East Channel varied from a maximum of 149 individuals/m^2 to a minimum of 28.3 individuals/m^2 during the period 1984-1994 (A. Miller, *unpubl. data*). Year-to-year variation could have been caused by slight differences in sample site locations, mortality of older age classes, and variation in recruitment. The rapid decline in native mussel density after 1996, first noted in 1998 (10.1 individuals/m^2) and continuing in 1999 (1.7 individuals/m^2), however, is almost certainly related to the presence of zebra mussels. Before 1999 *L. higginsii* comprised ≥1% of the total native mussel fauna in the East Channel in all study years. Live specimens of *L. higginsii* were not collected at this location during quantitative (*i.e.*, systematic, randomized) sampling in 1999 and 2000, however, and only one live *L. higginsii* was collected during qualitative sampling in those two years. In 1999, quantitative and qualitative samples were also collected in the main channel of the Mississippi River approximately 1 mile from the sampling location in the East Channel. A qualitative sample collected there included five *L. higginsii* out of a total of 198 unionids collected (*i.e.*, *L. higginsii* comprised 2.5% of the sample). Zebra mussel densities were lower in this main channel location than in the East Channel.

Data indicate that densities of live zebra mussels have declined recently at Prairie du Chien, at least temporarily. In 2003, mean zebra mussel density was 30.7 (SD = 42.8, n = 5, U.S. Army Corps of Engineers, unpubl. data), whereas in 2000 it was 9390 individuals/m^2 (SD = 2932.4, n = 10, U.S. Army Corps of Engineers, unpubl. data). Native mussels have persisted, but mean unionid densities are well below the minimum densities observed before zebra mussels invaded. In 2003, mean unionid density was 6.5 individuals/m^2 (SD = 4.9, n = 5, U.S. Army Corps of Engineers, unpubl. data).

The Corps has found similar declines in zebra mussel densities at Cassville, WI (U.S. Army Corps of Engineers, unpubl. data). Upstream populations of zebra mussels persist, however, most notably at Lake Pepin. Therefore, the threat of another devastating influx of zebra mussels at Prairie du Chien and other *L. higginsii* habitats is still imminent despite recent population trends. In the long term, zebra mussels may have only transitory or temporarily depressing impacts on native mussel populations, including those of *L. higginsii*. The current data indicate, however, that it is prudent to consider zebra mussels as a mortal threat to *L. higginsii* until new information indicates otherwise (*e.g.*, data indicating recovery of *L. higginsii* populations affected by zebra mussels).

Humans agents (*e.g.*, barges and recreational boats) are likely the most important and, perhaps, the only way by which zebra mussels spread upstream in rivers (Carlton 1993). Zebra mussels attach to nearly anything submerged and can survive for days out of water, depending on the temperatures and relative humidity to which they are exposed. Recreational and commercial vessels transport zebra mussels when they attach to exterior hulls or other structures or when they inhabit bilges, bait wells, water intake fittings, or any other wetted part of boats. They can be spread by any wetted equipment, such as construction equipment previously used in infested water or by diving equipment, including air tanks and dive suits used in infested waters.

Due to the presence of a veliger larvae in the life-cycle of zebra mussels, downstream transport by flow is common in river populations whereas human-mediated transport is the significant mode of

upstream transport. In Europe's Rhine River, studies indicate that upstream lakes and impounded reaches along the river provide the veligers necessary to maintain downstream populations of *Dreissena polymorpha* (Borcherding and De Ruyter Van Steveninck 1992; Janz and Neumann 1992; Kern *et al.* 1994). Kern *et al.* (1994) indicate that zebra mussel population fluctuations in upstream lakes (mainly caused by waterfowl - Cleven and Frenzel 1993) were responsible for downstream fluctuations in population levels, but tests by Johnson and Carlton (1996) seemed to discount the role of waterfowl in the overland transport of zebra mussels. Clarke (1992), Carlton (1993) and Martel (1995), among others, have indicated that upstream dispersal of zebra mussels is due to human transport, primarily on boats. Boats pulled overland on trailers may be the primary mechanism for overland dispersal (Ricciardi *et al.* 1995a; Bossenbroek *et al.* 2001); the majority of within-river upstream transport occurs by attachment to commercial and recreational boats.

Without upstream transport and a stable upstream population of zebra mussels, it is not clear whether downstream populations will remain stable. Whitney *et al.* (1995) reported drastic declines in zebra mussels in the Illinois River after large populations were reported in 1994. It is presumed that transport of zebra mussels from the Great Lakes through the Illinois River, with subsequent upstream transport on commercial barges, resulted in the current distribution of zebra mussels in the Mississippi River from St. Paul, MN and downstream. Whitney *et al.* (1995) indicate "Given the man-made connection with Lake Michigan ... we expect mussels numbers in the Illinois will fluctuate dramatically over the next few years ..."

There are large populations of zebra mussels as far upstream as Lake Pepin on the Mississippi River (Pool 4) and they are now also established in the lower St. Croix River, which is upstream of Lake Pepin. Zebra mussels have been found farther upstream at locks and dams as far as St. Paul, MN, but self-sustaining populations upstream of the mouth of the St. Croix River may not exist at this time, due to a lack of a significant upstream source of veligers. In the St. Croix River zebra mussel populations are recently established and appear to be self-sustaining in the mostly lacustrine portion of the lower river, upstream to Stillwater, MN (N. Rowse, USFWS, pers. comm. 2003); this reach of the St. Croix River includes both the Hudson and Prescott Essential Habitat Areas.

Currently, there is a proposal to develop an invasive species barrier between Lake Michigan and the Illinois River (Moy 1999), although at present the design would not restrict zebra mussels. The only hope of developing effective strategies for managing zebra mussels, or of determining if specific strategies are necessary or feasible, is to monitor the spread of zebra mussels and their potential effects on *L. higginsii*, particularly in Essential Habitat Areas.

Interagency Cooperation Between the Service and U.S. Army Corps of Engineers -- On 15 May 2000, the Service issued a biological opinion to the U.S. Army Corps of Engineers (Corps) in which it determined that the Corps' continued operation and maintenance of the 9-foot navigation channel on the Upper Mississippi River System (UMRS) would jeopardize the continued existence of *Lampsilis higginsii*. The Service based this finding on the effects to *L. higginsii* of the upriver transport of zebra mussels by commercial and recreational vessels. In its biological

opinion, the Service provided a reasonable and prudent alternative to the proposed action to avoid jeopardizing *L. higginsii* and mandated further measures to minimize the incidental take that would result from implementation of the proposed action. Implementation of the reasonable and prudent alternative and the reasonable and prudent measures is mandatory for the Corps. As a result, the Corps must (1) conduct a *L. higginsii* relocation feasibility analysis, (2) prepare a Higgins eye Pearlymussel Relocation Plan, (3) implement a monitoring program for *L. higginsii* and other unionids in the Upper Mississippi River System, (4) investigate opportunities to protect live *L. higginsii* individuals within essential habitat areas in the Upper Mississippi River System during the interim period between issuance of the biological opinion and implementation of the relocation phase, and (5) develop and implement an action plan to monitor abundance and distribution of zebra mussels on the Upper Mississippi River System.

In response to the biological opinion, the U.S. Army Corps of Engineers established a Mussel Coordination Team with a Partnership Agreement signed by agency heads of the U.S. Army Corps of Engineers, St. Paul and Rock Island Districts; the USFWS; the U.S. Geological Survey; the National Park Service; the U.S. Coast Guard; and the departments of natural resources from the states of Minnesota, Wisconsin, Iowa and Illinois. The purpose of the Mussel Coordination Team is to work cooperatively to coordinate and plan relevant mussel studies and projects and to share information on the management of native mussel resources and control of invasive non-indigenous mussel species.

The Corps subsequently developed draft interim and long-term goals and objectives to address the conservation of *L. higginsii* (U.S. Army Corps of Engineers 2002). The Interim Goal (next 10 years) is to maintain and/or establish reproductively viable populations of Higgins Eye Pearlymussels based on the following objectives:

Objective 1. Maintain viable populations of *L. higginsii* and other native mussels at the Interstate, Hudson, Prescott and Orion Essential Habitat Areas.

Objective 2. Protect as many *L. higginsii* as practical in the following Essential Habitat Areas and/or other important habitats: Lower St. Croix River (Hudson), Lower St. Croix River (Prescott), UMR - Pool 9 (Whiskey Rock), UMR - Pool 10 (Harpers Slough), UMR - Pool 10 (Prairie du Chien), UMR - Pool 10 (McMillan Island), UMR – Pool 13 (Bellevue), UMR - Pool 14 (Cordova), UMR - Pool 15 (Sylvan Slough).

Objective 3. Establish a minimum of five new and viable populations of *L. higginsii* in the UMR and/or tributaries un-infested or with low level infestations of zebra mussels.

Objective 4. Monitor trends in abundance and distribution of *L. higginsii* and other native mussels.

Objective 5. Monitor trends in abundance and distribution of zebra mussels in the UMRS.

The Long-term Goal of the Corps' conservation plan is to maintain existing (year 2000) population levels of Higgins eye pearlymussels within at least four geographically separate areas meeting the criteria for Essential Habitat.

Objective 1. Prevent zebra mussel infestation above Lake Pepin and into the Lower Wisconsin River and other UMRS tributaries and reverse current zebra mussel population trends in the UMRS, especially from Lake Pepin downstream to the confluence of the Illinois River.

Objective 2. Restore *L. higginsii* populations and habitat in essential and other habitat areas.

Various aspects of these plans were initiated in summer 2001. Higgins eye pearlymussel and zebra mussel populations will be monitored at Essential Habitat Areas and at other key study sites over the next 10-25 years to evaluate the effectiveness of past and current management strategies.

Currently, the areas above Pool 4 include areas of historic *L. higginsii* populations as well as two Essential Habitat Areas (both in the St. Croix River). Invasion of those two areas could result in the relocation of *L. higginsii* to river reaches where zebra mussels are absent or present at low densities. Relocation of *L. higginsii* to uninfested rivers or other waters may become the only means of preserving the species. Thus, there is need for (1) capability to identify suitable *L. higginsii* habitat refuge areas, (2) measures to safely and effectively remove all life stages of zebra mussels from *L. higginsii* to be relocated to avoid contaminating release sites, and (3) safe and effective *L. higginsii* relocation methods and protocols.
The Team, therefore, stresses the importance of:

1. Preventing zebra mussels from spreading to the remaining uninfested *L. higginsii* areas in the St. Croix and Wisconsin rivers.

2. Monitoring, studying, and documenting zebra mussels and their impacts on *L. higginsii*, particularly in infested Essential Habitat Areas.

3. Researching and developing *L. higginsii* habitat identification guidelines for selecting refuge areas outside present *L. higginsii* range.

4. Developing *L. higginsii* relocation techniques.

Black Carp (*Mylopharyngodon piceus*) – Black carp, which were introduced from Asia into aquaculture operations in several southern states, are molluscivores that consume snails and bivalves. Their establishment in the Mississippi River would likely threaten Higgins eye. Black carp inhabit large rivers in their native range, which extends from 22-51° north latitude (K. Duncan, U.S. Fish and Wildlife Service, pers. comm. 2004). Nico *et al.* (2001) found that the likelihood of black carp becoming established in open waters in the U.S. is "High – Very Certain" because many aquaculture facilities in the southern U.S. are highly vulnerable to flooding. Subsequent to their analysis, on March 26, 2003, a commercial fisherman caught one black carp,

evidently a sterile triploid specimen, in an oxbow that is "occasionally connected to the Mississippi River during floods" (Chick *et al.* 2003). The Mississippi is among the four major river basins that appear to provide appropriate habitat for the spread of this species (Nico *et al.* 2001). Other Asian carps – bighead (*Hypophthalmichthys nobilis*) and silver (*H. molitrix*) – are already "firmly established and spreading in the Mississippi River system (Nico *et al.* 2001).

Round goby (Neogobius melanostomus) – Round goby is another species introduced into North America from Eurasia that may threaten Higgins eye. Unlike black carp, it was introduced unintentionally from freighter ballast. It has become established in several areas in North America, including the Mississippi River Basin – it now occurs in the upper 18% of the Chicago Sanitary and Shipping Canal, which flows into the Illinois River (P. Thiel, USFWS, pers. comm., 2004). Their size (approx. 7-10 cm) would likely limit their impact to the consumption of Higgins eye < 10 mm in length (Ray and Corkum 1997). Therefore, the consequences of round goby establishment in the range of Higgins eye may be less than that of black carp, but they still pose a potential threat to this and other unionids.

Habitat Alteration (see Tasks under 1.2, 1.3, 1.4, 1.8, and 2.1 in the step-down outline)

Modifications to the Upper Mississippi River (UMR) for navigation began about 1878 when Congress authorized a 4 ½-foot navigation channel. Modifications consisted primarily of clearing and snagging, construction of wing and closing dams, and a canal to bypass the Des Moines rapids at Keokuk, Iowa. In 1907, a 6-foot channel was authorized, with construction of more wing and closing dams, dredging, bank revetment, and two locks at the Rock Island rapids, Illinois. In 1930, a 9-foot channel was authorized, including the construction of locks and dams; it was completed by 1940 (Crittenden 1980). These modifications have resulted in profound changes in the nature of the river, primarily replacing a free-flowing alluvial system with a stepped gradient river. Continual maintenance of the 9-foot channel requires dredging, wing and closing dam reconstruction and maintenance, and bank stabilization. The last major modification on the UMR occurred in 1995 when a second lock at Melvin Price Locks and Dam (Alton, Illinois) became operational, theoretically increasing the capacity of the lock and dam system to pass tow traffic upriver.

Although the immediate result of lock and dam construction was an increase in the volume of backwater lakes and sloughs, over time an equilibrium between flow and cross-section was restored by an increase in sedimentation rates in these new navigation pools. Substrate stability is of paramount importance in maintaining mussel populations (Vannote and Minshall 1982; Strayer 1983, 1993). Therefore, changes in substrate composition are likely to have important impacts on mussel communities. Siltation rates in pools 7, 8 and 9 have been estimated at approximately 0.7-2.9 cm/year (LePage *et al.* 1980). In addition, there has been an increase in sediment deposition in Lake Pepin (Pool 4) since the early 1900s, leading to a shift from a coarse gravel mixed with mud to one dominated by silt (Thiel 1981). Much of this sedimentation has taken place in backwaters, however, rather than in main channel and main channel border habitats where *L. higginsii* is typically found.

These changes have undoubtedly influenced, and continue to influence, mussel habitat. Fuller (1980), Havlik (1983), Hornbach *et al.* (1992) and Thiel (1981) have all shown that there has been a decline in the mussel species richness found in the Upper Mississippi River, compared to species richness found in pre-impoundment studies by Ellis (1931a,b). *L. higginsii* has apparently always been a relatively minor component of the mussel community (USFWS 1983). Therefore, a direct link between changes in the distribution and abundance of this species and habitat alteration is difficult to ascertain.

In 1987, the Corps of Engineers consulted with the Service on the effects of increased tow traffic on *L. higginsii* due to the proposed construction of the second lock at the Melvin Price Locks and Dam. The resulting biological opinion and incidental take statement required the Corps to conduct a baseline and navigation effects study of four mussel beds on the UMR (USFWS 1987). Miller *et al.* (1990) designed and initiated the study in 1988. They indicated that evidence of negative effects of commercial traffic on mussels and *L. higginsii* would be assessed using the following six parameters: 1) decrease in the density of five common-to-abundant species, 2) absence of *L. higginsii*, 3) decrease in live-to-recently-dead ratios for dominant species, 4) loss of more than 25 percent of the mussel species, 5) no evidence of recent recruitment and, 6) significant reduction in growth rates or increase in mortality. These constituted triggering mechanisms, any one of which would necessitate the reinitiation of consultation with the Corps of Engineers to assess the impacts of tow traffic on the species. The baseline phase of this study has been completed (Miller and Payne 1991, 1992, 1993, 1994, 1995a,1995b, 1996a, 1997) and is now in the monitoring phase. In the year 2004, the two agencies will meet and reevaluate the necessity of monitoring beyond that date.

Miller and Payne (1996a) noted that, at no time, could velocity changes from a single or multiple tow passage be considered damaging to benthic organisms or their habitat. Furthermore, they state that tow-induced changes in turbidity and suspended solids at mussel beds in the UMR were minor, of short duration and likely to have only minimal effects (Miller and Payne 1996a). Studies from 1990 to 1994 by Clarke and Loter (1995) on *L. higginsii* populations at Prairie du Chien, indicated that barge traffic did not damage mussels at any site and that no significant changes in the numbers of *L. higginsii* occurred at any sites. They also found that condition indices of a common species (*Amblema plicata*) did not change. Clarke and Loter (1995) did find some changes in the number of mussel species, increases at some sites and decreases at others, which they attributed to the Great Flood of 1993 and not to barge traffic. However, as tow traffic is projected to increase on the UMRS in future years, it is essential that monitoring of these potential effects be continued.

Much of the habitat alterations due to navigation since the late 1800s, including the 4-foot, 6-foot, and 9-foot channel projects, and operation and maintenance of the navigation system, have already occurred. The Corps, in cooperation with USFWS and other agencies, work to ensure that ongoing maintenance activities, such as dredging and disposal, are implemented to avoid *L. higginsii* habitat. Future habitat alterations associated with navigation and increasing tow traffic over the next 50 years, however, may adversely affect the species. These impacts are the subject of two ongoing consultations conducted under section 7(a)(2) of the Endangered Species Act

between the Service and the Corps of Engineers on the operation and maintenance of the 9-foot channel project (see above) and system-wide navigation improvements.

The Corps of Engineers indicated that, in their best professional judgement, a 220 percent increase in barge traffic in specific areas of the East channel at Prairie du Chien could result in up to a 20 percent reduction in the number of *L. higginsii* as a result of chronic perturbations over a 40-year period (U.S. Army Corps of Engineers 1993). Based on 10 years of studies in both the main and east channels at Prairie du Chien (Miller and Payne 1991, 1992, 1993, 1994, 1995a, 1995b, 1996a, 1997), there were no significant changes in populations. Intergenerational changes, however, could occur and 10 years is a small portion of the life span of many mussels. Tow traffic impacts should continue to be studied, particularly in main channel borders areas such as those at Prairie du Chien, Wisconsin, where tows move in close proximity to beds containing *L. higginsii*.

The types of activities currently affecting *L. higginsii* habitat on the UMR are primarily related to the development of land-based, water-oriented facilities such as barge loading and off-loading sites, small boat harbors, dredging of access channels, construction of highway bridges and the establishment of fleeting areas. These can have negative impacts to mussels. Dredging access channels directly eliminates habitat and, over time, may cause the slumping of adjacent areas into the channel, further reducing available habitat. The operation of small boats and larger vessels (*e.g.*, casino boats) in the vicinity of mussel beds can have impacts through the redistribution of sediment or accidental spills of fuel and other contaminants. Fleeting barges over mussel beds may directly crush or bury mussels. Pier construction for new highway bridges has taken place in or near mussel beds.

To adequately address these threats, Intermediate Goal 1D (limit construction in areas of essential *L. higginsii* habitat) must be met. In the event that impacts to *L. higginsii* cannot be avoided, they may be mitigated by the relocation of mussels before construction.

Water Quality (see Tasks under 1.5 and 2.3 in the step-down outline)

Water quality issues, including point and non-point contaminant and pollutant sources, and chronic and episodic events, have not been documented as presently having significant adverse impacts to *L. higginsii*. The lack of documented impacts may be a consequence of the lack of investigation as much as a lack of actual impacts. Contaminants and pollutants may have had a role in the presumed decline of the species; they may be presently affecting *L. higginsii* abundance, distribution, and health, and they may be rendering otherwise suitable potential reintroduction areas unfit for the species. Harm to *Lampsilis higginsii* has not been documented as a result of a single contaminant spill or other short-term contaminant episode, but such episodes have been strongly implicated in mussel die-offs elsewhere (Sheehan *et al.* 1989). The presumption must be that *L. higginsii* are as vulnerable to contaminant events as are other mussel species and accidental or unintended contaminant events that occurred elsewhere could also occur where *L. higginsii* is present.

This lack of information and documentation is itself the most significant water-quality related threat to *L. higginsii*. Undocumented harm may be occurring because of the limited availability of data assessing the significance of specific water and sediment quality parameters in relation to life cycle requirements of the species. Data gaps identified in the Water Quality section of this document include the unknown relative susceptibilities of the different life stages to contaminants, as well as the need for comparative data on the different modes of potential contaminant uptake (food sources, surface water, pore water, sediments). Related water quality information at areas designated as, or considered for, *L. higginsii* Essential Habitat Area can then be better evaluated to more effectively manage the recovery of the species. Additional information is also needed to improve laboratory culture and toxicity study requirements for freshwater mussels, thereby facilitating the documentation and use of toxicity data for *L. higginsii*.

Water quality parameters identified to potentially affect *L. higginsii* include un-ionized ammonia, select metals, and possibly some organic compounds. Although these contaminants may exist at varying concentrations throughout the UMR, the species' preferred habitat (coarser substrates in main channel and channel borders) generally would not contain toxic concentrations of these contaminants in finer substrates of depositional areas, thereby offsetting much of the potential threat. Consequently, environmental perturbations resulting from episodic events are probably the most likely water quality factors to affect the recovery of *L. higginsii*. Such events may include spills of oil or hazardous materials, seasonal-runoff or "flushing" of contaminants into river systems, and water development projects unintentionally releasing contaminants from previously deposited sediments. The relative immobility of mussels, combined with the potentially high toxicity associated with such releases, increases the significance of these types of threats to *L. higginsii*.

Both point source discharges and non-point-runoff represent continuing threats to the species. Without the referenced toxicity data, however, it is unknown what water quality criteria or guidelines for specific contaminant or pollutant levels are necessary to protect *L. higginsii* in areas influenced by permitted point-source discharges. Low flow river conditions may result in increased concentrations of contaminants and thus increase impacts to the species from compounds such as un-ionized ammonia associated with fine sediments.

Commercial Harvest (see Tasks under 1.7 in the step-down outline)

The commercial harvest of mussels in the Upper Mississippi River peaked during the pearl button period of the 1920s and later during the cultured pearl era in the late-1980s and early 1990s (Thiel and Fritz 1993). The five Upper Mississippi River States (Iowa, Illinois, Minnesota, Missouri and Wisconsin) have regulated mussel harvest since the latter portion of the pearl button era in the late 1930s (Waters 1980) and are continuing to revise the regulations to strive for uniformity among the states and to reflect present-day biological data and concerns.

No commercial harvest is presently allowed in the Wisconsin and St. Croix Rivers or at the Sylvan Slough refuge on the Mississippi River. There is concern, however, over potential illegal harvest in these areas. Officials indicate that mussel poaching in other areas of the U.S. is an increasing

problem (Luoma 1997). Gary Jagodzinski (USFWS, pers. comm.) has indicated that at least 100 cases of illegal take, record keeping and sales violations were made in Wisconsin during 1996 in the Mississippi River or other inland waters. Most violations were for record keeping violations or illegal take such as undersized or prohibited species. Increased enforcement activities at sites in the Wisconsin and St. Croix Rivers and at the Sylvan Slough refuge on the Mississippi River is recommended. In other Essential Habitat Areas, the recovery team recommends that harvest be eliminated.

There are few documented reports of commercial clammers taking *L. higginsii*, but impacts to associated species have been documented. Other than harvest activities such as brailing that may have influenced the entire mussel community, little is known regarding the direct impacts of commercial harvest on *L. higginsii.* Mathiak (1979), based on observations he made at a commercial clamming operation, concluded that hundreds of *L. higginsii* had probably been harvested in 1975 before the species was placed on the list of Threatened and Endangered Species. Although there may be little or no available data to support the contention that commercial clamming is specifically harmful to *L. higginsii* populations, it is reasonable to conclude that clamming could threaten the species in Essential Habitat Areas. Hart (1999), for example, found that commercial harvest depressed threeridge (*Amblema plicata*) populations in Lake Pepin in the early 1990's. He found that if harvest exceeded "5% of the population or if *D. polymorpha* infestations continue at the current rate" threeridge populations were in danger of local extinctions. Threeridge is one of four species that is common at all known *L. higginsii* sites (Heath 1995). Although it is distinct morphologically from *L. higginsii*, it is reasonable to assume that clammers in pursuit of *A. plicata* or other species would inadvertently collect or harm *L. higginsii*.

Conservation Measures

There were four recommendations for immediate action in the initial Higgins Eye Pearlymussel Recovery Plan. In this section we review the progress that has been made on these recommendations and other actions that have been taken to conserve the species.

The following were recommendations for immediate action:

1. Conduct ten-year field studies in Essential Habitat Areas (with initial emphasis on the Prairie du Chien site) to determine the status of each population and its habitat.

2. Develop relocation (translocation) techniques for Higgins Eye Pearlymussels.

3. Develop artificial propagation techniques. This should include a thorough literature review, development of methodology, testing of methodology on closely related, non-endangered species, propagation of Higgins Eye Pearlymussels, and determination of suitable stocking sites.

4. Develop uniform regulations concerning clam harvesting methods that would best manage and protect the resource. These regulations should be developed cooperatively by the states, the USFWS, and commercial clammers. Two specific items that should be included in the development of these regulations are:

a. Policies restricting dredging as a method of commercial harvesting clams on the Mississippi River, and

b. A study to determine the potential beneficial and/or detrimental effects of brailing on mussel beds, relative to other harvesting methods (such as diving), with subsequent appropriate regulation.

Ten-Year Field Studies in Essential Habitat Areas

There have been a number of studies of *L. higginsii* since the initial recovery plan was written (Table 6 - Cawley 1996 - see Section IV). Only studies by Miller and Payne (1991, 1992, 1993, 1994, 1995a, 1995b, 1996a, 1997) and Heath (1995, 2002) have chronicled the change in mussel communities over a ten-year period. Their work was conducted at the Prairie du Chien (Miller and Payne) and Orion (Heath) Essential Habitat Areas, respectively.

Development of Relocation (Translocation) Techniques

As stated by Waller *et al.* (1995), "State and Federal agencies are actively conducting ... relocation operations in an effort to preserve the remaining unionid fauna. Information of threshold and tolerance limits of different mussel species to collection and handling conditions is especially critical at this time for planning management and conservation activities for unionid mussels." Although they did not specifically examine *L. higginsii,* they conclude that with proper precautions, handling and exposure associated with relocation efforts should not cause significant levels of mortality in unionid mussels.

A number of relocations of *L. higginsii* have occurred since the initial recovery plan was developed. Before 2000 these relocations were usually associated with construction projects and were not designed to examine the effects of relocation methods on the mussels. However, one relocation project at the I-94 bridge over the St. Croix River included a monitoring program designed specifically to examine the effects of handling, placement methods, and buffer zones on the survivorship of relocated mussels (Dunn 1996a, 1996b).

Oblad (1980) discussed a relocation experiment with *L. higginsii* at Sylvan Slough, one of the Essential Habitat Area Sites designated in the initial Recovery Plan (Table 6 - see Section IV). Three *L. higginsii* were collected from mid-channel and were relocated nearby. A year following the relocation all three *L. higginsii* were recovered.

The US Highway 10 bridge over the St. Croix River near Prescott, Wisconsin, was replaced in 1988 and mussels were transplanted to a region upstream of the project (Heath 1989). Nearly

8000 mussels were transplanted including 42 *L. higginsii*. A large number of the mussels from this relocation died, including greater than 30 *L. higginsii*, possibly because the relocation took place when air and water temperatures were too low and because the mussels may have been harmed by a water surface oil sheen they were exposed to during the relocation effort (Paul Burke, USFWS, pers. comm.). However, when Hornbach *et al.* (1995), sampled the relocation bed in 1994, seven *L. higginsii* relocated in the 1988 project were found. Some of these specimens had experienced measurable growth, and all appeared to be in good condition.

The I-94 bridge over the St. Croix River at Hudson, Wisconsin, has been replaced. This project over the St. Croix River required the relocation of 9,042 mussels in 1994 (Dunn 1996a) and 14,043 mussels in 1995 (Dunn 1996b). A total of 43 *L. higginsii* were moved in 1994 and 36 were moved in 1995. A two-year monitoring program was developed for each year to (1) evaluate overall mussel survival, (2) growth and survival of endangered species, including *L. higginsii*, (3) handling methods, (4) placement methods, and (5) buffer zone size. At each relocation phase, mortality was assessed at one month, one year and two years after relocation. Results of two years of monitoring of the 1994 relocation yielded one dead *L. higginsii* and an average increase in shell length for 35 *L. higginsii* of 4.2 mm (Dunn 1996a). Results of one year of monitoring of the 1995 relocation also yielded only one dead *L. higginsii*; average shell length had increased 1.3 mm (Dunn 1996b). Results of monitoring the general population and experimental subsamples will be used to develop guidelines for future relocation projects.

In 1996, an *in-situ* relocation project was begun in the St. Croix River (D. Waller, pers. comm.). This project involves the refinement of protocols for relocating mussels to *in-situ* refugia from zebra mussels and to assess the suitability of potential refugia for mussels in the St. Croix River. One hundred *L. higginsii* mussels were relocated from the St. Croix River at Hudson, Wisconsin, upstream to a site near Franconia, Minnesota. Mussels will be monitored for a minimum of two years to evaluate growth and survival at the refugium site relative to those at the source site.

In 2000, state and federal agencies markedly increased their attempts to relocate *L. higginsii* to reduce their exposure to zebra mussels. As stated above, the USFWS issued a Biological Opinion to the Corps' on May 15, 2000 that required the Corps to (1) conduct a Higgins eye relocation feasibility analysis and (2) prepare a Higgins eye Pearlymussel Relocation Plan. As a result, the Corps drafted seven interim and long-term objectives to conserve Higgins eye associated with the continued operation and maintenance of a nine-foot navigation channel in the Upper Mississippi River. One of these objectives is to "Establish a minimum of five new and viable populations of Higgins eye in the UMRS and/or tributaries un-infested or with low level infestations of zebra mussels." Work toward this objective has resulted in several relocation attempts (Table 1) and additional attempts are likely to continue for several more years. Of the 63 *L. higginsii* recovered in 2002 at the Hidden Falls (Pool 2) and Hastings (Pool 3) adult relocation sites (59 females, 4 males), only one was found dead, although several had abnormal growth patterns exhibited by "exaggerated growth arrest lines and in-turning along the ventral margin of the shell" (Davis 2003). These mussels appear to have resumed normal growth patterns in 2003 (M. Davis, pers. comm. 2003).

Development of Artificial Propagation Techniques

The recent and severe infestation of the Upper Mississippi River and several tributaries by zebra mussels has significantly raised the importance of the development of artificial propagation techniques for the conservation of *L. higginsii*. Before 2000, workers had explored a variety of techniques for propagating this and other mussel species, including the use of artificial media. Since 2000, however, propagation has mostly focused on the artificial infestation and release of fish into areas where zebra mussels are not an imminent threat.

Waller and Kammer (1985) indicated that a surrogate for *L. higginsii* (*L. cardium*) could artificially infect largemouth bass and walleye. They compared the propagation of *L. higginsii* glochidia in an artificial medium with the use of infested fish in the laboratory (Holland-Bartels and Waller 1988). They were able to successfully transform glochidia with the artificial medium and by infesting fish. Waller and Kammer (1985) indicated that both techniques have potential use for the production of juvenile mussels. Welke *et al.* (2000) used similar techniques to artificially infest largemouth bass and walleye with *L. higginsii* glochidia. Results from the walleye treatment were confounded after an ectoparasitic infection resulted in total fish mortality, but some juvenile mussels successfully excysted from walleye gill tissue incubated in a separate water system and from largemouth bass. Further work on congeners of *L. higginsii* by Holland-Bartels and Zigler (1990) showed that nutritional requirements appeared to be a factor limiting successful laboratory culture of glochidia. They used a combined laboratory/field culture approach to bypass this area of difficulty by infesting fish in the laboratory and then stocking them in the field in floating cages just before metamorphosis. Gordon (2001, 2002) has found greater transformation success with centrarchids (*e.g.*, smallmouth bass) than with percids (walleye) at Genoa National Fish Hatchery. A number of other studies have examined artificial propagation techniques in other species of freshwater mussels (Watters 1994b; Beaty and Neves 1996; Gatenby *et al.* 1997; O'Beirn *et al.* 1998; and references therein).

As with adult translocation, artificial propagation of Higgins eye has increased greatly since the issuance of the Biological Opinion to the Corps in 2000 (see above). Biologists have collected gravid Higgins eye from several locations each year between 2000-2002, taken them to Genoa National Fish Hatchery (Hatchery), and infested fish using the methods described by Welke *et al.* (2000). In May 2002, workers infested 7466 fish (largemouth bass, smallmouth bass, and walleye) with Higgins eye glochidia at the Hatchery. A portion of the fish was retained at the Hatchery to refine techniques for producing juvenile Higgins eye, but most were kept in the Hatchery for about three weeks before being sent to release sites. At these sites, workers simply released the fish to swim freely or confined them in cages secured to the river bottom (Table 1). Cages facilitate monitoring of transformation success and, in some cases, are used to grow juvenile Higgins eye for release elsewhere (M. Davis, pers. comm. 2002). Fish are released from cages after glochidia have excysted.

Biologists have exhibited significant success in culturing Higgins eye since 2000. Juvenile Higgins eye (*i.e.*, less than < 30 mm) have been identified in or beneath several cages containing infested largemouth bass, smallmouth bass, and walleye and as of January 2004, there were several

thousand juvenile Higgins eye in cages awaiting release at reintroduction or augmentation sites. Confirmation of success (*i.e.*, transformation of glochidia to independent juveniles) or failure of the caged fish releases is not always possible and a few attempts were likely complete failures due to excessive sedimentation. There are no data yet to evaluate the success of the free-swimming fish releases.

Biologists involved in propagation of Higgins eye continue to refine propagation and release techniques (Gordon 2002). Pre-release mortality of infested fish has been significant (*e.g.*, >20%) in some cases and may be exacerbated by the stress of the mussel infestation process (Gordon 2002). Gordon (2002) counted the number of glochidia and number of juveniles that transformed from a subset of the fish that were inoculated in 2002. Number of glochidia per fish ranged from 146-283 and transformation to the independent juvenile stage in the Hatchery was 38-47%. Assuming that the percent transformation is similar in released fish, a cage of 100 infested fish may produce approximately 4000 juvenile Higgins eye. Attempts to support the transformation and initial growth of juveniles in the hatchery have been hampered by fish mortality, introduction of mussel predators into the culture facilities, and power failures (Gordon 2001, 2002). Nevertheless, approximately 8000 juvenile *L. higginsii* have been released in four separate events since 2000 and, as stated above, several thousand are now in cages in the St. Croix and Mississippi Rivers and available for reintroduction.

Development of Uniform Regulations Concerning Clam Harvesting Methods

Sparks and Blodgett (1983) conducted a study to examine the effects of three types of mussel harvest methods: crowfoot bar (brail), basket dredge and diver. They indicated that crowfoot bar and diving resulted in less dislodgement and damage than the basket dredge. Based on their work they supported Illinois' prohibition of basket dredges and recommended that hand dredges also be banned. They indicated that diving appeared to be the least harmful and most selective method for harvesting mussels and that the crowfoot bar should be retained as a legal device because it appeared to be fairly non-destructive and was safer than diving.

Thiel and Fritz (1993) have reviewed the history of mussel harvest and regulation in the UMR. They indicated that there has been significant improvement in the coordination among the states of the Upper Mississippi River regarding mussel harvest. The main results of the improved coordination are restricted seasons for harvest, size limits for harvest, and the requirement for permit or license in each state. Prime among these are restricted seasons for harvest in each state. Thiel and Fritz (1993) did not comment on the impact of improved harvest regulations on the viability of *L. higginsii* populations. They did indicate that harvest impact has been great on the washboard (*Megalonaias nervosa*), and that catch-per-unit-effort has declined since 1990, partially due to the increase in the minimum size limits for live washboards put in place in 1990. This decrease in catch-per-unit-effort has led to an increase in price. They also indicated that slow-growing washboard populations may no longer be able to keep up with the harvest pressure and concluded that there must be sound scientific management of this resource.

In 1996, the Upper Mississippi River Conservation Committee (UMRCC) Executive Board approved a set of proposed mussel regulations developed by the Fisheries Technical Section's *ad hoc* mussel committee (P. Thiel, pers. comm. 1996). The recommendations were crafted in cooperation with representatives of the Shell Exporters of America, Inc. The goals of the proposed regulation are to: 1) move toward standardizing mussel harvest regulations among the five UMRCC states, 2) close loopholes which make enforcement of existing regulations difficult, and 3) protect populations of species, such as washboard, *Megalonaias nervosa*, from overharvest, with a long-term purpose of sustained harvest of freshwater mussels in the Upper Mississippi River. The proposed regulations address eleven different topics, including season, gear, size limit, license fees, and reporting, and are being routed through each UMRCC member state's natural resource agency for consideration and potential rule-making.

Summary of Current State Mussel Harvest Regulations in the Range of Higgins Eye

Iowa – In Iowa holders of commercial mussel licenses, residents or nonresidents, may take mussels for sale from April 1 to August 31 in the Mississippi River and connected backwaters by hand, diving, or crowfoot bar. Iowa license holders may take six species of mussels: "three-ridge, mapleleaf, pimpleback, pigtoe, hickory nut, and pink heelsplitter." Although several species are commonly referred to as "pigtoe", only the Wabash pigtoe (*Fusconaia flava*) occurs in Iowa. Two species found in Iowa are referred to commonly as "pimpleback", *Quadrula nodulata* and *Q. pustulosa*. Hickory-nut (*Obovaria olivaria*) is similar in appearance to Higgins eye, whereas the other species that may be commercially taken in Iowa are noticeably different in appearance. Holders of sport fishing licenses may take mussels throughout the year in the Mississippi River and connected backwaters and may possess up to 24 whole mussels or 48 shell halves; mussels listed by Iowa as threatened or endangered may not be taken.

Illinois – In Illinois holders of commercial mussel licenses, residents or nonresidents, may take mussels for sale from April 1 to August 31 in the Mississippi River by hand, diving, or crowfoot bar. Illinois license holders may take only "threeridge, mapleleaf, pimpleback, monkeyface, wartyback, pigtoe, pocketbook, hickory nut, and pink heelsplitter." Although several species are commonly referred to as "pigtoe", only the Wabash pigtoe (*Fusconaia flava*) occurs in the Mississippi River in Illinois. Q. *nodulata* and *Q. pustulosa* are both referred to commonly as "wartyback" and "pimpleback." Of the species referred to commonly as "pocketbook" only the plain pocketbook (*Lampsilis cardium*) may be legally collected in Illinois; the fat pocketbook (*Potamilus capax*) is also called "pocketbook", but is listed as endangered by the Illinois Endangered Species Protection Board and under the federal Endangered Species Act. Both fat pocketbook and hickory-nut (*Obovaria olivaria*) are similar in appearance to Higgins eye, whereas the other species that may be commercially taken in Illinois are noticeably different in appearance. Illinois prohibits commercial mussel harvest in several sanctuaries. Only one includes an Essential Habitat Area identified in this plan -- the sanctuary that extends from RM 485.8 to RM 482.6 includes all but the upper 0.2 River Miles of the Sylvan Slough EHA (Fig. 11). The second EHA in Illinois identified in this plan at Cordova, IL is not protected as an Illinois mussel sanctuary. A portion of this EHA lies within Upper Mississippi National Fish and Wildlife Refuge waters (Fig. 10). All of Mark Twain National Fish and Wildlife Refuge waters

are protected as Illinois mussel sanctuaries, but Upper Mississippi National Fish and Wildlife Refuge waters are not.

Minnesota – In Minnesota, only residents possessing a valid angling license may apply for a commercial mussel permit. A person may not take, possess, buy, sell, or transport live mussels or more than 24 dead whole shells or 48 dead shell halves without a commercial mussel permit. Commercial permittees may take mussels for sale from May 16 through August 31 only by hand, with or without SCUBA. Harvest sites must be specified in the commercial permit application and in the permit. Only three-ridge mussels (*Amblema plicata*) greater than 3 inches in diameter at the narrowest point may be taken commercially. Additional species may be taken by special permit. Minnesota prohibits commercial mussel harvest within 1000' downstream of dams. A commercial permit can only be issued if it is first determined that harvest will not be detrimental to the species being harvested. If any of the state's twenty endangered or threatened species of mussels "…are found within the harvest site, all harvest operations must immediately stop." Persons possessing an angling license may take (by hand only) and possess up to 24 whole shells or 48 shell halves of dead mussels that are not endangered or threatened.

Wisconsin – In Wisconsin, holders of commercial mussel licenses may take mussels for sale from April 1 to August 31 in the Mississippi River and connected backwaters "by hand when you are diving or wading; or by using crow-foot bars." Only residents of Wisconsin may hold commercial clamming licenses. Three-ridge, mapleleaf, pimpleback, and pigtoe may be commercially harvested. Although several species are commonly referred to as "pigtoe", only the Wabash pigtoe and round pigtoe (*Pleurobema coccineum*) occur in Wisconsin. Two species found in Wisconsin are referred to commonly as "pimpleback", *Quadrula nodulata* and *Q. pustulosa*. None of these species are likely to be confused with Higgins eye. Wisconsin prohibits commercial mussel harvest in the St. Croix River, but allows "pearl hunting" and "personal clamming." on all public Wisconsin waters. For pearl hunting, it is legal to open mussels to hunt for pearls, but you may not open more than 50 pounds of mussels a day or sell or barter any pearls you find unless you hold a commercial clam shelter's license and comply with commercial clamming regulations. Under Wisconsin's clamming law, anyone who takes, possesses or transports 50 or fewer pounds of mussels a day and who does not sell or barter any clams is considered a non-commercial Clammers and does not need to obtain a license or permit. Under current rules, non-commercial clammers may take any clam species (except state-listed threatened or endangered species, including Higgins eye) of any size throughout the year in any waters of the state. Personal clammers may take clams by hand while wading or diving or by using up to three crowfoot bars, each measuring no more than 20 feet long. Only one boat may be used for brailing (collecting clams with a crowfoot bar).

St. Croix River National Scenic Riverway – Minnesota/Wisconsin – In addition to the state rules summarized above, the St. Croix River National Scenic Riverway (Riverway) in Minnesota and Wisconsin prohibits the gathering and use of all live and dead mussels and empty mussel shells. The Riverway includes the three Essential Habitat Areas at Franconia, MN, Hudson, WI, and Prescott, WI.

II. RECOVERY

Recovery Strategy

This revised recovery plan adopts the approach of the previous recovery plan for *L. higginsii* by focusing recovery on the conservation of the species at identified Essential Habitat Areas. In the 1983 recovery plan, Essential Habitat Areas were specific areas throughout the historical range of *L. higginsii* that supported dense and diverse mussel beds where *L. higginsii* was successfully reproducing. This revised recovery plan identifies three additional "Essential Habitat Areas" (EHA) (Orion, WI, Prescott, WI, and Interstate Park, MN/WI), but also outlines specific criteria for evaluating additional areas for this designation and for when any EHA would provide the basis for reclassification and delisting decisions. The plan recommends the development of a uniform protocol for collecting information on populations of *L. higginsii*. Use of this protocol will allow for ongoing evaluation of the list of Essential Habitat Areas and of progress towards recovery.

The highest priority recovery actions for *L. higginsii* are primarily intended to address the severe impacts and threats posed by zebra mussels. Of the ten Essential Habitat Areas designated in this revised plan, zebra mussels have had severe impacts on the mussel communities at Harpers Slough, Prairie du Chien, and Cordova and are imminent threats at the Prescott, and Hudson, WI areas. The Prairie du Chien Essential Habitat Area, for example, may have contained the largest population of *L. higginsii* before its severe infestation by zebra mussels, but Miller and Payne (2001) found nearly 10,000 zebra mussels/m^2 in this area in 2000.

The removal of zebra mussels in a manner and scale necessary to benefit *L. higginsii* is evidently not currently feasible. Therefore, the plan focuses on developing methods to prevent new infestations, monitoring zebra mussels at Essential Habitat Areas, and developing and implementing contingency plans to alleviate impacts to infested populations. Based on recent activities, the latter may consist largely of removing *L. higginsii* from areas where zebra mussels pose an imminent risk to the persistence of the population and releasing them into suitable habitats within their historical range where zebra mussels are not an imminent threat. Within the last two years, workers have removed 471 adult *L. higginsii* from areas near Cassville, WI and Cordova, IL on the Upper Mississippi River and relocated them into Pools 2 and 3 near Minneapolis, MN and Hastings, MN, respectively (Table 1). Cleaning fouled adults *in situ* and artificial propagation and release (Table 1) are also currently being implemented in an attempt to offset the effects of zebra mussels on the conservation of *L. higginsii.*

Although zebra mussels are currently the most important threat to *L. higginsii*, construction activities and environmental contaminants may also pose significant threats. Therefore, the Corps and other agencies must continue to assess and limit the potential impacts of their actions on the species. The plan also outlines tasks needed to improve our understanding of the potential importance that contaminants play in the conservation of *L. higginsii* and calls on the U.S. Coast Guard, Environmental Protection Agency, and other agencies, to take actions to minimize the potential impacts of toxic spills.

Interagency partnerships will be key to the recovery of *L. higginsii*. In addition to the USFWS, the Implementation Table identifies five other federal agencies and four states as being responsible for various aspects of the recovery of the species. The U.S. Army Corps of Engineers, for example, is called on to implement several of the tasks. The Corps' implementation of the 2000 Biological Opinion on continued operation and maintenance and operation of the 9-foot navigation channel has resulted in the formation of the Mussel Coordination Team (MCT). This MCT has assisted the Corps in the implementation of extensive relocation and reintroduction of *L. higginsii* since 2000 (Table 1). These activities, although necessary to avoid jeopardizing the species, are leading to the development and refinement of techniques for propagating *L. higginsii* and other mussel species.

Recovery Goals and Recovery Criteria

The goal of the recovery plan is the recovery of Higgins eye to levels where its protection under the Act is no longer necessary and it may be removed from the Federal list of Endangered and Threatened Wildlife (50 CFR 17.11). This plan also contains an intermediate goal of reclassifying the species from Endangered to Threatened.

Essential Habitat Areas

Essential Habitat Areas used to support the reclassification or delisting of *L. higginsii* (see below) must meet the following criteria.

1. *L. higginsii* constitute at least 0.25% of the mussel community and the mussel habitat appears to be stable and supports a dense and diverse mussel community; or,

2. *L. higginsii* are found, but constitute <0.25% of the community, the mussel habitat appears to be stable and supports a dense and diverse mussel community, and zebra mussel densities are $< 0.5/m^2$.

For each definition, "dense and diverse" mussel communities are those that:

- include a total mussel density of $> 10/m^2$ (Mississippi River) or $> 2/m^2$ (other rivers); and,
- contain at least 15 other mussel species, each at densities greater than 0.01 individual/m^2.

<u>Intermediate Goal (Reclassification of *Lampsilis higginsii* to Threatened Status)</u>

Criteria for Intermediate Goal (Goal 1: Reclassification)

1. *Lampsilis higginsii* may be considered for reclassification from Endangered to Threatened when at least five identified Essential Habitat Areas contain reproducing, self-sustaining populations of *L. higginsii* that are not threatened by zebra mussels. The five Essential

Habitat Areas must meet the above criteria and must include the Prairie du Chien Essential Habitat Area and at least one Essential Habitat Area each in the St. Croix River and in Mississippi River Pool 14.

a. *L. higginsii* populations will be considered to be "reproducing" if there is evidence that they include a sufficient number of strong juvenile year classes.[3]

b. Populations will be considered to be "self-sustaining" if they have maintained stable or increasing population densities for at least twenty years.[4] *L. higginsii* populations will be considered stable or increasing if:

i. total mussel density in each of the identified Essential Habitat Areas is stable or increasing for at least twenty years (significance level (α) ≤ 0.2 and power ≥ 0.9);

ii. and, in each of the identified Essential Habitat Areas *L. higginsii* comprises at least 0.25% of the mussel community in Mississippi River sites or, in other rivers, are consistently present throughout the twenty year period.

The Service will develop standardized sampling protocols (Task 1.2.1) to evaluate the status of populations relative to these criteria.

c. This criterion will be met if zebra mussels are not present in locations where they or their offspring are likely to adversely affect *L. higginsii* populations in any of the five identified Essential Habitat Areas. The Service will make this determination by evaluating zebra mussel densities in the source areas and identified Essential Habitat Areas, the distances between the zebra mussel populations and identified Essential Habitat Areas, water velocities, larval development times, and any other relevant information.

2. Complete the following tasks to determine if water quality criteria for the Final Goal (Delisting) are necessary to ensure the conservation of *L. higginsii* and, if so, to develop measurable water quality criteria for Goal 2.

a. Develop a freshwater mussel toxicity database for sediment and water quality parameters to define *L. higginsii* habitat quality goals. (7 sub-tasks)

b. Characterize specific sediment and water quality parameters in *L. higginsii* Essential Habitat Areas and reestablishment areas. (1 sub-task)

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[3] Task 1.2.2 details the questions that the Service must answer to determine the number of strong juvenile year classes sufficient to allow for stable or increasing populations of *L. higginsii*.

[4] For all analyses of trends use a significance level (α) ≤ 0.2 and power ≥ 0.9.

3. Harvest of freshwater mussels is prohibited by law or regulation in Essential Habitat Areas. This applies to all Essential Habitat Areas, not just the five identified for criterion 1.

Final Goal (Delisting)

1. Delisting *L. higginsii* requires that populations of *L. higginsii* in at least five Essential Habitat Areas are reproducing, self-sustaining, not threatened by zebra mussels, and are sufficiently secure to assure long-term viability of the species. The five Essential Habitat Areas must meet the above criteria and must include the Prairie du Chien Essential Habitat Area and at least one Essential Habitat Area each in the St. Croix River and in Mississippi River Pool 14. "Reproducing" and "self-sustaining" are defined above under the Intermediate Goal (Reclassification).

   Populations at the identified Essential Habitat Areas will be "sufficiently secure to assure long-term viability of the species" if each of the following four conditions is met:

   a. The Service can identify no activities that are likely to take place in the foreseeable future that will result in a change in the predominant substrate conditions within each identified Essential Habitat Area to shifting, unstable sands, silt, cobble, boulder, or artificial substrates (*e.g.*, concrete) to the extent that such changes would appreciably reduce the likelihood of conserving the Higgins eye population in the Essential Habitat Area.

   b. The Service can identify no activities that are likely to take place in the foreseeable future that will result in water quality characteristics (*e.g.*, harmful concentrations of un-ionized ammonia) in Essential Habitat Areas that have been shown to cause detrimental effects to *L. higginsii* or to sympatric or surrogate species to the extent that such effects would appreciably reduce the likelihood of conserving the Higgins eye population in the Essential Habitat Area.

   c. There is no indication that construction of barge loading or off-loading sites, boat harbors, highway bridges, or fleeting areas or dredging of access channels is likely to occur in the foreseeable future within the identified Essential Habitat Areas to the extent that such activities would appreciably reduce the likelihood of conserving the Higgins eye population in the Essential Habitat Area.

   d. Measures that provide for review of federally funded, permitted, or planned activities in or near *L. higginsii* habitat pursuant to the Fish and Wildlife Coordination Act and Clean Water Act are in place.

   e. This criterion will be met if zebra mussels are not present in locations where they or their offspring are likely to adversely affect *L. higginsii* populations in any of

the five identified Essential Habitat Areas. The Service will make this determination by evaluating zebra mussel densities in the source areas and identified Essential Habitat Areas, the distances between the zebra mussel populations and identified Essential Habitat Areas, water velocities, larval development times, and any other relevant information.

2. The use of double hull barges or other actions have alleviated the threat of spills to each of the identified Essential Habitat Areas.

3. *L. higginsii* habitat information and protective responses to conserve each of the identified Essential Habitat Areas have been incorporated into all applicable spill contingency planning efforts.

4. Water quality criteria may be added to the criteria for the Final Goal (Delisting) upon completion of the tasks referred to under the Criteria for the Intermediate Goal (Reclassification) (see 2a-b above and Tasks 1.5.1 and 1.5.2).

Narrative Outline for Recovery Activities

1 Preserve *L. higginsii* and its Essential Habitat Areas.

1.1 Assess and limit impact of the zebra mussel, *Dreissena polymorpha*, on *L. higginsii*.

1.1.1 Develop strategies to prevent zebra mussel infestation.

1.1.2 Monitor zebra mussel populations at Essential Habitat Areas that are currently infested.

1.1.3 Develop and implement a response plan for *L. higginsii* in Essential Habitat Areas.

1.2 Develop uniform protocols for collecting and maintaining information on *L. higginsii* populations.

1.2.1 Develop a uniform protocol for collecting information for populations of *L. higginsii*.

1.2.2 Answer the following three questions to facilitate the implementation of this recovery plan:

1. What would constitute sufficient evidence of a strong juvenile year class of *L. higginsii*?

2. What methods should be used to evaluate the strength of juvenile year classes of *L. higginsii*?

3. How many strong juvenile year classes should be detected to determine that reproduction is sufficient to allow for stable or growing populations of *L. higginsii*?

1.2.3 Develop a central database of information based on the protocol developed in task 1.2.1.

1.2.4 Develop and implement a long-term monitoring plan at Essential Habitat Areas.

1.3 Maintain a list and an ongoing evaluation of Essential Habitat Areas.

1.3.1 Evaluate the ten Essential Habitat Areas recommended in this plan based on the best available information.

Essential Habitat Areas are areas that are of utmost importance to the conservation of *L. higginsii*. Maintain an ongoing evaluation of each of the ten recommended Essential Habitat Areas based on the best available scientific information. Key factors to assess and monitor include native mussel density and diversity, the geographic extent of the Essential Habitat, and threats, such as zebra mussels.

1.3.2 Identify new Essential Habitat Areas.

In addition to the four specific areas discussed below, the Service and its partners will use the guidelines in this plan to assess other areas that may contain the features that indicate that they are of utmost importance for the conservation of Higgins eye.

1.3.2.1 Survey Pool 10 to determine whether additional Essential Habitat Areas may be identified in this pool.

1.3.2.2 Examine a site near river mile 454, Muscatine, Iowa, for inclusion as an Essential Habitat Area.

1.3.2.3 Examine a site near river mile 556.4, Bellevue, Iowa, for inclusion as an Essential Habitat Area.

1.3.2.4 Examine shallow shoreline habitats in Pool 14 to determine if these habitats may currently support significant unknown populations of *L. higginsii.*

1.3.3 Estimate population size in Essential Habitat Areas.

1.3.4 Estimate recruitment in Essential Habitat Areas.

1.3.5 Estimate the existing genetic variability of the populations in Essential Habitat Areas.

Conduct genetic studies on the populations of *L. higginsii* in Essential Habitat Areas to assess the number of populations needed to ensure the maintenance of the species' genetic diversity.

1.3.6 Maintain an up-to-date list of Essential Habitat Areas and the supporting data for each at the Service's Twin Cities Field Office and make this information, or a summary thereof, available through the internet.

1.4 Limit construction in areas of essential *L. higginsii* habitat. Mitigation, including translocation, may be an acceptable alternative in limited instances.

1.4.1 Determine the potential impact of construction projects on Essential Habitat Areas.

1.4.2 Determine alternatives to harmful construction practices.

Ensure that water development projects are designed and reviewed to minimize the potential for resuspension of contaminated sediments in the vicinities of *L. higginsii* Essential Habitat Areas.

1.4.3 Continue monitoring the impacts of commercial navigation activities on Essential Habitat Areas.

1.5 Continue to examine the relationship between water quality, especially contaminants, and *L. higginsii* populations in Essential Habitat Areas.

To most effectively address water quality threats discussed in this document, it is recommended that priority be given to filling data gaps identified under *Water Quality*. As *L. higginsii* toxicity data becomes more available, the relative degree of other water quality-related threats may be better evaluated. In summary, there is need to (1) obtain information on the water and sediment quality requirements of the various life history stages of *L. higginsii*, and (2) take concurrent actions to prevent acute and chronic point and non-point source contamination that is reasonably presumed harmful to the species.

1.5.1 Develop a freshwater mussel toxicity database for sediment and water quality parameters to define *L. higginsii* habitat quality goals.

1.5.1.1 Identify suitable surrogate species for *L. higginsii* for use in laboratory toxicity tests.

1.5.1.2 Determine necessary handling protocols and culturing requirements of each life history stage to be tested.

1.5.1.3 Document existing toxicity data (including test type) available for the species and/or its surrogates.

1.5.1.4 Identify inorganic and organic contaminant compounds and mixtures present in *L. higginsii* Essential Habitat Areas. Use these data to determine realistic ranges of environmental concentrations for use in laboratory exposures.

Report pH, temperature, and hardness associated with data collected in *L. higginsii* Essential Habitat Areas to allow for a robust comparison to existing or proposed water quality criteria.

1.5.1.5 Design and complete acute and chronic laboratory toxicity tests based on Tasks 1.5.1.1 through 1.5.1.4. Include glochidium, juvenile, and adult life stages.

Determine effects of organic and inorganic environmental contaminants identified under 1.5.1.4.

1.5.1.6 Document the exposure pathways and various modes of contaminant uptake for *L. higginsii* (or suitable surrogate species), emphasizing the relative significance of uptake from food sources, surface water, pore water, and sediments.

1.5.1.7 Determine the biological effects and significance of contaminant residues documented in mussel tissues.

1.5.2 Characterize specific sediment and water quality parameters in *L. higginsii* Essential Habitat Areas and reestablishment areas.

1.5.2.1 Collect sediment and pore water from areas identified as currently supporting viable *L. higginsii* populations and proposed reestablishment areas; analyze for a range of organic and inorganic contaminants.

This is especially important in the Sylvan Slough area of Upper Mississippi River Pool 15, where the potential for PCBs in sediments to adversely affect benthic biota has been identified. Report pH, temperature, and hardness for water collected in Essential Habitat Areas and reestablishment areas to allow for a robust comparison to existing or proposed water quality criteria. This assessment may include endocrine disrupters.

1.5.2.2 Develop and implement water quality criteria that would conserve Higgins eye; these criteria should be directly or indirectly protective of sediment and pore water quality, as necessary to conserve Higgins eye.

1.5.3 Promote best management practices in the watersheds of *L. higginsii* Essential Habitat Areas and relocation areas to minimize potential non-point source impacts.

Water quality threats to *L. higginsii* and to future reintroduction efforts may be reduced by ensuring that water development projects minimize re-suspension of contaminated sediments in vicinities of *L. higginsii* Essential Habitat Areas and potential reestablishment areas. Best management practices (erosion control, cropping systems, livestock waste management, etc.) recommended and approved by the U.S. Department of Agriculture and the U.S. Environmental Protection Agency should continue to be encouraged in the watersheds of Essential Habitat Areas to minimize potential run-off impacts to the species.

1.5.3.1 Coordinate with local land use planning and technical assistance offices to increase awareness and need to protect water quality in *L. higginsii* Essential Habitat Areas and relocation areas.

1.6 Develop plans to enhance the safety of shipping toxic or hazardous materials, reduce the introduction of these materials near *L. higginsii* habitat, and develop response plans for any spills that may occur.

1.6.1 Promote the use of double hull barges.

1.6.2 Incorporate *L. higginsii* habitat information into applicable spill contingency planning efforts; identify protective response actions available.

1.6.2.1 Coordinate with state and Federal natural resource trustees responsible for spill planning and response. Identify *L. higginsii* water quality requirements and Essential Habitat Area information, as well as applicable facility, local, state, Federal, and area spill contingency planning efforts.

1.6.2.2 Identify potential response actions that may prevent or minimize impacts to *L. higginsii* (including habitat) in the event of a spill of oil or hazardous materials. Incorporate into applicable response plans as necessary.

1.6.2.3 Identify potential *L. higginsii* habitat restoration and compensation measures that state and Federal natural resource trustees may consider under Natural Resource Damage Assessment responsibilities in the event of a spill of oil or hazardous materials. Incorporate into applicable response plans as necessary.

1.7 Review current regulations of mussel harvest in the upper Mississippi River drainage and develop additional regulations to reduce impacts on *L. higginsii.*

1.7.1 Develop regulations to prevent mussel harvest in Essential Habitat Areas.

1.7.2 Review existing harvest regulations and make recommendations to the USFWS and the States on any regulations needed outside of Essential Habitat Areas.

1.7.3 Enhance enforcement of existing harvest regulations.

1.8 Continue to develop materials to inform the public on the nature of endangered mussels and *L. higginsii*, in particular.

1.8.1 Educate commercial navigation industry, commercial mussel harvesters, and state transportation agencies on the nature of endangered mussels.

2 Enhance the abundance and viability of *L. higginsii* in areas where it currently exists and restore populations within historic range.

2.1 Identify and rank potential sites of existing *L. higginsii* populations for enhancement.

2.1.1 Estimate the population size in non-Essential Habitat Areas.

2.1.2 Estimate recruitment in non-Essential Habitat Areas.

2.1.3 Estimate the genetic variability of the populations in non-Essential Habitat Areas.

2.2 Increase the number of *L. higginsii* at enhancement sites to current levels found in Essential Habitat Areas or to numbers appropriate for the local habitat.

2.2.1 Determine the best method to increase population size.

2.2.2 Utilize the best method to increase population size.

2.2.3 Assess the efficacy of the method used.

2.3 **Determine the feasibility of reestablishing *L. higginsii* into historic habitats, particularly streams that are at lower risk for zebra mussel colonization.**

2.3.1 **Rank historic habitats for the likelihood of zebra mussel colonization.**

2.3.2 **Examine habitat suitability and fish assemblage for reintroduction.**

Sediment and water quality should be characterized in areas designated for reestablishment; comparisons to sediment and water quality parameters in existing *L. higginsii* habitat should provide at least a partial indication of habitat integrity.

2.3.3 **Develop a reintroduction/augmentation plan and utilize best method(s) of reintroduction**

2.4 **Examine the taxonomic validity of *L. higginsii* especially since *L. abrupt* is found in noncontiguous geographic areas.**

2.4.1 **Examine the morphological, conchological and genetic differences between *L. higginsii* and *L. abrupt*.**

3 **Update, revise, or add to the plan to keep it current and useful.**

Follow USFWS procedures to keep the plan current and useful and to determine whether an update, revision, or addendum is most appropriate.

4 **Develop a plan to monitor *L. higginsii* after it is removed from the list of Endangered Species.**

The Endangered Species Act (4)(g)(1) requires the Service to "...implement a system in cooperation with the States to monitor effectively for not less than five years the status of all species which have recovered to the point at which the measures provided pursuant to this Act are no longer necessary." The Service should begin working on this plan when it determines that the species has met its recovery criteria and its protection under the Act is no longer required and should consider monitoring for at least ten years.

III. IMPLEMENTATION SCHEDULE

The following Implementation Schedule outlines actions and estimated costs for the recovery program. It is a guide for meeting the objective discussed in Part II of this Plan. This schedule indicates task priorities, task numbers, task descriptions, duration of tasks, recovery partners, and estimated costs. These actions, when accomplished, should lead to the recovery of the species and protect its essential habitat. The estimated funding needs for all parties anticipated to be involved in recovery are identified. Part III reflects the estimated costs for the first three years of the recovery program for this species. Costs for year 4 and beyond will be determined approximately every three years by the USFWS and cooperating agencies. When delisting occurs due to recovery of the species, a minimum of five years of monitoring is required by the Act to assess the adequacy of recovery actions and determine if there will be cause to consider relisting. Because of special concerns with the biology of *Lampsilis higginsii*, a minimum of ten years of monitoring is necessary for this species.

Tasks in the first column of the following Implementation Schedule are assigned priorities as follows:

Priority 1: An action that ***must*** be taken to prevent extinction or to prevent the species from declining irreversibly in the ***foreseeable*** future.

Priority 2: An action that must be taken to prevent a significant decline in species population/habitat quality or some other significant negative impact short of extinction.

Priority 3: All other actions necessary to meet the recovery objectives.

Acronyms used in the Implementation Schedule:

	Recovery Partner -- USFWS Program
ES-TE	U.S. Fish and Wildlife Service, Division of Ecological Services, Threatened and Endangered Species Program
ES-EQ	U.S. Fish and Wildlife Service, Division of Ecological Services, Environmental Quality Program
ES-HC	U.S. Fish and Wildlife Service, Division of Ecological Services, Habitat Conservation Program
F	U.S. Fish and Wildlife Service, Division of Fisheries
RW	U.S. Fish and Wildlife Service, Division of Refuges and Wildlife
EA	U.S. Fish and Wildlife Service, Division of External Affairs
LE	U.S. Fish and Wildlife Service, Division of Law Enforcement
Partners	U.S. Fish and Wildlife Service, Partners for Fish and Wildlife Program

	Recovery Partner -- Other Federal Agencies and States
ACOE	U.S. Army Corps of Engineers
USCG	U.S. Coast Guard
USDA	U.S. Department of Agriculture
EPA	U.S. Environmental Protection Agency
BRD	U.S. Geological Survey, Biological Resources Division
WRD	U.S. Geological Survey, Water Resources Division
NPS	National Park Service
States	Minnesota Department of Natural Resources, Division of Ecological Services
	Wisconsin Department of Natural Resources, Bureau of Endangered Resources
	Iowa Department of Natural Resources, Division of State Parks, Recreation and Preserves
	Illinois Department of Natural Resources, Division of Natural Heritage
	Missouri Department of Conservation

Task Nos.	Task Priority	Task Description	Duration (Years)	Recovery Partner		Cost Estimate $ X 1000			Comments
				USFWS Program	Other	Year 1	Year 2	Year 3	
1.1. Assess and limit the impact of the zebra mussel, *Dreissena polymorpha*, on *L. higginsii*.									
1.1.1	1	Develop strategies to prevent zebra mussel infestation.	2	ES-TE	ACOE States BRD	50	50	---	
1.1.2	1	Monitor zebra mussel populations at Essential Habitat Areas that are currently infested.	Ongoing	ES-TE	ACOE States BRD	20	20	20	
1.1.3	1	Develop and implement a response plan for *L. higginsii* in Essential Habitat Areas.	Ongoing	ES-TE	ACOE States BRD	30	50	50	year 2 and 3 cost only if plan is implemented
1.2. Develop uniform protocols for collecting and maintaining information on *L. higginsii* populations.									
1.2.1	2	Develop a uniform protocol for collecting information for populations of *L. higginsii*.	1	ES-TE	ACOE States BRD	50	---	---	

Task Nos.	Task Priority	Task Description	Duration (Years)	Recovery Partner		Cost Estimate $ X 1000			Comments
				USFWS Program	Other	Year 1	Year 2	Year 3	
1.2.2	2	Answer the following three questions to facilitate the implementation of this recovery plan: What would constitute sufficient evidence of a strong juvenile year class of *L. higginsii*? What methods should be used to evaluate the strength of juvenile year classes of *L. higginsii*? How many strong juvenile year classes should be detected to determine that reproduction is sufficient to allow for stable or growing populations of *L. higginsii*?	3	ES-TE	States BRD	10	10	10	
1.2.3	2	Develop a central database of information based on the protocol developed in task 1.2.1.	1	ES-TE	ACOE States BRD	---	50	---	
1.2.4	2	Develop and implement a long-term monitoring plan at Essential Habitat Areas.	Cont.	ES-TE	States ACOE	100	100	100	

Task Nos.	Task Priority	Task Description	Duration (Years)	Recovery Partner		Cost Estimate $ X 1000			Comments
				USFWS Program	Other	Year 1	Year 2	Year 3	
1.3. Maintain a list and an ongoing evaluation of Essential Habitat Areas.									
1.3.1	2	Evaluate the ten Essential Habitat Areas recommended in this plan based on the best available scientific information.	3	ES-TE	States BRD ACOE	100	100	100	
1.3.2	2	Identify new Essential Habitat Areas.	3	ES-TE	States BRD ACOE	100	100	100	
1.3.2.1	2	Survey Pool 10 to determine whether additional Essential Habitat Areas may be identified in this pool.	3	ES-TE	States BRD ACOE	20	20	20	
1.3.2.2	3	Examine a site near river mile 454, Muscatine, IA, for inclusion as an Essential Habitat Area.	1	ES-TE	States BRD	10	---	---	
1.3.2.3	3	Examine a site near river mile 556.4, Bellevue, IA, for inclusion as an Essential Habitat Area.	1	ES-TE	States BRD ACOE	10	---	---	
1.3.2.4	3	Examine shallow shoreline habitats in Pool 14 to determine if these habitats may currently support significant unknown populations of *L. higginsii*.	1	ES-TE	States BRD ACOE	---	10	---	

Task Nos.	Task Priority	Task Description	Duration (Years)	Recovery Partner		Cost Estimate $ X 1000			Comments
				USFWS Program	Other	Year 1	Year 2	Year 3	
1.3.3	2	Estimate population size in Essential Habitat Areas.	Cont.	ES-TE	States BRD	TBD[5]	TBD	TBD	
1.3.4	2	Estimate recruitment in Essential Habitat Areas.	Cont.	ES-TE	States BRD	TBD	TBD	TBD	
1.3.5	3	Estimate the existing genetic variability of the populations in Essential Habitat Areas.	3	ES-TE	States BRD	50	50	50	
1.3.6	2	Maintain an up-to-date list of Essential Habitat Areas and the supporting data for each at the Service's Twin Cities Field Office and make this information, or a summary thereof, available through the internet.	3	ES-TE		-	-	-	
1.4. Limit construction in areas of essential *L. higginsii* habitat. Mitigation, including translocation may be an acceptable alternative in limited instances.									
1.4.1	3	Determine the potential impact of construction projects on Essential Habitat Areas.	Ongoing & cont.	ES-HC	ACOE	TBD	TBD	TBD	
1.4.2	3	Determine alternatives to harmful construction practices.	Ongoing & cont.	ES-HC	ACOE	TBD	TBD	TBD	

[5]To be determined. The Recovery Team was not able to estimate the costs of these tasks.

Task Nos.	Task Priority	Task Description	Duration (Years)	Recovery Partner		Cost Estimate $ X 1000			Comments
				USFWS Program	Other	Year 1	Year 2	Year 3	
1.4.3	3	Continue monitoring the impacts of commercial navigation activities on Essential Habitat Areas.	Ongoing & cont.	ES-HC	ACOE	50	50	50	
1.5. Continue to examine the relationship between water quality, especially contaminants, and *L. higginsii* populations in Essential Habitat Areas.									
1.5.1	3	Develop a freshwater mussel toxicity database for sediment and water quality parameters to help define *L. higginsii* habitat quality goals.	---	ES-EQ F	BRD WRD EPA ACOE	---	---	---	Reference specific tasks for total 1.5.1 cost estimates and duration
1.5.1.1	3	Identify suitable surrogate species for *L. higginsii* for use in laboratory toxicity tests.	3	ES-EQ	EPA BRD	75	75	50	
1.5.1.2	3	Determine necessary handling protocols and culturing requirements of each life history stage to be tested.	3	F ES-TE	BRD EPA	50	50	50	
1.5.1.3	3	Document existing toxicity data (including test type) available for the species and/or its surrogates.	3	ES-EQ	BRD EPA	40	40	0	
1.5.1.4	3	Identify inorganic and organic contaminant compounds and mixtures present in *L. higginsii* Essential Habitat Areas. Use these data to determine realistic ranges of environmental concentrations for use in laboratory exposures.	3	ES-EQ	BRD EPA	75	75	40	

Task Nos.	Task Priority	Task Description	Duration (Years)	Recovery Partner		Cost Estimate $ X 1000			Comments
				USFWS Program	Other	Year 1	Year 2	Year 3	
1.5.1.5	3	Design and complete acute and chronic laboratory toxicity tests based on Tasks Task 1.5.1.1 through Task 1.5.1.4. Include glochidium, juvenile, and adult life stages.	3	ES-EQ	BRD EPA ACOE	75	75	50	
1.5.1.6	3	Document the various modes of contaminant uptake for *L. higginsii* (or suitable surrogate species), emphasizing the relative significance of uptake from food sources, surface water, pore water, and sediments.	3	ES-EQ	BRD WRD EPA	100	100	50	
1.5.1.7	3	Determine the biological effect and significance of contaminant residues documented in mussel tissues.	3	ES-EQ	BRD WRD EPA	150	150	100	
1.5.2	3	Characterize specific sediment and water quality parameters in *L. higginsii* Essential Habitat Areas and reestablishment areas.	---	ES-EQ	BRD WRD EPA ACOE	---	---	---	Reference task 1.5.2.1 for 1.5.2 cost estimates and duration
1.5.2.1	3	Collect sediment and pore water from areas identified as currently supporting viable *L. higginsii* populations and proposed reestablishment areas; analyze for a range of organic and inorganic contaminants.	3	ES-EQ	BRD WRD EPA ACOE	150	150	100	

Task Nos.	Task Priority	Task Description	Duration (Years)	Recovery Partner		Cost Estimate $ X 1000			Comments
				USFWS Program	Other	Year 1	Year 2	Year 3	
1.5.2.2	3	Develop and implement water quality criteria that would conserve Higgins eye; these criteria should be directly or indirectly protective of sediment and pore water quality, as necessary to conserve Higgins eye.	3	ES-EQ	BRD EPA States	10	10	10	
1.5.3	3	Promote best management practices in the watersheds of *L. higginsii* Essential Habitat Areas and relocation areas to minimize potential non-point source impacts.	Cont.	ES-EQ ES-TE RW Partners	States EPA USDA NPS	---	---	---	Reference 1.5.3.1 for 1.5.3 cost estimate
1.5.3.1	3	Coordinate with local land use planning and technical assistance offices to increase awareness and need to protect water quality in *L. higginsii* Essential Habitat Areas and relocation areas	Cont.	ES-EQ ES-TE RW Partners	States EPA USDA NPS	30	30	30	

Task Nos.	Task Priority	Task Description	Duration (Years)	Recovery Partner		Cost Estimate $ X 1000			Comments
				USFWS Program	Other	Year 1	Year 2	Year 3	
1.6. Develop plans to enhance the safety of shipping toxic or hazardous materials, reduce the introduction of these materials near *L. higginsii* habitat, and develop response plans for any spills that may occur.									
1.6.1	2	Promote the use of double hull barges.	Ongoing	ES-TE	USCG	---	---	---	
1.6.2	3	Incorporate *L. higginsii* habitat information into applicable spill contingency planning efforts; identify protective response actions available.	On-going	ES-EQ ES-TE F RW LE	USCG EPA States NPS	---	---	---	Reference tasks 1.6.2.1, 1.6.2.2, and 1.6.2.3 for 1.6.2 cost estimate.
1.6.2.1	3	Coordinate with state and Federal natural resource trustees responsible for spill planning and response. Identify *L. higginsii* water quality requirements and Essential Habitat Area information, as well as applicable facility, local, state, Federal, and area spill contingency planning efforts.	On-going	ES-EQ ES-TE F RW LE	USCG EPA States NPS	10	10	10	
1.6.2.2	3	Identify potential response actions that may prevent or minimize impacts to *L. higginsii* (including habitat) in the event of a spill of oil or hazardous materials. Incorporate into applicable response plans as necessary.	On-going	ES-EQ ES-TE F RW LE	USCG EPA States NPS	10	10	10	

Task Nos.	Task Priority	Task Description	Duration (Years)	Recovery Partner		Cost Estimate $ X 1000			Comments
				USFWS Program	Other	Year 1	Year 2	Year 3	
1.6.2.3	3	Identify potential *L. higginsii* habitat restoration and compensation measures that state and Federal natural resource trustees may consider under Natural Resource Damage Assessment responsibilities in the event of a spill of oil or hazardous materials. Incorporate into applicable response plans as necessary.	On-going	ES-TE ES-EQ F RW LE	States NPS	20	20	20	
1.7. Review current regulations and develop additional regulation of mussel harvest in the upper Mississippi River drainage to reduce impacts on *L. higginsii*.									
1.7.1	2	Develop regulations to prevent mussel harvest in Essential Habitat Areas.	1	ES-TE	States	---	---	---	
1.7.2	3	Review existing harvest regulations and make recommendations to the USFWS and the States on any regulations needed outside of Essential Habitat Areas.	1	ES-TE	States	---	---	---	
1.7.3	2	Enhance enforcement of existing regulations.	Cont.	LE	States	---	---	---	
1.8. Continue to develop materials to educate the public on the nature of endangered mussels and *L. higginsii*, in particular.									
1.8.1	3	Educate commercial navigation industry, commercial mussel harvesters, and state transportation agencies on the nature of endangered mussels.	On-going	ES-TE PA	ACOE States	10	---	---	

Task Nos.	Task Priority	Task Description	Duration (Years)	Recovery Partner		Cost Estimate $ X 1000			Comments
				USFWS Program	Other	Year 1	Year 2	Year 3	
2.1. Identify and rank potential sites of existing *L. higginsii* populations for enhancement.									
2.1.1	3	Estimate the population size in non-Essential Habitat Areas.	3	ES-TE	BRD States	100	100	100	Combined with 2.1.2
2.1.2	3	Estimate recruitment in non-Essential Habitat Areas.	3	ES-TE	BRD States	See 2.1.1	---	---	Combined with 2.1.1
2.1.3	3	Estimate the genetic variability of the populations in non-Essential Habitat Areas.	3	ES-TE	BRD States	70	70	50	In con-junction with 2.1.1
2.2. Increase the number of *L. higginsii* at enhancement sites to current levels found in Essential Habitat Areas or to numbers appropriate for the local habitat.									
2.2.1	3	Determine the best method to increase population size.	2	ES-TE	BRD States	50	50	---	
2.2.2	3	Utilize the best method to increase population size.	2	ES-TE	BRD States	---	100	100	
2.2.3	3	Assess the efficacy of the method used.	2	ES-TE	BRD States	---	---	---	

Task Nos.	Task Priority	Task Description	Duration (Years)	Recovery Partner		Cost Estimate $ X 1000			Comments
				USFWS Program	Other	Year 1	Year 2	Year 3	
2.3. Determine the feasibility of reestablishing *L. higginsii* into historic habitats, particularly streams that are at lower risk for zebra mussel colonization.									
2.3.1	2	Rank historic habitats for the likelihood of zebra mussel colonization.	Ongoing	ES-TE	BRD States	---	---	---	Combine with 2.3.2
2.3.2	2	Examine habitat suitability and fish assemblage for reintroduction.	Ongoing	ES-TE	BRD States	100	100	100	Combine with 2.3.1
2.3.3	2	Develop a reintroduction/augmentation plan and utilize best method(s) of reintroduction	Ongoing	ES-TE	BRD State	300	300	300	
2.4. Examine the taxonomic validity of *L. higginsii* especially since *L. abrupt* is found in noncontiguous geographic areas.									
2.4.1	3	Examine the morphological, conchological and genetic differences between *L. higginsii* and *L. abrupt*.	1	ES-TE	BRD States	---	---	25	
3	**3**	**Update, revise, or add to the plan to keep it current and useful.**	**Ongoing**	**ES-TE**		**---**	**---**	**---**	**No specific costs anticipated Years 1-3**
4	**3**	**Develop a plan to monitor *L. higginsii* after it is removed from the list of Endangered Species.**	**2**	**ES-TE**		**---**	**---**	**---**	**No costs anticipated Years 1-3**

LITERATURE CITED

Aldridge, D.W., Payne, B.S., Miller. 1987. The effects of intermittent exposure to suspended solids and turbulence on three species of freshwater mussels. Environmental Pollution 45:17-28.

Apgar, A.C. 1887. The muskrat and the *Unio*. Journal of the Trenton Natural History Society. 1:58-59.

Arthur, J.W., W.W. Corlis, K.N. Allen, and S.F. Hedtke. 1987. Seasonal toxicity of ammonia to five fish and nine invertebrate species. Bulletin of Environmental Contamination and Toxicology 38:324-331.

Augspurger, T., A. E. Keller, M. C. Black, W. G. Cope, and F. J. Dwyer. 2003. Water quality guidance for protection of freshwater mussels (Unionidae) from ammonia exposure. Environmental Toxicology and Chemistry 22:2569-2575.

Baker, F.C. 1928. The fresh water Mollusca of Wisconsin. Part II. Pelecypoda. Bulletin of the Wisconsin Geological and Natural History Survey, No. 70. 495 p.

Bartsch, M. R., T. J. Newton, J. W. Allran, J. A. O'Donnell, and W. B. Richardson. 2003. Effects of pore-water ammonia on in situ survival and growth of juvenile mussels (*Lampsilis cardium*) in the St. Croix Riverway, Wisconsin, USA. Environmental Toxicology and Chemistry 22:2561-2568.

Beaty, B. B., and R. J. Neves. 1996. Factors influencing the growth and survival of juvenile Villosa iris (Bivalvia: Unionidae) in an artificial stream system. Journal of Shellfish Research 15(2):483-484.

Berg, D.J., W.R. Hoeh, and S.I. Guttman. 1997. Alternate models of genetic structure in unionid populations: conservation and management implications. In: National Shellfisheries Association Program and Abstracts of the 89th Annual Meeting. p 22-23.

Blodgett, K.D., and R.E. Sparks. 1987a. Documentation of a mussel die-off in pools 14 and 15 of the upper Mississippi River. In: Neves, R.J., editor. Proceedings of the workshop on die-offs of freshwater mussels in the United States. Upper Mississippi River Conservation Committee, Rock Island, Illinois. p. 76-90.

_____. 1987b. A summary of freshwater mussel sampling in Mississippi River pool 15 during June 1987. Natural History Survey and the Illinois Department of Conservation. Aquatic Biology Technical Report 87/16.

Bossenbroek, J. M., J. C. Nekola, and C. E. Kraft. 2001. Prediction of long-distance dispersal using gravity models: zebra mussel invasion of inland lakes. Ecological Applications 11:1778-1788.

Borcherding, J., and E.D. De Ruyter Van Steveninck. 1992. Abundance and growth of *Dreissena polymorpha* larvae in the water column of the River Rhine during downstream transportation. In: D. Neumann and H.A. Jenner, editors. The zebra mussel *Dreissena*. Symposium on Ecology and Biomonitoring. Gustav Fischer Verlag, Stuttgart, New York. p. 29-44.

Boyer, H. A. 1984. Trace elements in the water, sediments, and fish of the Upper Mississippi River, Twin Cities Metropolitan Area. Pages 195-230 in J. G. Wiener, R. V. Anderson, and D. R. McConville, editors. Contaminants in the Upper Mississippi River. Butterworth Publishers, Boston, Massachusetts.

Burky, A.J. 1983. Physiological ecology of freshwater bivalves. In: Russell-Hunter, W.D., editor. The Mollusca, Vol. 6. Ecology. Academic Press, New York. p. 281-327.

Caraco, N.F., J.J. Cole, P.A. Raymond, D.L. Strayer, M.L. Pace, S.G. Findlay, and D.T. Fischer. 1997. Zebra mussel invasion in a large turbid river: phytoplankton response to increased grazing. Ecology 78:588-602.

Carlton, J.T. 1993. Dispersal mechanisms of the zebra mussel (*Dreissena polymorpha*). In: Nalepa, T.F. and D.W. Schlosser, editors. Zebra mussels: biology, impacts, and control. Lewis Publishers, Boca Raton, Florida. p. 677-697.

Cawley, E.T. 1989. A survey of unionid mussel populations of the Sylvan Slough mussel sanctuary, Pool 15, upper Mississippi River. Environmental Research Center, Loras College, Dubuque, Iowa. 32 p.

______. 1996. A compendium of reports of mussel studies containing *Lampsilis higginsii* from the period 1980-1996. Report for the Higgins Eye Recovery Team - Fish and Wildlife Service. Environmental Research Center - Loras College, Dubuque, Iowa. 84 p.

Cherry, D. S., J. H. Van Hassel, J. L. Farris, D. J. Soucek, and R. J. Neves. 2002. Site-Specific Derivation of the Acute Copper Criteria for the Clinch River, Virginia. Human and Ecological Risk Assessment 8:591-601.

Chick, J.H., R.J. Maher, B.M. Burr and M.R. Thomas. 2003. First black carp captured in U.S. Science 300:1876-1877.

Clarke, A.H., Jr., and C.O. Berg. 1959. The freshwater mussels of central New York with an illustrated key to the species of northeastern North America. Cornell University Agricultural Experiment Station Memoirs 367:1-79.

_____. 1992. Ontario's Sydenham River, an important refugium for native freshwater mussels against competition from the zebra mussel *Dreissena polymorpha*. Malacology Data Net 3:43-55.

Clarke, A.H., Jr., and J.C. Loter. 1992. The nineteen ninety-one mussel monitoring program in the east branch of the Mississippi River at Prairie du Chien, Wisconsin. A report for DeWitt, Porter and Co. for Didion, Inc.

_____. 1993. The nineteen ninety-two mussel monitoring program in the east branch of the Mississippi River at Prairie du Chien, Wisconsin. A report for DeWitt, Porter, and Co. for Didion, Inc.

_____. 1994. The nineteen ninety-three mussel monitoring program in the east branch of the Mississippi River at Prairie du Chien, Wisconsin. A report for DeWitt, Porter, and Co. for Didion, Inc.

_____. 1995. The nineteen ninety-four mussel monitoring program in the east branch of the Mississippi River at Prairie du Chien, Wisconsin. A report for DeWitt, Porter, and Co. for Didion, Inc.

Cleven, E.J., and P. Frenzel. 1993. Population dynamics and production of *Dreissena polymorpha* (Palas) in River Seerhein, the outlet of Lake Constance (Obersee). Archiv für Hydrobiologie 127:395-407.

Coker, R.E. 1919. Fresh water mussels and mussel industries of the United States. Bulletin of the Bureau of Fisheries 36:13-89.

Coker, R.E., A.F. Shira, H.W. Clark, and A.D. Howard. 1921. Natural history and propagation of fresh-water mussels. Bulletin of the U.S. Bureau of Fishes 37:77-181.

Convey, L.E., J.M. Hanson, and W.M. MacKay. 1989. Size-selective predation on unionid clams by muskrats. Journal of Wildlife Management 53:654-657.

Cope, W.G., M.R. Bartsch, and R.R. Hayden. 1996. Spatial assessment of zebra mussel density in the upper Mississippi River: 1995. National Biological Service, Upper Mississippi Science Center, La Crosse, Wisconsin. 8 p.

Crittenden, J. 1980. Dredging Requirements Work Group Appendix to the Great River Environmental Action Team II Final Report. U.S. Army Corps of Engineers Rock Island, Illinois.

Cummings, K.S., and C.A. Mayer. 1992. Field guide to freshwater mussels of the Midwest. Illinois Natural History Survey Manual 5. 194 p.

Davis, G.M. 1984. Genetic relationships among some North American Unionidae (Bivalvia): sibling species, convergence, and cladistic relationships. Malacologia 25:629-648.

Davis, G.M. and S.L. Fuller. 1981. Genetic relationships among recent Unionacea (Bivalvia) of North America. Malacologia 20:217-253.

Davis, G.M., W.H. Heard, S.L. Fuller, and C. Hesterman. 1981. Molecular genetics and speciation in *Elliptio* and its relationship to other taxa of North American Unionidae (Bivalvia). Biological Journal of the Linnean Society 15:131-150.

Davis, M. 2003. Monitoring of adult relocation to pools 2 and 3 from pool 11 near Cassville, Wisconsin and from pool 14 near Cordova, Illinois. Minnesota Department of Natural Resources, Lake City, MN. 6 p.

Davis, M, and R. Hart. 1995. Mussel habitat in the Richmond Island/Lock and Dam 6 Tailwater area of Pool 7, Mississippi River and its importance for recovery of the federally endangered mussel, *Lampsilis higginsii*. Ecological Services Section, Minnesota Department of Natural Resources. 34 p.

Dawson, V.K., G.A. Jackson, and C.E. Korschgen. 1984. Water chemistry at selected sites on Pools 7 and 8 of the upper Mississippi River: A ten year survey. In: J. G. Wiener, R.V. Anderson, and D.R. McConville, editors. Contaminants in the Upper Mississippi River. Butterworth Publishers, Boston, Massachusetts p. 279-284.

Descy, J., E. Everbecq, V. Gosselain, L. Viroux, and J. S. Smitz. 2003. Modelling the impact of benthic filter-feeders on the composition and biomass of river plankton. Freshwater Biology 48:404-417.

DiMaio, J., and L.D. Corkum. 1995. Relationship between the spatial distribution of freshwater mussels (Bivalvia: Unionidae) and the hydrological variability of rivers. Canadian Journal of Zoology 73:663-671.

Duncan, R.E., and P.A. Thiel. 1983. A survey of the mussel densities in Pool 10 of the Upper Mississippi River. Wisconsin Department of Natural Resources, Technical Bulletin No. 139. 14 p.

Dunn, H.L. 1996a. St. Croix River I-94 bridge replacement unionid relocation monitoring. Report to Wisconsin Department of Transportation, Ecological Specialists, Inc. St. Peters, Missouri. 50 p.

_____. 1996b. St. Croix River I-94 bridge demolition unionid relocation monitoring. Report to Wisconsin Department of Transportation, Ecological Specialists, Inc. St. Peters, Missouri. 28 p.

Ecological Analysts, Inc. 1981a. Survey of freshwater mussels (Pelecypoda: Unionacea) at the Prescott Bridge sites in the St. Croix River. 11 p.

_____. 1981b. Relocation of freshwater mussels (naiades) in Sylvan Slough of the Mississippi River near Moline, Illinois. Report Prepared for Shappert Engineering Co. 5 p.

Ellis, M.M. 1931a. A survey of conditions affecting fisheries in the Upper Mississippi River. Fishery Circular 5:1-18.

_____. 1931b. Some factors affecting the replacement of commercial fresh-water mussels. Fishery Circular 7:1-10.

Errington, P.L. 1941. Versatility in feeding and population maintenance of the muskrat. Journal of Wildlife Management 5:68-89.

Evermann, B.W., and H.W. Clark. 1920. Lake Maxinkuckee: a physical and biological survey. Indiana Department of Conservation Publication, Indianapolis. 512 p.

Frazier, B.E., T.J. Naimo, and M.B. Sandheinrich. 1996. Temporal and vertical distribution of un-ionized ammonia and total ammonia nitrogen in sediment porewater from the upper Mississippi River. Environmental Toxicology and Chemistry 15:92-99.

Fréchette, M., C.A. Butman, and W.R. Geyer. 1989. The importance of boundary-layer flows in supplying phytoplankton to the benthic suspension feeder, *Mytilus edulis* L. Limnology and Oceanography 34:19-36.

Fuller, S.L.H. 1974. Clams and mussels (Mollusca: Bivalvia). In: C.W. Hart, and S.L.H. Fuller (eds.). Pollution Ecology of Freshwater Invertebrates. Academic Press, New York. p. 215-273.

_____. 1980. Freshwater mussels (Mollusca: Bivalvia: Unionidae) of the Upper Mississippi River: observations at selected sites within the 9-foot navigation channel project for the St. Paul District, United States Army Corps of Engineers, 1977-1979. Vol. I and II. Academy of Natural Sciences, Philadelphia.

Gatenby, C. M., B. C. Parker, and R. J. Neves. 1997. Growth and survival of juvenile rainbow mussels, *Villosa iris* (Lea, 1829) (Bivalvia: Unionidae), reared on algal diets and sediment. American Malacological Bulletin 14:57-66.

Gordon, R. 2001. *Lampsilis higginsii* recovery project; Genoa National Fish Hatchery; 2001. Unpublished Report, Genoa National Fish Hatchery, U.S. Fish and Wildlife Service, Genoa, WI. 10 p.

Gordon, R. 2002. *Lampsilis higginsii* recovery project: Genoa National Fish Hatchery, 2002. Genoa National Fish Hatchery, Genoa, WI. 6 p.

Graczyk, D.J. 1986. Water quality in the St. Croix National Scenic Riverway, Wisconsin. U.S. Geological Survey. Water Resources Investigations Report 85-4319. 48 p.

Haag, W., D.J. Berg, and D.W. Garton. 1993. Reduced survival and fitness in native bivalves in response to fouling by the introduced zebra mussel (*Dreissena polymorpha*) in Western Lake Erie. Canadian Journal of Fisheries and Aquatic Sciences 50:13-19.

Hanson, J.M., W.C. MacKay, and E.E. Prepas. 1989. Effect of size-selective predation by muskrats (*Ondatra zibethicus*) on a population of unionid clams (*Anodonta grandis simpsoniana*). Journal of Animal Ecology 58:15-28.

Harman, W.N. 1969. The effects of changing pH on the Unionidae. Nautilus 83:69-70.

_____. 1970. New distribution records and ecological notes on central New York Unionacea. American Midland Naturalist 84:46-58.

Hart, R.A. 1999. Population dynamics of unionid mussels in Lake Pepin, Upper Mississippi River, Minnesota and Wisconsin. Ph.D. Dissertation, North Dakota State University, Fargo. 162 p.

Havlik, M.E. 1980. The historic and present distributions of the endangered naiad mollusk, *Lampsilis higginsii*. Bulletin of the American Malacological Union 1980:19-22.

_____. 1983. Naiad mollusk populations (Bivalvia: Unionidae) in pools 7 and 8 of the Mississippi River near La Crosse, Wisconsin. American Malacological Bulletin 1:51-60.

_____. 1987. Probable causes and considerations of the naiad mollusk die-off in the upper Mississippi River. In: Neves, R.J., editor. Proceedings of the workshop on die-offs of freshwater mussels in the United States. Upper Mississippi River Conservation Committee, Rock Island, Illinois. p. 91-103.

Havlik, M.E. and L.L. Marking. 1987. Effects of contaminants on naiad mollusks (Unionidae): A review. U.S. Fish and Wildlife Service, Resource Publication 164. 20 p.

Hazard, E.B. 1982. The mammals of Minnesota. University of Minnesota Press, Minneapolis. 280 p.

Heath, D.J. 1989. Saint Croix River U.S. Highway 10 bridge freshwater mussel relocation project at Prescott, Wisconsin. Phase I: Mussel removal. Report prepared for Ayres Associates, Madison, Wisconsin. 26 p.

_____. 1995. A description of the Orion mussel aggregation of the Wisconsin River, Wisconsin with reference to *Lampsilis higginsii* (Lea, 1957) (Bivalvia: Unionidae). Wisconsin Department of Natural Resources, Prairie du Chien, WI. 21 p.

_____. 2003. Results of 2002 monitoring of freshwater mussel communities of the Wisconsin River near Orion, Richland County, Wisconsin. Wisconsin Department of Natural Resources, La Crosse, WI. 16 p.

Heath, David, R. Benjamin, M. Endris, D. J. Hornbach, J. Kroese, B. Miller, M. C. Hove, J E. Kurth, J. L. Sieracki, and A. R. Kapuscinski.1999. Determination of basic reproductive characteristics of the winged mapleleaf mussel (*Quadrula fragosa*) relevant to recovery. Preliminary Report No. 2 Submitted to U.S. Fish and Wildlife Service, Ft. Snelling, MN. 29 p.

_____. 2001. Results of 2000 monitoring of freshwater mussel communities of the Saint Croix National Scenic Riverway, Minnesota and Wisconsin. Report for Wisconsin Department of Natural Resources. 16 p.

Hebert, P.D.N., B.W. Muncaster, and G.L. Mackie. 1989. Ecological and genetic studies on *Dreissena polymorpha* (Pallas): a new mollusc in the Great Lakes. Canadian Journal of Fisheries and Aquatic Sciences 46:1587-1591.

Hebert, P.D.N., C.C. Wilson, M.H. Murdoch, and R. Lazar. 1991. Demography and ecological impacts of the invading mollusc *Dreissena polymorpha*. Canadian Journal of Zoology 69:405-409.

Helms, D. 2000. Mussel relocation at the proposed ramp/jetty modification site located in Mississippi River - Pool 14 (River Mile 503.6), Cordova, Illinois. 22. Helms & Associates, Bellevue, Iowa.

Holland-Bartels, L.E. 1990. Physical factors and their influence on the mussel fauna of a main channel border habitat of the upper Mississippi River. Journal of the North American Benthological Society 9:327-335.

Holland-Bartels, L.E. and D.L. Waller. 1988. Aspects of the life history of the endangered Higgins Eye Pearly Mussel, *Lampsilis higginsii* (Lea, 1957). U.S. Fish and Wildlife Service, National Fisheries Research Center, La Crosse, Wisconsin. 188 p.

Holland-Bartels, L.E. and S.J. Zigler. 1990. Laboratory and field culture of juvenile mussels in the genus *Lampsilis*. Bulletin of the North American Benthological Society 7:51.

Hornbach, D.J., A.C. Miller, and B.S. Payne. 1992. Species composition of the mussel assemblages in the upper Mississippi River. Malacological Review 25:119-128.

Hornbach, D.J., P. Baker, and T. Deneka. 1995. Abundance and distribution of the endangered mussel, *Lampsilis higginsii* in the lower St. Croix River, Minnesota and Wisconsin. Final Report to the U.S. Fish and Wildlife Service, Contract # 14-48-000394-1009. 40 p.

Hove, M.C. and A.R. Kapuscinski. 2002. Recovery information needed to prevent extinction of the federally endangered winged mapleleaf: Early life history of endangered Upper Mississippi River mussels. Department of Fisheries, Wildlife, and Conservation Biology, University of Minnesota, St. Paul, Minnesota. 11 p.

Hunter, R.D., and J.F. Bailey. 1992. *Dreissena polymorpha* (zebra mussel): Colonization of soft substrata and some effects on unionid bivalves. *Nautilus* 106: 60-67.

Jacobson, P.J., J.L. Farris, D.S. Cherry, and R.J. Neves. 1993. Juvenile freshwater mussel (Bivalvia: Unionidae) responses to acute toxicity testing with copper. Environmental Toxicology and Chemistry 12:879-883.

Janz, B. and, D. Neumann. 1992. Shell growth and aspects of the population dynamics of *Dreissena polymorpha* in the River Rhine. In: D. Neumann and H.A. Jenner, editors. The zebra mussel *Dreissena*. Symposium on Ecology and Biomonitoring. Gustav Fischer Verlag, Stuttgart, New York. p. 49-66.

Johnson, R.I. 1980. Zoogeography of North American Unionacea (Mollusca: Bivalvia) north of the maximum Pleistocene glaciation. Bulletin of the Museum of Comparative Zoology at Harvard University 149:77-189.

Johnson, L. E., and J. T. Carlton. 1996. Post-establishment spread in large-scale invasions: Dispersal mechanisms of the zebra mussel Dreissena polymorpha. Ecology 77:1686-1690.

Jokela, J., and P. Mutikainen. 1995. Effect of size-dependent muskrat (*Ondatra zibethica*) predation on the spatial distribution of a freshwater clam, *Anodonta piscinalis* Nilsson (Unionidae, Bivalvia). Canadian Journal of Zoology 73:1085-1094.

Jørgensen, C.B. 1975. Comparative physiology of suspension feeding. Annual Review of Physiology. 37:57-79.

Kat, P.W. 1983. Morphological divergence, genetics, and speciation among *Lampsilis* (Bivalvia: Unionidae). Journal of Molluscan Studies 49:133-145.

Keller, A.E. 1993. Acute toxicity of several pesticides, organic compounds, and a wastewater effluent to the freshwater mussel, *Anodonta imbecilis*, *Ceriodaphnia dubia*, and *Pimephales promelas*. Bulletin of Environmental Contamination and Toxicology 51:696-702.

Keller, A.E. and D. Shane Ruessler. 1997. The toxicity of Malathion to unionid mussels: Relationship to expected environmental concentrations. Environmental Toxicology and Chemistry 16:1028-1033.

Keller, A.E., and S.G. Zam. 1991. The acute toxicity of selected metals to the freshwater mussel, *Anodonta imbecilis*. Environmental Toxicology and Chemistry 10:539-546.

Kern, R., J. Borcherding, and D. Neumann. 1994. Recruitment of a freshwater mussel with a planktonic life-stage in running waters - studies on *Dreissena polymorpha* in the River Rhine. Archiv für Hydrobiologie 131:385-400.

Lacki, M.J., W.T. Peneston, K.B. Adams, F.D. Vogt, and J.C. Houppert. 1990. Summer foraging patterns and diet selection of muskrats inhabiting a fen wetland. Canadian Journal of Zoology 68:1163-1167.

Larsen, T., and J. Holzer. 1978. Survey of mussels in the Upper Mississippi River Pools 3 through 8. Wisconsin Department of Natural Resources 3-276-R. 84 p.

Lasee, B.A. 1991. Histological and ultrastructural study of larval and juvenile *Lampsilis* (Bivalvia) from the Upper Mississippi River. Ph.D. Dissertation. Iowa State University. Ames, Iowa. 146 p.

Lavrentyev, P. J., W. S. Gardner, and L. Yang. 2000. Effects of the zebra mussel on nitrogen dynamics and the microbial community at the sediment-water interface. Aquatic Microbial Ecology 21:187-194.

LePage, G.S., C.A. Weldon, and H.H. Calhoun. 1980. Sediment and Erosion Work Group Appendix (vol. 4) to the Great River Environmental Action Team I Final Report. USDA/SCS. St. Paul, Minnesota.

Levinton, J. 1972. Stability and trophic structure in deposit-feeding and suspension-feeding communities. American Naturalist 106:472-486.

Lewandowski, K. 1976. Unionidae as a substratum for *Dreissena polymorpha* Pall. Polish Archiv für Hydrobiologia 23:409-420.

_____. 1983. Occurrence and filtration capacity of young plant-dwelling *Dreissena polymorpha* (Pall.) in Majcz Wielki Lake. Polskie Archiwum Hydrobiologii 30:255-262.

Luoma, J.R. 1997. Shell game. Audubon 99:50-55, 95.

Lydeard, C., M. Mulvey, and G.M. Davis. 1996. Molecular systematics and evolution of reproductive traits of North American freshwater unionacean mussels (Mollusca: Bivalvia)

as inferred from 16S rRNA gene sequences. Philosophical Transactions of the Royal Society of London B 351:1593-1603.

MacIsaac, H.J., W.G. Sprules, and J.H. Leach. 1991. Ingestion of small-bodied zooplankton by zebra mussels (*Dreissena polymorpha*): can cannibalism on larvae influence population dynamics? Canadian Journal of Fisheries and Aquatic Sciences 48:2051-2060.

Mackie, G.L. 1991. Biology of the exotic zebra mussel, *Dreissena polymorpha,* relative to the native bivalves and its potential impact in Lake St. Clair. Hydrobiologia 219:251-268.

Makarewicz, J. C., P. Bertram, and T. W. Lewis. 2000. Chemistry of the Offshore Surface Waters of Lake Erie: Pre- and Post-Dreissena Introduction (1983-1993). Journal of Great Lakes Research. 26:82-93.

Martel, A. 1995. Demography and growth of the exotic zebra mussel (*Dreissena polymorpha*) in the Rideau River (Ontario). Canadian Journal of Zoology 73:2244-2250.

Mathiak, H.A. 1979. A river survey of the unionid mussels of Wisconsin, 1973-1977. Sand Shell Press, Horicon, Wisconsin. 75 p.

McCann, M.T. 1993. Toxicity of zinc, copper, and sediments to early life stages of freshwater mussels in the Powell River, Virginia. MS Thesis, Virginia Polytechnic Institute and State University, Blacksburg. 143 p.

McMahon, R.F. 1991. Mollusca: Bivalvia. In: Thorp, J.H., and A.P. Covich (editors). Ecology and Classification of North American Freshwater Invertebrates. Academic Press, New York, New York. p. 315-399.

Miller, A.C. and B.S. Payne. 1988. The need for quantitative sampling to characterize size demography and density of freshwater mussel communities. American Malacological Bulletin 6:49-54.

_____, and _____. 1991. Effects of increase commercial traffic on freshwater mussels in the Upper Mississippi River: 1989 studies. Technical Report EL-91-3, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

_____, and _____. 1992. The Effects of Commercial Navigation Traffic on Freshwater Mussels in the Upper Mississippi River: 1990 Studies. Technical Report EL-92-23, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

_____, and _____. 1993. Effects of increase commercial traffic on freshwater mussels in the Upper Mississippi River: 1991 studies. Technical Report EL-93-1, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

_____, and _____. 1994. Effects of increase commercial traffic on freshwater mussels in the Upper Mississippi River: 1992 studies. Technical Report EL-94-14, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

_____, and _____. 1995a. Effects of increase commercial traffic on freshwater mussels in the Upper Mississippi River: 1993 studies. Technical Report EL-95-11, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

_____, and _____. 1995b. The effects of commercial navigation traffic on freshwater mussels in the Upper Mississippi River: 1994 Studies. Technical Report EL-95-33, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

_____, and _____. 1996a. Effects of increased commercial navigation traffic on freshwater mussels in the Upper Mississippi River: Final Synthesis Report. Technical Report EL-96-6, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

_____, and _____. 1996b. The importance of a mussel bed near McMillan Island, Pool 10 of the Upper Mississippi River for *Lampsilis higginsii*. Report for the Fish and Wildlife Service from the Army Corps of Engineers, Waterways Experiment Station, Vicksburg, Mississippi. Technical Report EL-96-9.

_____, and _____. 1997. The value of selected mussel beds in the upper Mississippi River for *Lampsilis higginsii*. Aquatic Ecology Branch, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi. Technical Report EL-97-13.

_____, and _____. 2001. Effects of zebra mussels (*Dreissena polymorpha*) at Essential Habitats for *Lampsilis higginsi* in the upper Mississippi River System, 2000. Report for St. Paul District, U.S. Army Corps of Engineers. 31 p.

Miller, A.C., B.S. Payne, D.J. Hornbach, and D.V. Ragland. 1990. Physical effects of increased navigation on freshwater mussels in the upper Mississippi River: Phase I Studies. U.S. Army Engineer District, St. Louis, Missouri.

Morejohn, G.V. 1969. Evidence of river otter feeding on freshwater mussels and range extension. California Fish and Game 55:83-85.

Moy, P.B. 1999. An invasive species dispersal barrier for the Chicago Sanitary and Ship Canal. Dreissena! 9:1-7.

Naimo, T.J. 1995. A review of the effects of heavy metals on freshwater mussels. Ecotoxicology 4:341-362.

Naimo, T.J., G.J. Atchison, and L.E. Holland-Bartels. 1992a. Sublethal effects of cadmium on physiological responses in the pocketbook mussel, *Lampsilis ventricosa*. Environmental Toxicology and Chemistry 11:1013-1021.

Naimo, T.J., D.L. Waller, and L.E. Holland-Bartels. 1992b. Heavy metals in the threeridge *Amblema plicata plicata* (Say, 1817) in the Upper Mississippi River. Journal of Freshwater Ecology 7:209-217.

Nelson, D.A., and T.M. Freitag. 1980. Ecology, identification and recent discoveries of Higgins Eye (*Lampsilis higginsii*), Spectacle case (*Cumberlandia monodonta*), and Fat Pocketbook (*Potamilus capax*) mussels in the Upper Mississippi River. In: Rasmussen, J., editor. Proceedings of the UMRCC Symposium on Upper Mississippi River bivalve mollusks. Upper Mississippi River Conservation Committee, Rock Island, Illinois. p. 120-145.

Neves, R.J., editor. 1987. Proceedings of the workshop on die-offs of freshwater mussels in the United States. Upper Mississippi River Conservation Committee, Rock Island, Illinois.

Neves, R.J. and M.C. Odom. 1989. Muskrat predation on endangered freshwater mussels in Virginia. Journal of Wildlife Management 53: 934-941.

Neves, R.J. and J.C. Widlak. 1988. Occurrence of glochidia in stream drift and on fishes of the upper North Fork Holston River, Virginia. American Midland Naturalist 119:111-120.

Newton, T. J. 2003. The effects of ammonia on freshwater unionid mussels-letter to the editor. Environmental Toxicology and Chemistry 22:2543-2544.

Nico, L.G., J.D. Williams, and J.J. Herod. 2001. Black carp (*Mylopharyngodon piceus*): A biological synopsis and updated risk assessment. Report to The Risk Assessment and Management Committee of the Aquatic Nuisance Species Task Force. U.S. Geological Survey, Florida Caribbean Science Center, Gainesville, FL. 125 p.

O'Beirn, F.X., R. J. Neves, and M. B. Steg. 1998. Survival and growth of juvenile freshwater mussels (Unionidae) in a recirculating aquaculture system. American Malacological Bulletin 14:165-171.

Oblad, B.R. 1980. An experiment in relocating endangered and rare naiad mollusks from a proposed bridge construction site at Sylvan Slough, Mississippi River, near Moline, Illinois. In: Rasmussen, J. L., editor. Conservation and Management of Freshwater Mussels. Proceedings of a UMRCC symposium. Upper Mississippi River Conservation Committee. Rock Island, Illinois. p. 211-222.

Oesch, R.D. 1984. Missouri naiades: a guide to the mussels of Missouri. Missouri Department of Conservation. Jefferson City, Missouri.

Pennak, R.W. 1978. Fresh-water invertebrates of the United States. 2nd ed. John Wiley & Sons, New York. p. 736-768.

Perry, F.W. 1979. A survey of Upper Mississippi River mussels. In: Rasmussen, J.L., editor. A compendium of fishery information on the Upper Mississippi River. 2nd ed. Upper Mississippi River Conservation Committee. Rock Island, Illinois. p 118-139.

Ray, W.J. and L.D. Corkum. 1997. Predation of zebra mussels by round gobies, *Neogobius melanostomus*. Environmental Biology of Fishes 50:267-273.

Reeders, H.H., A. Bij de Vaate, and F.J. Slim. 1989. The filtration rate of *Dreissena polymorpha* (Bivalvia) in three Dutch Lakes with reference to biological water quality management. Freshwater Biology 22:133-141.

Ricciardi, A., R. Serrouya, and F.G. Whoriskey. 1995a. Aerial exposure tolerance of zebra and quagga mussels (Bivalvia: Dreissenidae): implications for overland dispersal. Canadian Journal of Fisheries and Aquatic Sciences 52:470-477.

Ricciardi, A., F.G. Whoriskey and J.B. Rasmussen. 1995b. Predicting the intensity and impact of *Dreissena* infestation on native unionid bivalves from *Dreissena* field density. Canadian Journal of Aquatic Science 52:1449-1461.

Ricciardi, A. 1996. Impact of the *Dreissena* invasion on native bivalves in the upper St. Lawrence River. Canadian Journal of Aquatic Science 53:1434-1444.

Rostad, C. E. 1997. From the 1988 drought to the 1993 flood: Transport of halogenated organic compounds with the Mississippi River suspended sediment at Thebes, Illinois. Environmental Science and Technology 31:1308-1312.

Schloesser, D. W. 1997. Zebra mussel induced mortality of unionids in firm substrata of western Lake Erie and a habitat for survival. American Malacological Bulletin 14:67-74.

Scholla, M.H., M.L. Hinman, S.J. Klaine, and J. Conder. 1987. Evaluation of a mussel die-off in the Tennessee River, Tennessee, in 1985, p. 144-151. Neves, R.J., editor. Proceedings of the workshop on die-offs of freshwater mussels in the United States. Upper Mississippi River Conservation Committee. Rock Island, Illinois.

Sheehan, R.J., R.J. Neves, and H.E. Kitchel. 1989. Fate of freshwater mussels transplanted to formerly polluted reaches of the Clinch and North Fork Holston Rivers, Virginia. Journal of Freshwater Ecology 5:139-149.

Sparks, R.E. and K.D. Blodgett. 1983. Effects of three commercial harvesting methods on mussel beds. Project No. 3-327-R. Illinois Natural History Survey, Aquatic Biology Section Technical Report 1983/10. 43 p.

Stanczykowska, A., W. Lawacz, J. Mattice, and K. Lewandowski. 1976. Bivalves as a factor affecting circulation of matter in Lake Mikolajskie (Poland). Limnologica 10:347-352.

Stanley Consultants. 1988. Mussel and substrate survey, Pool 14, Mississippi River. 15 p. + maps and append. Muscatine, Iowa.

Steingraeber, M.T., T.R. Schwartz, J.G. Wiener, and J.A. Lebo. 1994. Polychlorinated biphenyl congeners in emergent mayflies from the upper Mississippi River. Environmental Science and Technology 28:707-714.

Stiven, A.E., and J. Alderman. 1992. Genetic similarities among certain freshwater mussel populations of the *Lampsilis* genus in North Carolina. Malacologia 34:355-369.

Strayer, D.L. 1983. The effects of surface geology and stream size on freshwater mussel (Bivalvia: Unionidae) distribution in southeastern Michigan, USA. Freshwater Biology 13:253-264.

_____. 1993. Macrohabitats of freshwater mussels (Bivalvia: Unionacea) in streams of the northern Atlantic slope. Journal of the North American Benthological Society 12:236-246.

_____. 1999. Effects of alien species on freshwater molluscs in North America. Journal of the North American Benthological Society 18:74-98.

Strayer, D.L. and J. Ralley. 1993. Microhabitat use by an assemblage of stream-dwelling unionaceans (Bivalvia), including two rare species of *Alasmidonta*. Journal of the North American Benthological Society 12:247-258.

Strayer, D.L. and L.C. Smith. 1996. Relationships between zebra mussels (*Dreissena polymorpha*) and unionid clams during the early stages of the zebra mussel invasion of the Hudson River. Freshwater Biology 36:771-779.

Strayer, D.L., J. Powell, P. Ambrose, L.C. Smith, M.L. Pace, and D.T. Fischer. 1996. Early dynamics of the zebra mussel invasion of the Hudson River estuary. Canadian Journal of Fisheries and Aquatic Sciences 53:1143-1147.

Surber, T. 1912. Identification of the glochidia of freshwater mussels. U.S. Bureau of Fisheries Doc. 771:1-10.

Sylvester, J.R., L.E. Holland, and T.K. Kammer. 1984. Observations on burrowing rates and comments on host specificity in the endangered mussel *Lampsilis higginsii*. Journal of Freshwater Ecology 2:555-559.

Takos, M.J. 1947. A semi-quantitative study of muskrat food habits. Journal of Wildlife Management 11:331-339.

Tankersley, R.A., and R.V. Dimock. 1992. Quantitative analysis of the structure and function of the marsupial gills of the freshwater mussel *Anodonta cataracta.* Biological Bulletin 182:145-154.

_____. 1993a. Endoscopic visualization of the functional morphology of the ctenidia of the unionid mussel *Pyganodon cataracta.* Canadian Journal of Zoology 71:811-819.

_____. 1993b. The effect of larval brooding on the filtration rate and particle-retention efficiency of *Pyganodon cataracta* (Bivalvia: Unionidae). Canadian Journal of Zoology 71:1934-1944.

Tessier, A., and P.G.C. Campbell. 1987. Partitioning of trace metals in sediments: Relationships with bioavailability. Hydrobiologia 149:43-52.

Thiel, P.A. 1981. A survey of unionid mussels in the upper Mississippi River. Wisconsin Department of Natural Resources, Madison. Technical Bulletin 124. 25 p.

_____. 1987. Recent events in the mussel mortality problem on the upper Mississippi River. In: Neves, R.J., editor. Proceedings of the workshop on die-offs of freshwater mussels in the United States. Upper Mississippi River Conservation Committee, Rock Island, Illinois. p. 66-75.

Thiel, P.A. and A.W. Fritz. 1993. Mussel harvest and regulations in the Upper Mississippi River system. In: Cummings, K.S., A.C. Buchanan, and L.M. Koch, editors. Conservation and management of freshwater mussels. Proceedings of a UMRCC symposium, 12-14 October, 1992, St. Louis, Missouri. Upper Mississippi River Conservation Committee, Rock Island, Illinois. p. 11-18.

Thiel, P.A., M. Talbot, and J. Holzer. 1980. Survey of mussels in the Upper Mississippi River Pools 3 through 8. In: Rasmussen, J.L., editor. Proceedings of the UMRCC Symposium on Upper Mississippi River bivalve mollusks. Upper Mississippi River Conservation Committee, Rock Island, Illinois. p 148-157.

Toczylowski, S.A., and R.D. Hunter. 1996. Are post-larval zebra mussels attracted to conspecifics and/or unionids? p. 148. Sixth International Zebra Mussel and Other Aquatic Nuisance Species Conference. Michigan Sea Grant College Program.

Toweill, D.E. 1974. Winter food habits of river otters in western Oregon. Journal of Wildlife Management 38:107-111.

Trefry, J.H., T.A. Nelsen, R.P. Trocine, S. Metz, and T.W. Vetter. 1986. Trace metal fluxes through the Mississippi River Delta system. Rapport et Proces-Verbaux des Reunions Conseil International pour l'Exploration de la Mer 186:277-288.

Tucker, J.K. 1994. Colonization of unionid bivalves by the zebra mussel, *Dreissena polymorpha,* in Pool 26 of the Mississippi River. Journal of Freshwater Ecology 9:129-134.

Tucker, J.K., C.H. Theiling, K.D. Blodgett, and P.A. Thiel. 1993. Initial occurrences of zebra mussels (*Dreissena polymorpha*) on freshwater mussels (family Unionidae) in the upper Mississippi River system. Journal of Freshwater Ecology 8:245-251.

Tucker, J. K., C. H. Theiling, F. J. Janzen, and G. L. Paukstis. 1997. Sensitivity to aerial exposure: potential of system-wide drawdowns to manage zebra mussels in the Mississippi River. Regulated Rivers: Research & Management 13:479-487.

Turgeon, D.D., A.E. Bogan, E.V. Coan, W.K. Emerson, W.G. Lyons, W.L. Pratt, C.F.E. Roper, A. Scheltema, F.G. Thompson, and J.D. Williams. 1998. Common and scientific names of aquatic invertebrates from the United States and Canada: Mollusks. American Fisheries Society Special Publication 26:1-526.

Tyrrell, M., and D.J. Hornbach. 1998. Selective small mammal predation on freshwater mussels in two Minnesota rivers. Journal of the North American Benthological Society 17:301-310.

U.S. Army Corps of Engineers. 1993. Biological assessment of the impacts on federally listed threatened and endangered species from channel maintenance activities and a permit application to construct and expand barge terminal facilities in the east channel of the upper Mississippi River at Prairie du Chien, Wisconsin. Environmental Resources Branch, U.S. Army Engineer District, St. Paul, Minnesota.

U.S. Army Corps of Engineers. 2002. Final July 2002 definite project report and environmental assessment for relocation plan for the endangered Higgins eye pearlymussel (*Lampsilis higginsii*): Upper Mississippi River and tributaries, Minnesota, Wisconsin, Iowa, and Illinois. St. Paul District, St. Paul, MN. 56 p.

U.S. Environmental Protection Agency. 1999. 1999 update of ambient water quality criteria for ammonia. U.S. EPA, Office of Water -- Office of Science and Technology Washington, D.C. and Office of Research and Development Mid-Continent Ecology Division Duluth, Minnesota. 147 p.

U.S. Fish and Wildlife Service. 1983. Higgins Eye mussel recovery plan. Ft. Snelling, Minnesota. 98 p.

_____. 1987. Biological opinion on the effects of a second lock at Locks and Dam 26(R), Alton, Illinois. Manuscript. U.S. Fish and Wildlife Service, Rock Island, Illinois. 35 p.

Van Cleave, H.J. 1940. Ten years of observation on a fresh-water mussel population. Ecology. 21:363-370.

Vannote, R.L., and G.W. Minshall. 1982. Fluvial processes and local lithology controlling abundance, structure, and composition of mussel beds. Proceedings of the National Academy of Science 79:4103-4107.

Villella, R., T. King, and C. Starliper. 1997. Translocation programs in freshwater mussels: genetic and disease concerns. In: National Shellfisheries Association Program and Abstracts of the 89th Annual Meeting. p. 26-27.

Waller, D.L., and L.E. Holland-Bartels. 1988. Fish hosts for glochidia of the endangered freshwater mussel *Lampsilis higginsii* Lea (Bivalvia: Unionidae). Malacological Review 21:119-122.

Waller, D.L. and L.G. Mitchell. 1988. Morphology of glochidia of *Lampsilis higginsii* (Bivalvia: Unionidae) compared with three related species. American Malacological Bulletin 6:39-43.

Waller, D.L. and T.W. Kammer. 1985. Artificial infection of largemouth bass and walleye with glochidia of *Lampsilis ventricosa* (Pelecypoda: Unionidae). Freshwater Invertebrate Biology 4:152-153.

Waller, D.L., J.J. Rach, and T.W. Kammer. 1995. Effects of handling and aerial exposure on the survival of unionid mussels. Journal of Freshwater Ecology 10:199-207.

Waters, S.J. 1980. The evolution of mussel harvest regulations on the Upper Mississippi River. In: Rasmussen, J.L., editor. Proceedings of the UMRCC Symposium on Upper Mississippi River bivalve mollusks. Upper Mississippi River Conservation Committee, Rock Island, Illinois. p. 191-202.

Watters, G.T. 1994a. Form and function of unionidean shell sculpture and shape (Bivalvia). American Malacological Bulletin 11:1-20.

_____. 1994b. An annotated bibliography of the reproduction and propagation of the Unionoidea (primarily of North America). Ohio Biological Survey Miscellaneous Contributions (1). 165 p.

_____. 1995. Sampling freshwater mussel populations: the bias of muskrat middens. Walkerana. 7:63-69.

Welke, K., T. Turner, R. Gordon, V. Hyde and P.A. Thiel. 2000. Propagation of the federally endangered Higgins Eye Pearlymussel (*Lampsilis higginsi*) at the Genoa National Fish

Hatchery as a survival strategy. Interim Report. Wisconsin Department of Natural Resources. 5 p.

Whitney, S.D., K.D. Blodgett, and R.E. Sparks. 1995. Update of zebra mussels and native unionids in the Illinois River. Report released by the Illinois Natural History Survey, Havana, IL. January 3, 1995.

Wiener, J.G., R.V. Anderson, and D.R. McConville. 1984. Introduction--Contaminants in the upper Mississippi River. In: J.G. Wiener, R.V. Anderson, and D.R. McConville, editors. Contaminants in the Upper Mississippi River. Butterworth Publishers, Boston, Massachusetts. p. 1-4.

Wiktor, J. 1963. Research on the ecology of *Dreissena polymorpha* Pall. in the Szczecin Lagoon (Zalew Szczecunski). Ekologia Polska. 11(9):275-280.

Wilcox, D.B., D.D. Anderson, and A.C. Miller. 1993. Survey procedures and decision criteria for estimating the likelihood that *Lampsilis higginsii* is present in areas in the Upper Mississippi River system. In: Cummings, K.S., A.C. Buchanan, and L.M. Koch, editors. Conservation and management of freshwater mussels. Proceedings of a UMRCC symposium, 12-14 October 1992, St. Louis, Missouri. Upper Mississippi River Conservation Committee, Rock Island, Illinois. p. 163-167.

Wildish, D.J., and D.D. Kristmanson. 1984. Importance to mussels of the benthic boundary layer. Canadian Journal of Fisheries and Aquatic Sciences 41:1618-1625.

Williams, J.D., M.L. Warren Jr., K.S. Cummings, J.L. Harris, and R.J. Neves. 1993. Conservation status of freshwater mussels of the United States and Canada. Fisheries 18:6-22.

Wilson, C.B. 1916. Copepod parasites of fresh-water fishes and their economic relations to mussel glochidia. Bulletin of the U.S. Bureau of Fisheries 34:331-374.

Winter, T.E. 1978. A review on the knowledge of suspension-feeding in Lamellibranchiate bivalves, with special reference to artificial aquaculture systems. Aquaculture 13:1-33.

Yeager, M.M., D.S. Cherry, and R.J. Neves. 1994. Feeding and burrowing behaviors of juvenile rainbow mussels, *Villosa iris* (Bivalvia: Unionidae). Journal of the North American Benthological Society 13:217-222.

IV. TABLES

Table 1. Summary of recent (2000-2003) reintroductions, adult translocations, and other releases of *Lampsilis higginsii*. Releases between sites in the same river include experimental releases and movements of adults and releases of artificially propagated *L. higginsii* into areas with low densities of zebra mussels. Largemouth bass, smallmouth bass, walleye, freshwater drum, spotted bass (*Micropterus punctulatus*), and white bass (*Morone chrysops*) were used as host fish species for artificial propagation. Gordon (2002) estimated 60-68 (smallmouth bass), 57-65 (walleye), and 78-133 (largemouth bass) transformed juveniles per fish. USFWS maintains an up-to-date database of reintroduction events at its Twin Cities Field Office in Bloomington, Minnesota. UMR = Upper Mississippi River.

Action	Source River	Relocation River	No. Mussels	No. Fish
Adult Relocation	UMR	UMR	101	n/a
Adult Relocation	UMR	UMR	99	n/a
Adult Relocation	UMR	UMR	271	n/a
Infested Fish in Cage(s)	St. Croix River	St. Croix River	n/a	100
Infested Fish in Cage(s)	St. Croix River	St. Croix River	n/a	100
Infested Fish in Cage(s)	St. Croix River	St. Croix River	n/a	150
Infested Fish in Cage(s)	St. Croix River	St. Croix River	n/a	150
Infested Fish in Cage(s)	St. Croix River	St. Croix River	n/a	50
Infested Fish in Cage(s)	St. Croix River	St. Croix River	n/a	150
Infested Fish in Cage(s)	St. Croix River	UMR	n/a	150
Infested Fish in Cage(s)	St. Croix River	UMR	n/a	150
Infested Fish in Cage(s)	St. Croix River	UMR	n/a	100
Infested Fish in Cage(s)	St. Croix River	UMR	n/a	50

Table 1. Summary of recent (2000-2003) reintroductions, cont.

Action	Source River	Relocation River	No. Mussels	No. Fish
Infested Fish in Cage(s)	St. Croix River	Wisconsin River	n/a	445
Infested Fish in Cage(s)	St. Croix River	Wisconsin River	n/a	150
Infested Fish in Cage(s)	UMR	UMR	n/a	245
Infested Fish in Cage(s)	UMR	UMR	n/a	520
Infested Fish in Cage(s)	UMR	UMR	n/a	804
Release Free-Ranging Fish	UMR	Wapsipinicon River	n/a	1890
Release Free-Ranging Fish	St. Croix River	Cedar River	n/a	793
Release Free-Ranging Fish	St. Croix River	Cedar River	n/a	405
Release Free-Ranging Fish	St. Croix River	Wisconsin River	n/a	450
Release Free-Ranging Fish	UMR	Cedar River	n/a	615
Release Free-Ranging Fish	UMR	Iowa River	n/a	1000
Release Free-Ranging Fish	UMR	Iowa River	n/a	11
Release Free-Ranging Fish	UMR	Iowa River	n/a	87
Release Free-Ranging Fish	UMR	Iowa River	n/a	577
Release Free-Ranging Fish	UMR	Iowa River	n/a	60
Release Free-Ranging	UMR	Iowa River	n/a	615

Table 1. Summary of recent (2000-2003) reintroductions, cont.

Action	Source River	Relocation River	No. Mussels	No. Fish
Fish				
Release Free-Ranging Fish	UMR	Iowa River	n/a	65
Release Free-Ranging Fish	UMR	Wapsipinicon River	n/a	620
Release Free-Ranging Fish	Wisconsin River	Wisconsin River	n/a	300
Release Juveniles	St. Croix River	Black River	1914	n/a
Release Juveniles	St. Croix River	Black River	1200	n/a
Release Juveniles	St. Croix River	St. Croix River	3	n/a
Release Juveniles	St. Croix River	Wisconsin River	3750	n/a
Release Juveniles	St. Croix River	Wisconsin River	1100	n/a

Table 2. List of primary and secondary habitats described in the 1983 *L. higginsii* recovery plan.

Habitat Type	Site	UMRS Pool	River Mile
Primary	Sylvan Slough, IL	15	485.5-486
	Cordova, IL	14	503-505.5
	McMillan Island, IA	10	616.4-619.1
	Prairie du Chien, WI/MN	10	634-636
	Harper's Slough, IA/WI	10	639-641.1
	Whiskey Rock, IA	9	655.8-658.4
	Hudson, WI (Lakeland, MN)	St. Croix River	16.2-17.6
Secondary	Jonas Johnson Island, IL	17	439
	Barkis Island, IL	17	444
	Andalusia Slough, IL	16	473
	Lower Sylvan Slough, IL	16	482
	Rapids City, IL	14	496
	Adams Island (vicinity), IA	14	507
	Dubuque, IA	12	580
	Cassville, WI	11	607
	Guttenberg, IA	11	613

Table 3. Fishes that have been examined as potential hosts for *L. higginsii.*

Fish species	Common name	Family	Suitability as a host	Reference
Stizostedion canadense	sauger	Percidae	Suitable	Surber (1912); Wilson (1916); Coker *et al.* (1921); Hove and Kapuscinski (2002)
Aplodinotus grunniens	freshwater drum	Sciaenidae	Suitable	Wilson (1916); Coker *et al.* (1921)
Micropterus salmoides	largemouth bass	Centrarchidae	Suitable	Sylvester *et al.* (1984); Waller & Holland-Bartels (1988); Hove and Kapuscinski (2002)
Micropterus dolomieu	smallmouth bass	Centrarchidae	Suitable	Waller & Holland-Bartels (1988)
Stizostedion vitreum vitreum	walleye	Percidae	Suitable	Sylvester *et al.* (1984); Waller & Holland-Bartels (1988)
Perca flavescens	yellow perch	Percidae	Suitable	Waller & Holland-Bartels (1988)
Pomoxis nigromaculatus	black crappie	Centrarchidae	Suitable	Hove and Kapuscinski (2002)
Lepomis macrochirus	bluegill	Centrarchidae	Marginal	Waller & Holland-Bartels (1988)
Esox lucius	northern pike	Esocidae	Marginal	Waller & Holland-Bartels (1988)
Lepomis cyanellus	green sunfish	Centrarchidae	Marginal	Waller & Holland-Bartels (1988); Sylvester *et al.* (1984)
Lepomis macrochirus	bluegill	Centrarchidae	Unsuitable	Sylvester *et al.* (1984)
Lepomis humilis	orange-spotted sunfish	Centrarchidae	Unsuitable	Hove and Kapuscinski (2002)
Lepomis gibbosus	pumpkinseed	Centrarchidae	Unsuitable	Hove and Kapuscinski (2002)
Ambloplites rupestris	rock bass	Centrarchidae	Unsuitable	Hove and Kapuscinski (2002)
Percina maculata	blackside darter	Centrarchidae	Unsuitable	Hove and Kapuscinski (2002)
Cyprinus carpio	common carp	Cyprinidae	Unsuitable	Sylvester *et al.* (1984)
Pimephales promelas	fathead minnow	Cyprinidae	Unsuitable	Waller & Holland-Bartels (1988)
Luxilus cornutus	common shiner	Cyprinidae	Unsuitable	Hove and Kapuscinski (2002)
Semolitus atromaculatus	creek chub	Cyprinidae	Unsuitable	Hove and Kapuscinski (2002)
Nocomis biguttatus	hornyhead chub	Cyprinidae	Unsuitable	Hove and Kapuscinski (2002)
Cyprinella spiloptera	spotfin shiner	Cyprinidae	Unsuitable	Hove and Kapuscinski (2002)
Ictalurus punctatus	northern hognose sucker	Ictaluridae	Unsuitable	Sylvester *et al.* (1984); Hove and Kapuscinski (2002)
Ameiurus melas	black bullhead	Ictaluridae	Unsuitable	Sylvester *et al.* (1984)
Pylodictis olivaris	flathead catfish	Ictaluridae	Unsuitable	Hove and Kapuscinski (2002)

Table 3. Fishes that have been examined as potential hosts for *L. higginsii*, cont.

Fish species	Common name	Family	Suitability as a host	Reference
Nocturus gyrinus	tadpole madtom	Ictaluridae	Unsuitable	Hove an`d Kapuscinski (2002)
Ameiurus natalis	yellow bullhead	Ictaluridae	Unsuitable	Hove and Kapuscinski (2002)
Carpiodes carpio	river carpsucker	Catostomidae	Unsuitable	Sylvester *et al.* (1984)
Catostomus commersoni	white sucker	Catostomidae	Unsuitable	Sylvester *et al.* (1984)
Hypentelium nigricans	northern hognose sucker	Catostomidae	Unsuitable	Hove and Kapuscinski (2002)
Oncorhynchus mykiss	rainbow trout	Salmonidae	Unsuitable	Sylvester *et al.* (1984)
Acipenser fulvescens	lake sturgeon	Acipenseridae	Unsuitable	Hove and Kapuscinski (2002)
Lepisosteus osseus	longnose gar	Lepisosteidae	Unsuitable	Hove and Kapuscinski (2002)
Percopsis omiscomaycus	trout-perch	Percoppsidae	Unsuitable	Hove and Kapuscinski (2002)
Lota lota	burbot	Lotidae	Unsuitable	Hove and Kapuscinski (2002)

Table 4. Water quality data from the St. Croix River at St. Croix Falls, Wisconsin, during 1975-1983. During the sampling period mean pH was 7.3 (6.4-8.3, n = 76); mean concentrations of calcium and magnesium were 21 (SD=5.0, n=81) and 6.7 (SD=1.5, n=81) mg/L, respectively. All data are summarized from Graczyk (1986).

Measure	Mean	Range	Number of observations
Total cadmium, ug/L	1.0	<1-3	30
Total chromium, ug/L	9	<20-20	30
Total copper, ug/L	4	<2-24	30
Total mercury, ug/L	0.20	<0.01-0.6	30
Total zinc, ug/L	30	<10-380	29
Alkalinity, mg/L	76	28-110	60
Calcium, mg/L	21	8.5-40	81
Conductivity, umhos	180	65-295	91
Total Nitrogen, mg/L	0.83	0.25-1.8	67
Ammonia Nitrogen, mg/L	0.61	0.13-1.6	89
Dissolved oxygen, mg/L	9.7	6.6-14	68
pH	7.3	6.4-8.3	76
Total phosphorus, mg/L	0.05	0.01-.016	82
Suspended sediment, mg/L	7.5	1-54	72

Table 5. Heavy metals and hydrocarbons in surficial sediments in 1986 from five locations in Pool 10 near Prairie du Chien, Wisconsin. Concentrations are mg/kg dry weight or ppm. Data are unpublished data from the U.S. Army Corps of Engineers (locations 1, 5, 6, 7, and 8).

Measure	Mean	Range	N
Heavy metals			
Cd	0.4	<0.3-0.5	10
Cr	11.6	8.3-17.0	10
Cu	8.8	5.0-15.0	10
Zn	41.2	28.9-63.5	10
*Aliphatic hydrocarbons**			
n-pentadecane	0.03	0.02-0.05	10
n-hexadecane	0.02	0.01-0.05	7
n-heptadeccane	0.06	0.02-0.12	10
pristane	0.02	0.01-0.03	4
n-octadecane	0.03	0.02-0.06	10
n-nonadecane	0.07	0.03-0.18	10
n-eicosane	0.03	0.01-0.10	9
Polyaromatic hydrocarbons			
napthalene	0.01	0.01	2
anthracene	0.01	0.01-0.03	5
fluroanthrene	0.04	0.01-0.20	7
pyrene	0.05	0.01-0.27	7
1,2-	0.01	0.01	5
chrysene	0.09	0.01-0.34	5
benzo(b)fluoranth	0.02	0.01-0.03	7
benzo(a)pyrene	0.01	0.01-0.02	7
1,2,5,6-	0.05	0.01-0.16	4
benzo(g,h,i)peryle	0.02	0.01-0.04	5

***In addition to the aliphatic hydrocarbons listed in the table, sediments were also analyzed for n-dodecane, n-tridecane, n-tetradecane, octylcyclohexane, and nonylcyclohexane. Concentrations of these compounds were below the lower level of detection of 0.01 ppm.. Sediments were also analyzed for 20 organochlorine compounds including HCB, BHC, oxychlordane, heptachlor epoxide, t-nonachlor, total PCBs, arochlor 1242, 1248, 1254, and 1260, o, p'-DDE, p, p'-DDE, dieldrin, o, p'-DDD, endrin, cis-nonachlor, o, p'-DDT, p, p'-DDD, p, p'-DDT, and mirex. Concentrations of these organochlorine pesticides were below the lower level of detection of 0.01 ppm (0.05 ppm for total PCBs).**

Table 6. Studies conducted at the Essential Habitat sites that were recommended in the 1983 *L. higginsii* recovery plan.

Site	UMRS Pool	River Mile	References
Sylvan Slough, IL	15	485.5-486	Ecological Analysts (1981b); Blodgett & Sparks (1987b); Cawley (1989); Miller and Payne (2001)
Cordova, IL	14	503-505.5	Stanley Consultants (1988); Miller *et al.* (1990); Miller and Payne (1991,1993,1994,1996a,b, 1997, 2001); Helms (2000)
McMillan Is., IA	10	616.4-619.1	Miller *et al.* (1990); Miller & Payne (1996b, 2001)
Prairie du Chien, WI/MN	10	634-636	Thiel (1981); Havlik (1983);Duncan & Thiel (1983); Andrew Miller and Barry Payne (U.S. Army Corps of Engineers, in litt. 1984); Miller and Payne (1991, 1992, 1993, 1994, 1995a, 1995b, 1996a, 1996b, 1997, 2001); Holland-Bartels & Waller (1988); Clarke & Loter (1992, 1993, 1994, 1995)
Harper's Slough, IA/WI	10	639-641.1	Duncan & Thiel (1983); Miller & Payne (1996b, 2001); David Heath (Wisconsin Department of Natural Resources, in litt. 1996)
Whiskey Rock, IA	9	655.8-658.4	Miller & Payne (1996b, 2001)
Hudson, WI/MN	St. Croix River	16.2-17.6	Fuller (1980); Heidi Dunn (Ecological Specialists, in litt. 1994); Hornbach *et al.* (1995); Heath *et al.* (2001)

V. FIGURES

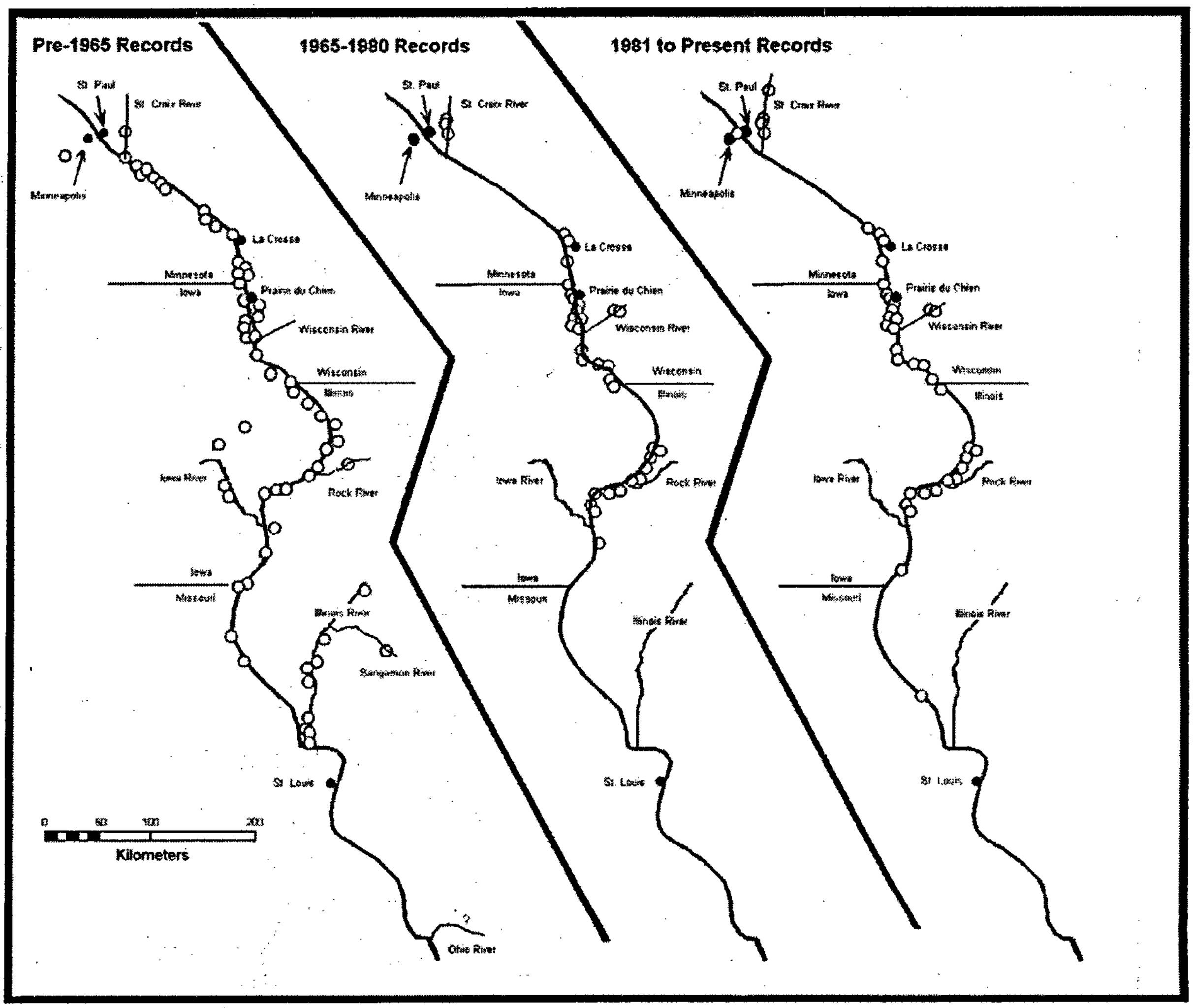

Figure 1. Distribution of *Lampsilis higginsii* in the Upper Mississippi River and major tributaries (from Havlik 1980 and Cawley 1996). *L. higginsii* has recently been introduced into some areas not indicated on this map (see Table 1). Open circles indicate locations of *L. higginsii* records; solid circles show locations of cities for geographic reference.

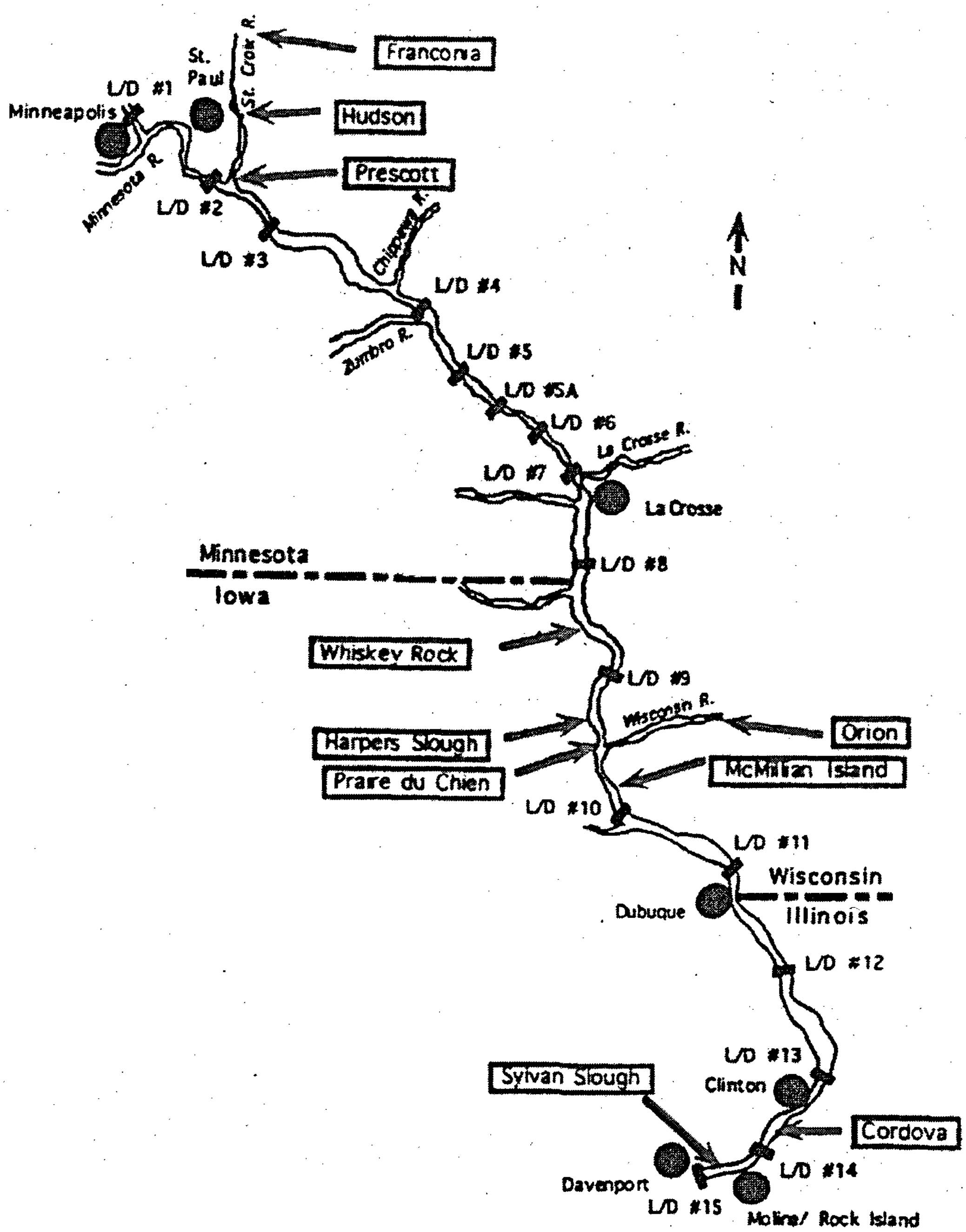

Figure 2. Recommended Essential Habitat Areas for Higgins' Eye Pearlymussel.

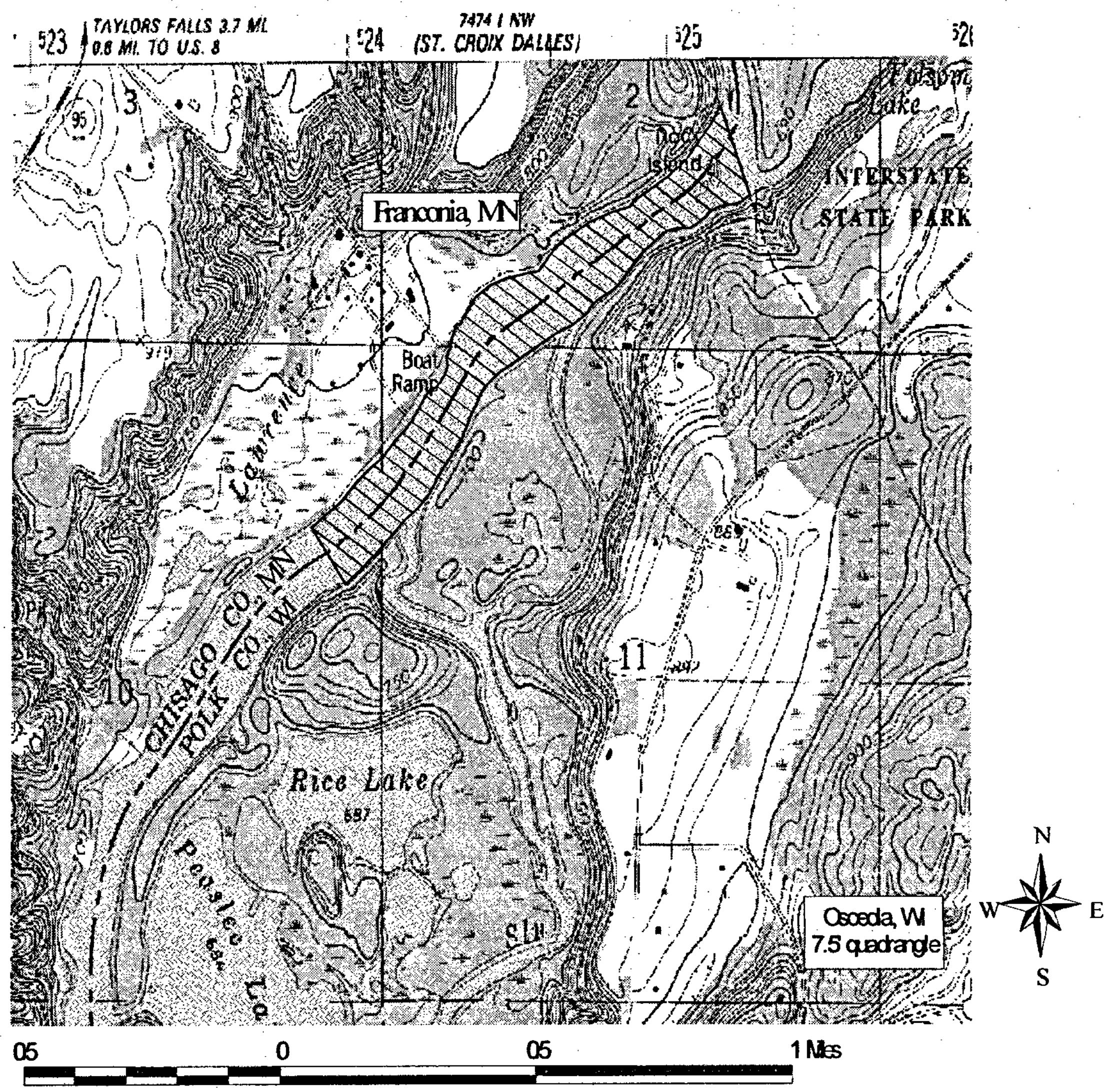

Figure 3. Essential Habitat Area at Franconia, Minnesota, St. Croix River, Chisago County, Minnesota, and Polk County, Wisconsin.

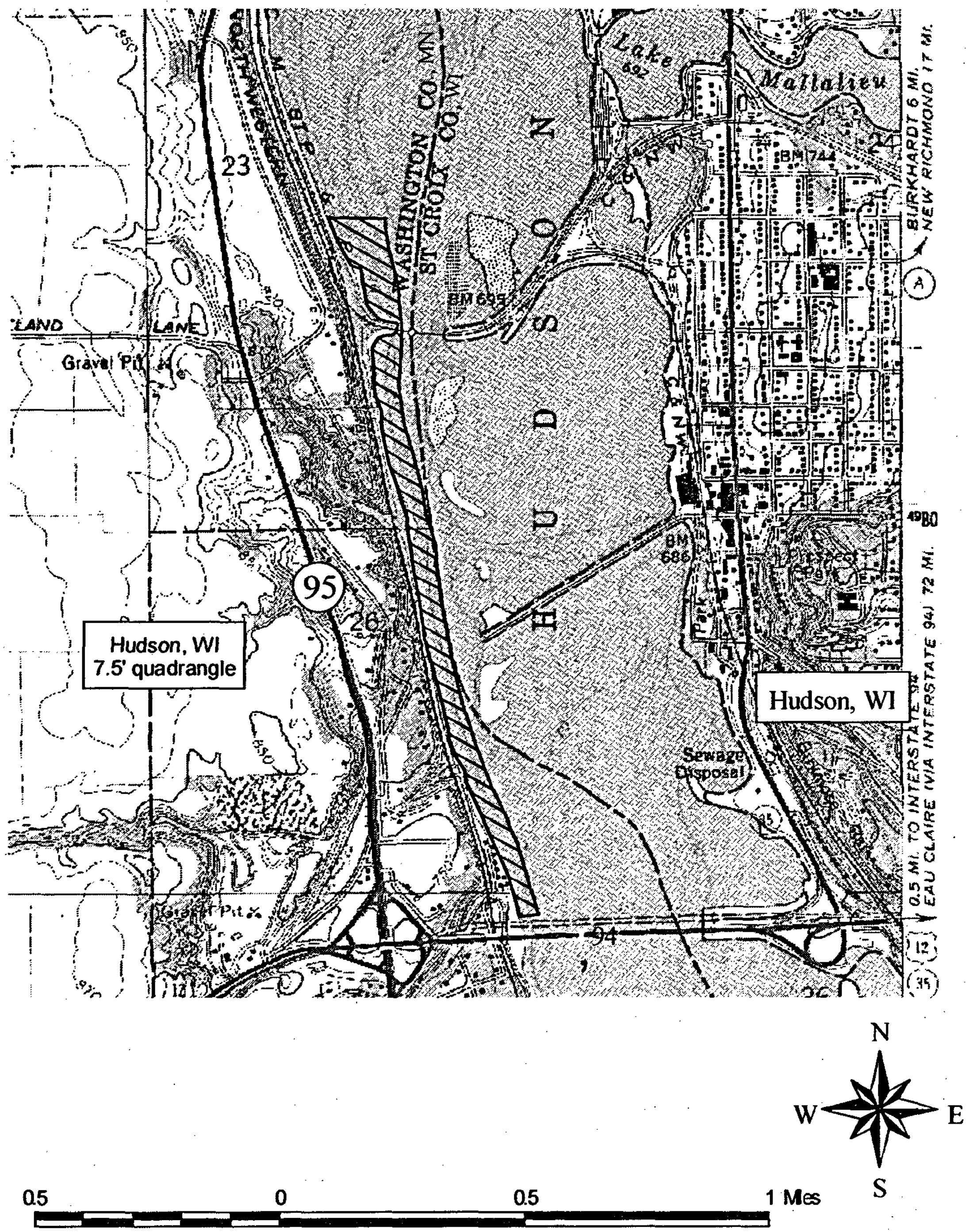

Figure 4. Essential Habitat Area at Hudson, Wisconsin, St. Croix River Washington County, Minnesota.

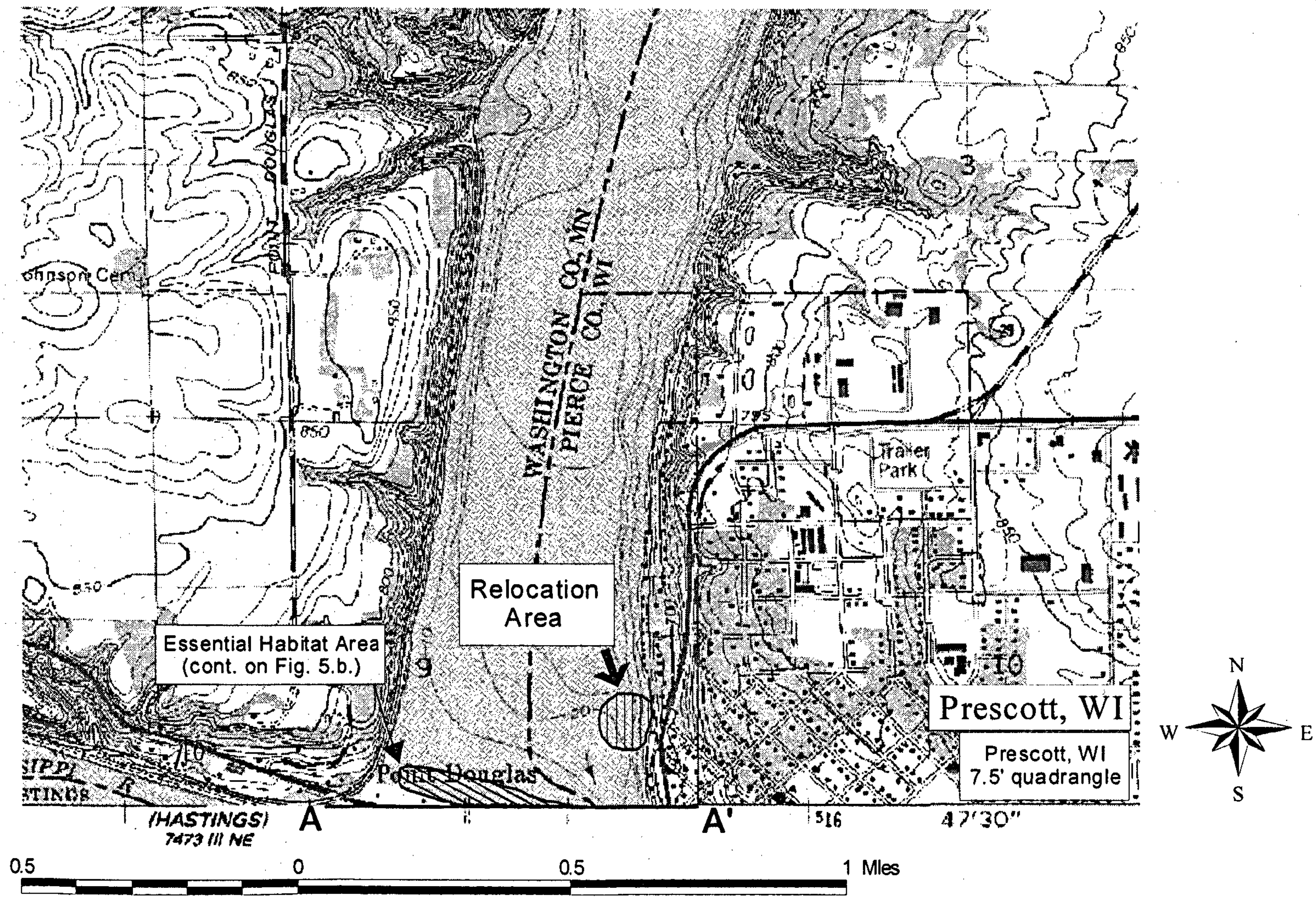

Figure 5.a. Essential Habitat Area at Prescott, Wisconsin, St. Croix River, Washington County, Minnesota, and Pierce County, Wisconsin. Match line A-A' to Figure 5.b.

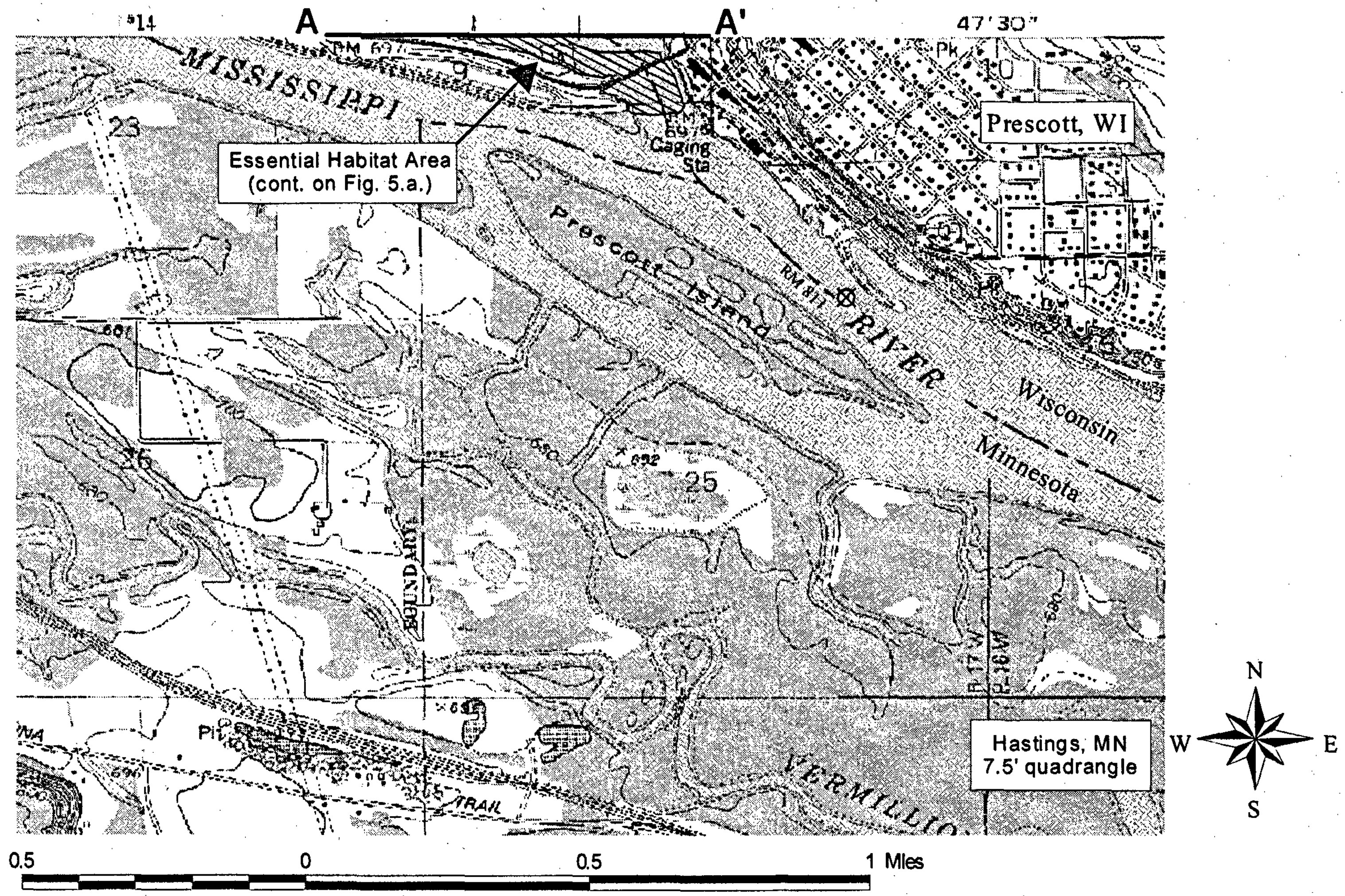

Figure 5.b. Essential Habitat Area at Prescott, Wisconsin, St. Croix River, Washington County, Minnesota, and Pierce County, Wisconsin. Match line A-A' to Figure 5.a.

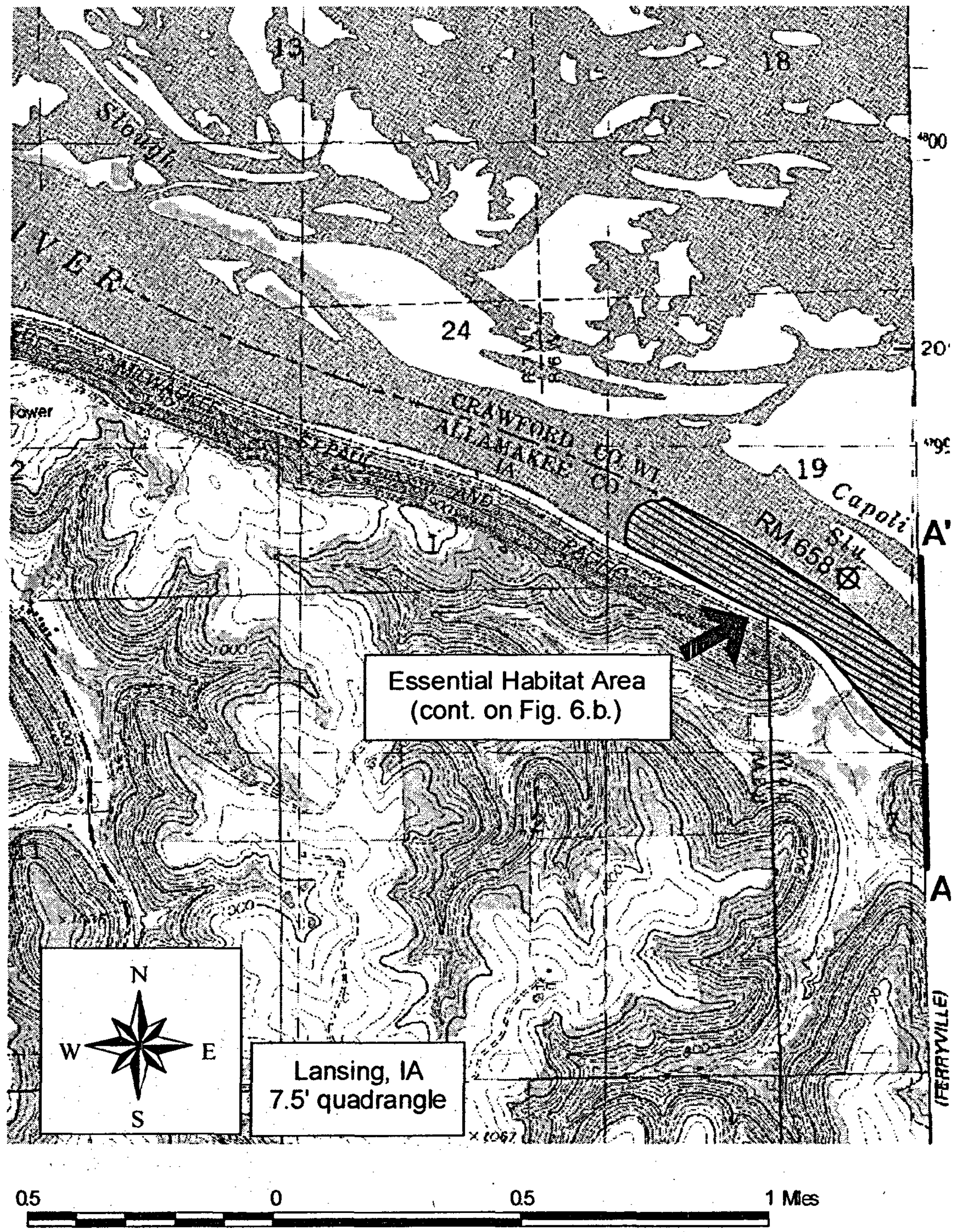

Figure 6.a. Essential Habitat Area at Whiskey Rock, Iowa, Pool 9, Mississippi River, Allamakee County, Iowa, and Crawford County, Wisconsin. Match line A-A' to Figure 6.b.

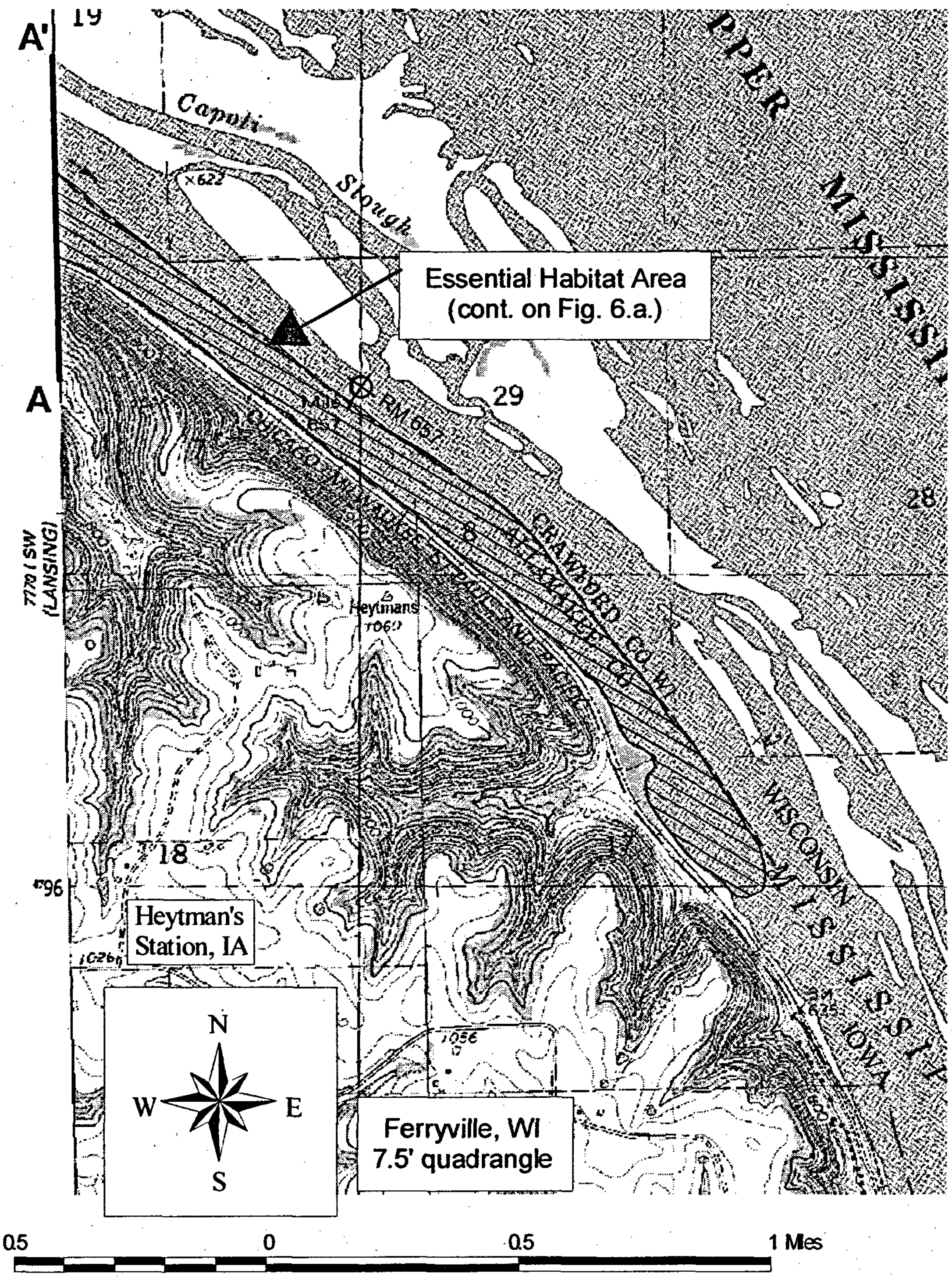

Figure 6.b. Essential Habitat Area at Whiskey Rock, Iowa, Pool 9, Mississippi River, Allamakee County, Iowa, and Crawford County, Wisconsin. Match line A-A' to Figure 6.a.

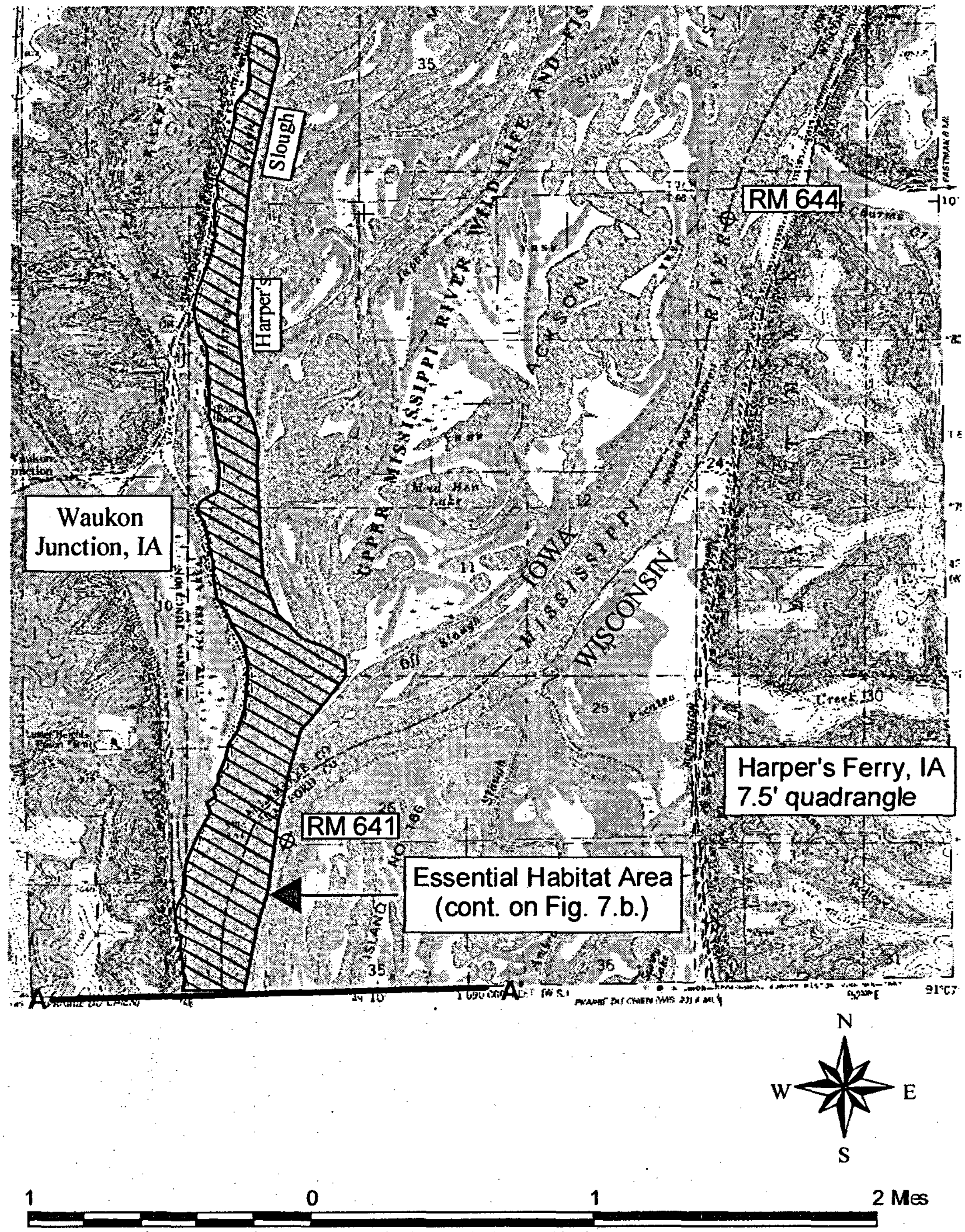

Figure 7.a. Essential Habitat Area at Harper's Slough, Pool 10, Mississippi River, Allamakee County, Iowa, and Crawford County, Wisconsin. Match line A-A' to Figure 7.b.

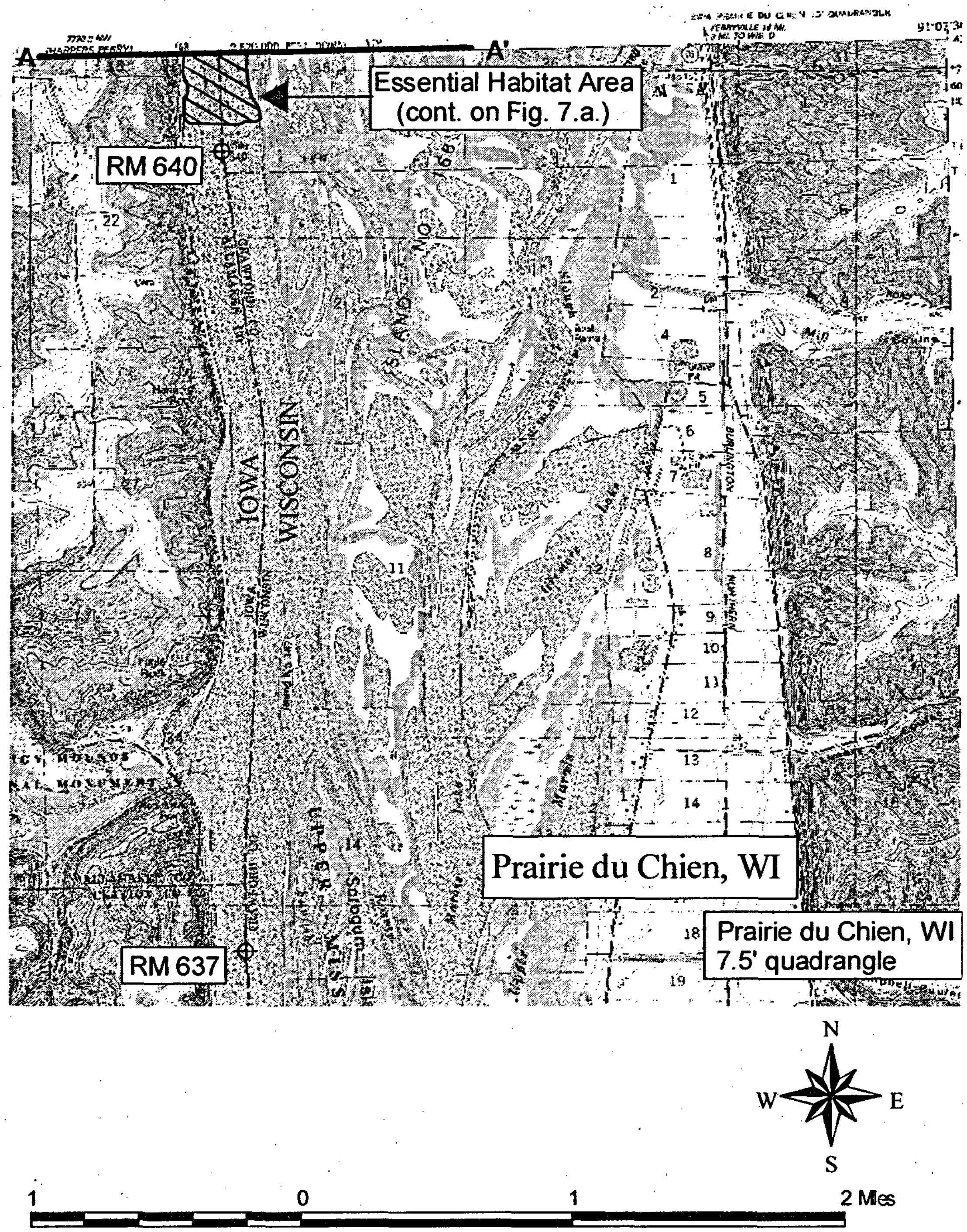

Figure 7.b. Essential Habitat Area at Harper's Slough, Pool 10, Mississippi River, Allamakee County, Iowa, and Crawford County, Wisconsin. Match line A-A' to Figure 7.a.

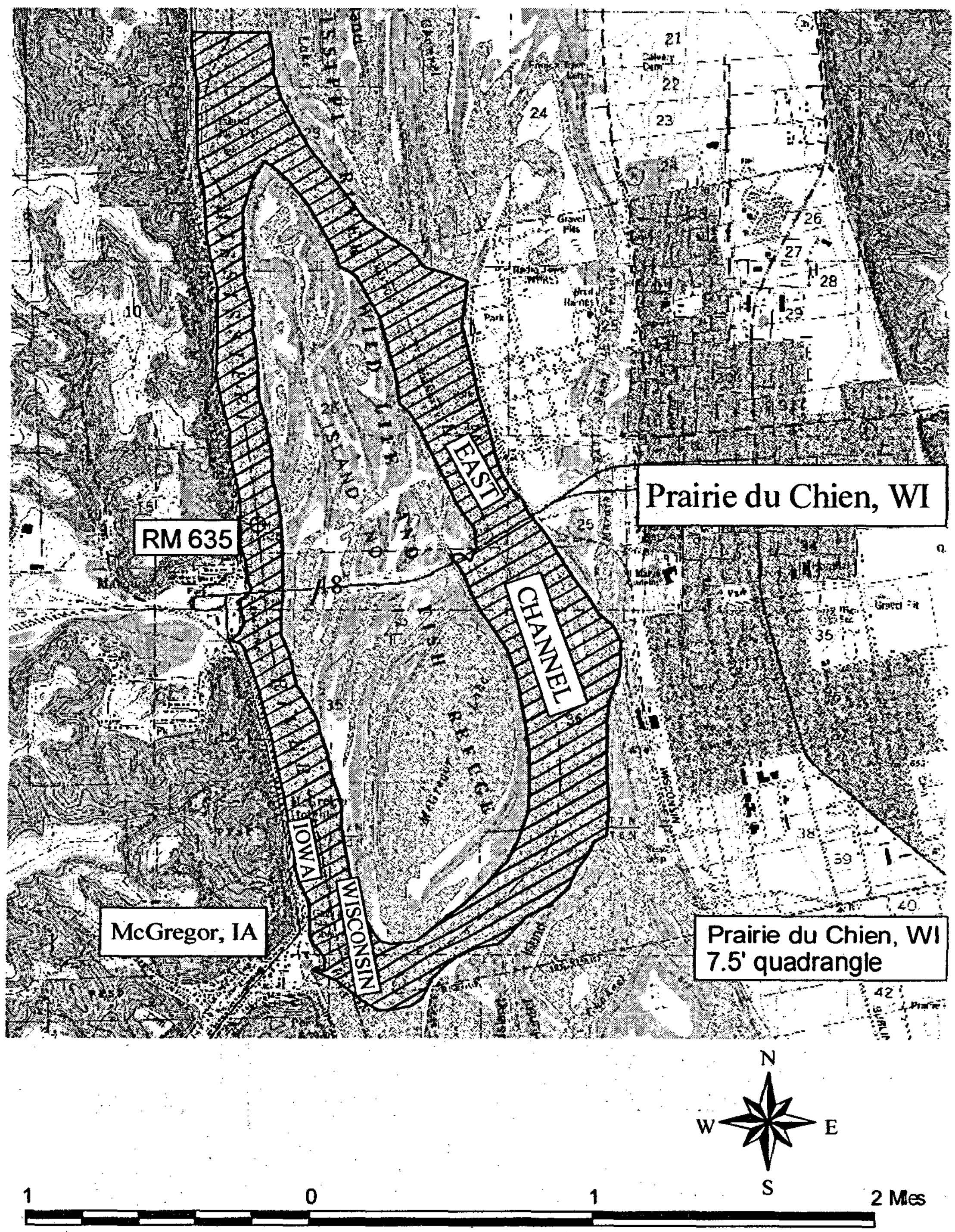

Figure 8. Essential Habitat Area at Prairie du Chien, Wisconsin, Pool 10, Mississippi River Clayton County, Iowa, and Crawford County, Wisconsin.

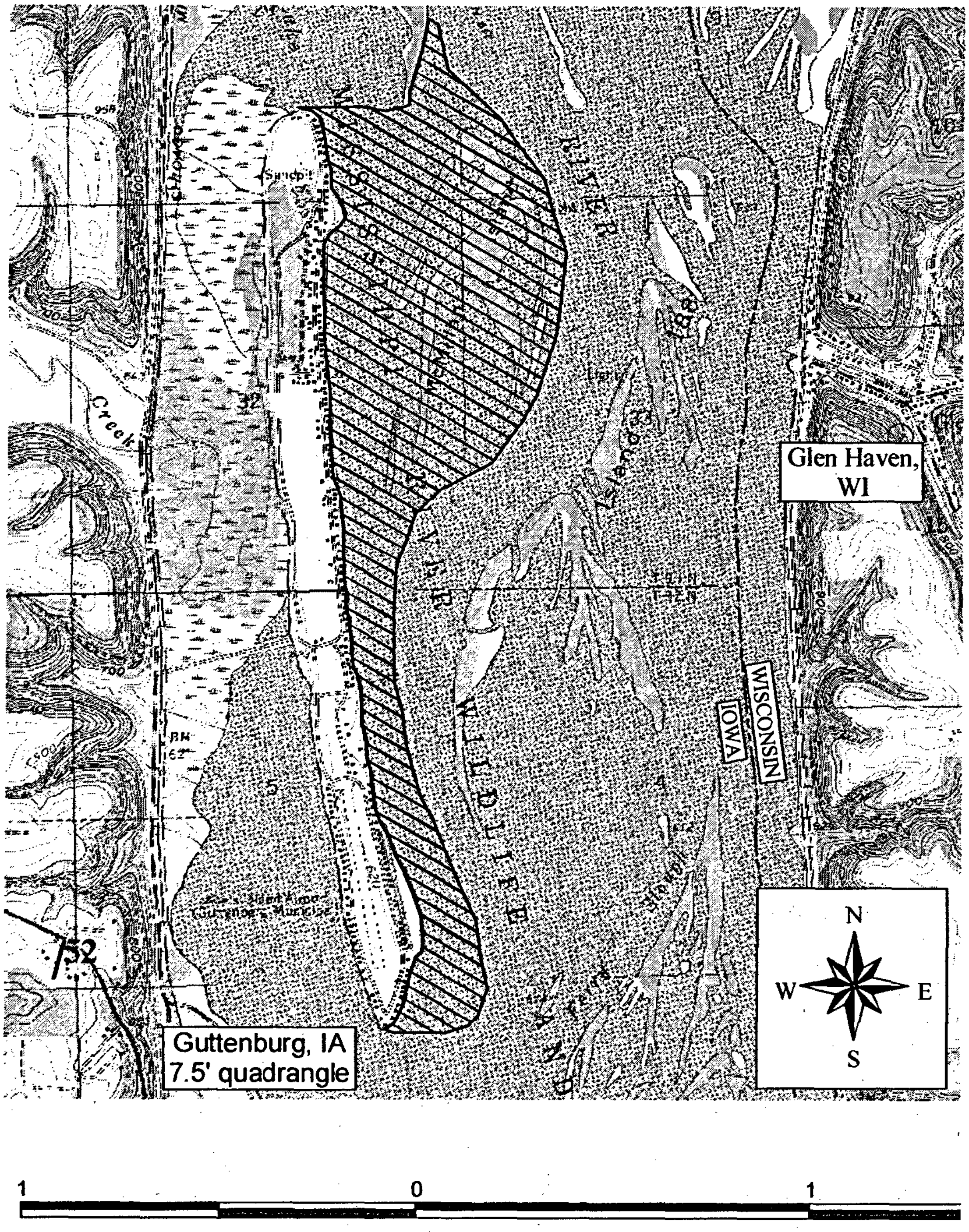

Figure 9. Essential Habitat Area at McMIllan Island, Pool 10, Mississippi River, Clayton County, Iowa.

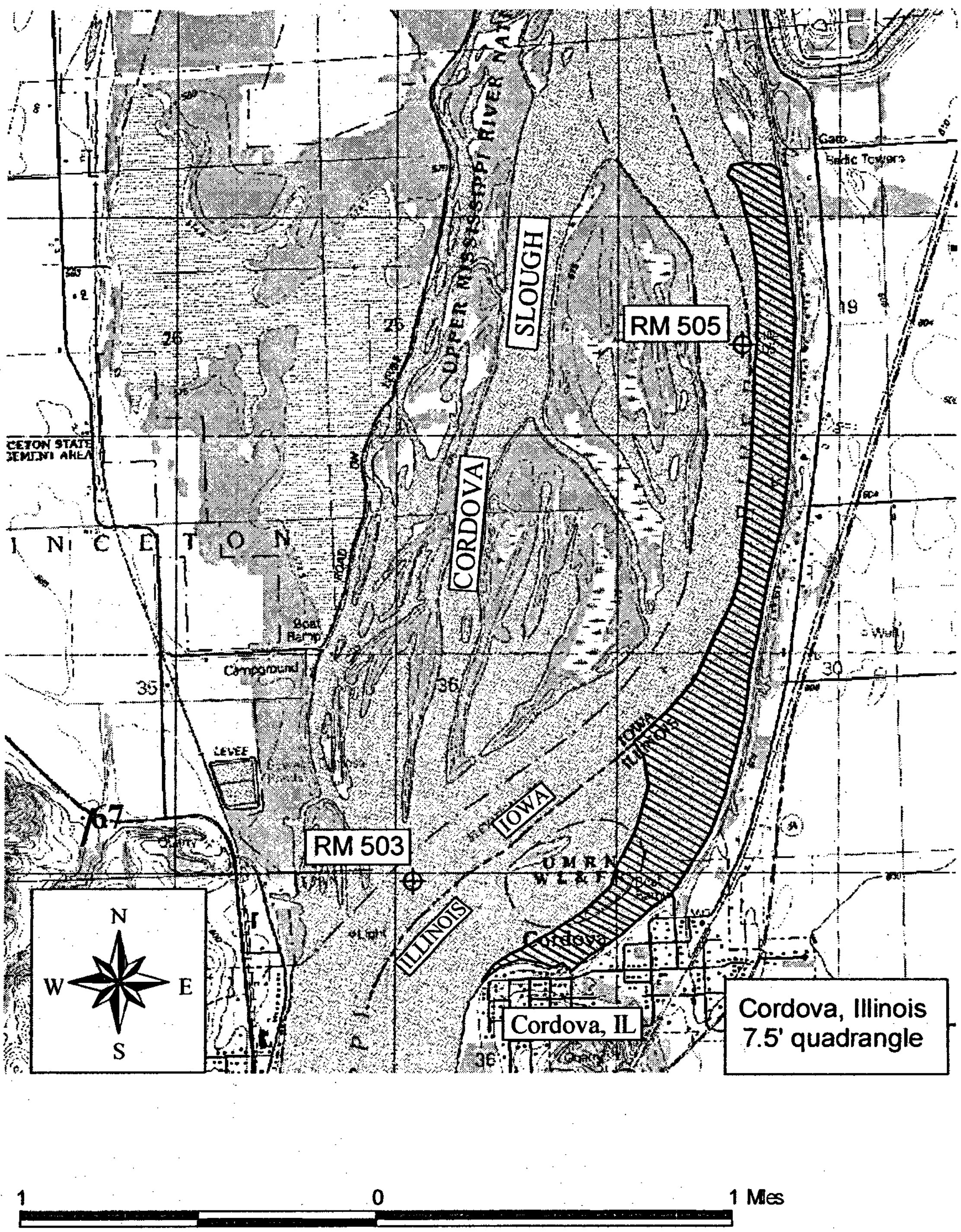

Figure 10. Essential Habitat Area at Cordova, Illinois, Pool 14, Mississippi River, Rock Island County, Illinois.

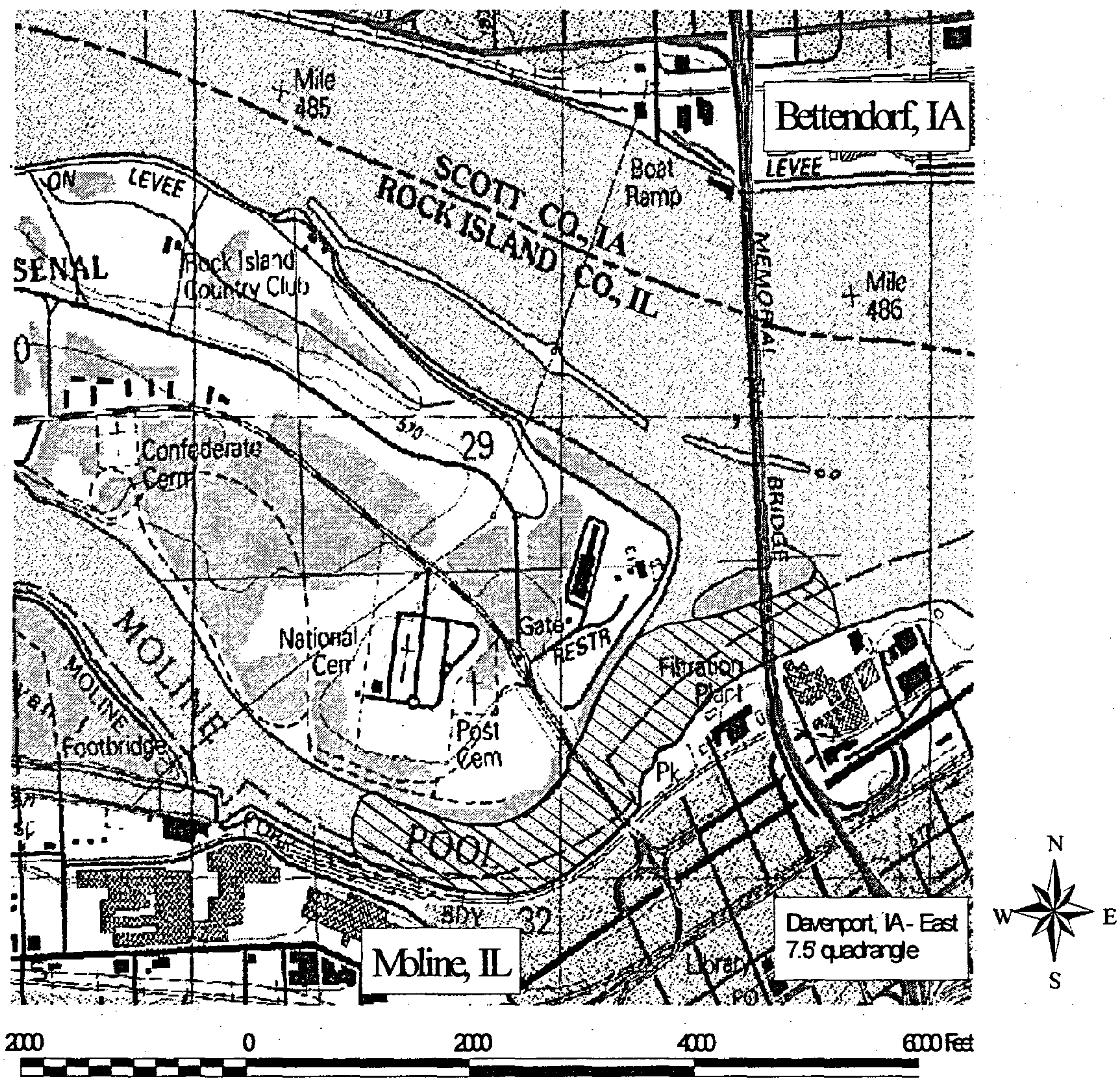

Figure 11. Essential Habitat Area at Sylvan Slough, Pool 15, Mississippi River, Rock Island County, Illinois.

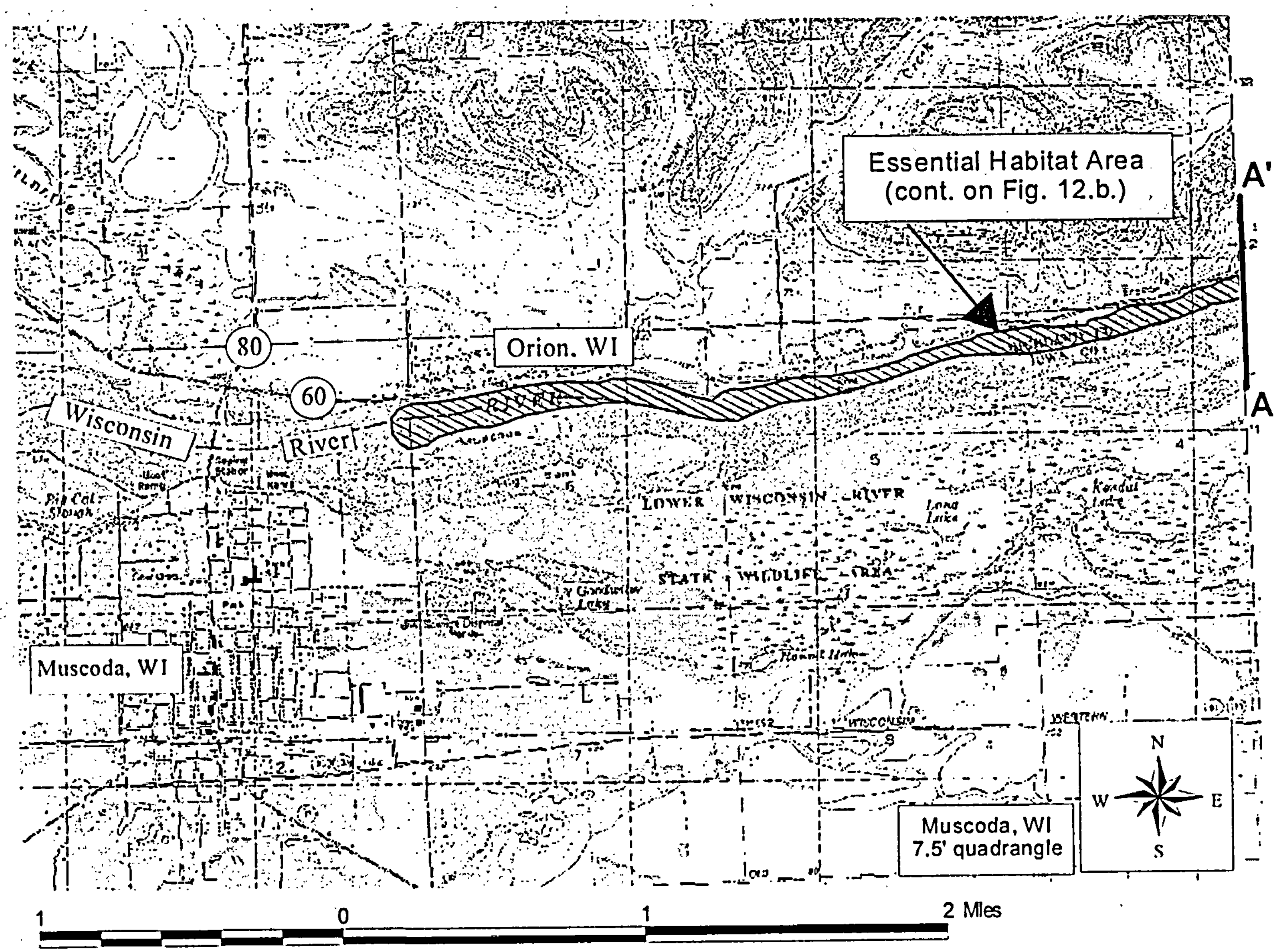

Figure 12.a. Essential Habitat Area at Orion, Wisconsin River, Richland and Iowa Counties, Wisconsin. Match line A-A' to Figure 12.b.

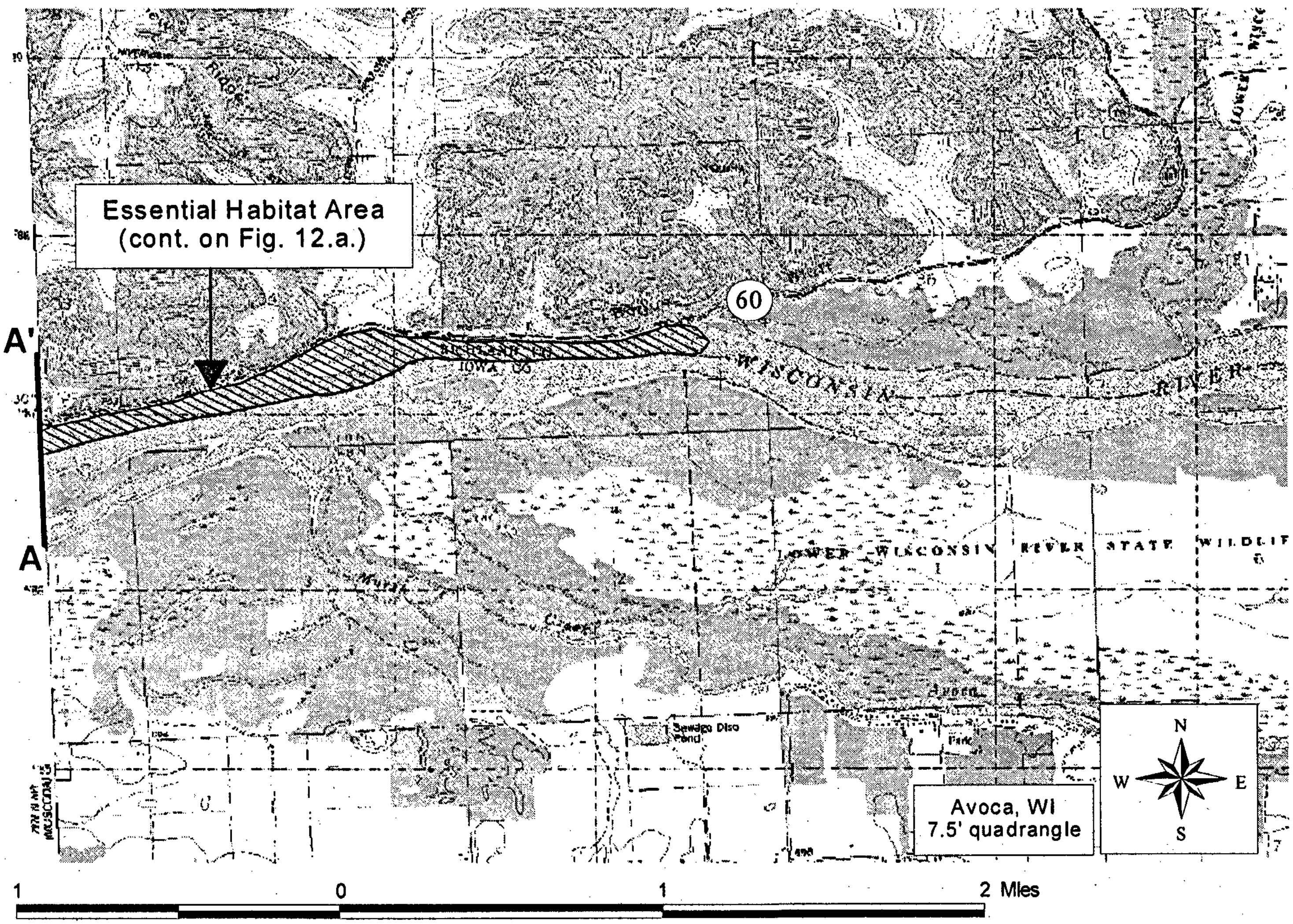

Figure 12.b. Essential Habitat Area at Orion, Wisconsin River, Richland and Iowa Counties, Wisconsin. Match line A-A' Figure 12.a.

VI. APPENDICES

Appendix A. Peer Review and Peer Contributors

The U.S. Fish and Wildlife Service extends special thanks to various experts, in addition to the experts on the recovery team, who reviewed drafts and/or provided their information or expert recommendations for the draft Higgins Eye Pearlymussel Revised Recovery Plan. This peer input was invaluable in bringing current biological information on the species and ecosystem management concepts to the current draft of the plan.

The following expert peers provided review and/or scientific information to the Service. Dr. Neves provided peer review for the 1998 and 2003 drafts.

Dr. G. Thomas Watters
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Virginia Polytechnic Institute and State University
Blacksburg, Virginia

Dr. Anne Keller
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Athens, Georgia

Appendix B. Higgins Eye Pearlymussel 1998 Technical/Agency Draft Revised Recovery Plan Review

The Service published a notice of availability of a technical/agency draft revised plan on June 22, 1998 (63 FR 33944) and transmitted the document for public review and comment shortly thereafter. The Service and individual members of the Higgins Eye Recovery Team received substantial formal and informal comments addressing a variety of format, content, and organizational points of the technical/agency draft. The team carefully considered all comments received. As a result of the technical/agency draft plan comment period, the recovery team was able to substantially improve the revised plan by incorporating the latest available biological information on the species and the measurement of its recovery, and by improving the flexibility and practicality of the plan's tasks and recovery criteria.

The following individuals/agencies provided comments on the 1998 technical/agency draft revised plan:

T.J. Miller
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Fort Snelling, Minnesota

Colonel James V. Mudd, District Engineer
Army Corps of Engineers
Rock Island, Illinois

Anthony L. Anderson, Superintendent
National Park Service
St. Croix Falls, Wisconsin

George Garklavs, District Chief
U.S. Geological Survey
Mounds View, Minnesota

Kathy Lee
U.S. Geological Survey
Mounds View, Minnesota

James D. Gruendler, Administrator
Wisconsin Department of Transportation
Madison, Wisconsin

Kurt Welke
Wisconsin Department of Natural Resources
Prairie du Chien, Wisconsin

Charles M. Pils, Director
Bureau of Endangered Species
Wisconsin Department of Natural Resources
Madison, Wisconsin

Kevin Cummings
Illinois Natural History Survey
Champaign, Illinois

Marian E. Havlik
Malacological Consultants
LaCrosse, Wisconsin

Lou Bubala
Indianapolis, Indiana

Comments and individual responses are maintained in the administrative record at the U.S. Fish and Wildlife Service, 4101 E. 80th Street, Bloomington, Minnesota 55425-1665.

Appendix C. Summary of Threats and Recommended Recovery Actions.

Listing Factor	Threat	Recovery Criteria	Tasks and Task Numbers
A	Habitat Alteration	Final Goal - 1a, 1c, 3, 4	Develop uniform protocols for collecting and maintaining information on *L. higginsii* populations. Confirm and modify the list of Essential Habitat Areas in the initial recovery plan. Limit construction in areas of essential *L. higginsii* habitat. Mitigation, including translocation, may be an acceptable alternative in limited instances. Develop plans to enhance the safety of shipping toxic or hazardous materials, reduce the introduction of these materials near *L. higginsii* habitat, and develop response plans for any spills that may occur. (see Tasks 1.3, 1.3.1, 1.3.2, 1.3.2.1, 1.3.2.2, 1.3.2.3, 1.3.3, 1.3.4, 1.3.5, 1.3.6, 1.4.1, 1.4.2, 1.4.3, 1.6.1, 1.6.2, 1.6.2.1, 1.6.2.2, 1.6.2.3)
A	Water Quality	Intermediate Goal - 2 Final Goal - 1b, 6	Continue to examine the relationship between water quality, especially contaminants, and *L. higginsii* populations in Essential Habitat Areas. (See Tasks 1.2.4, 1.5.1, 1.5.1.1, 1.5.1.2, 1.5.1.3, 1.5.1.4, 1.5.1.5, 1.5.1.4, 1.5.1.5, 1.5.1.6, 1.5.1.7, 1.5.2, 1.5.2.1, 1.5.2.2, 1.5.3, 1.5.3.1)
B and D	Commercial Harvest	Intermediate Goal - 3 Final Goal - 5	Review current regulations and develop additional regulation of mussel harvest in the upper Mississippi River drainage to reduce impacts on *L. higginsii*. Continue to develop materials to educate the public on the nature of endangered mussels and *L. higginsii*, in particular. (see Tasks 1.7.1, 1.7.2, 1.7.3 1.8.1)
E	Zebra mussels	Intermediate Goal - 1 Final Goal - 2	Assess and limit the impact of the zebra mussel, *Dreissena polymorpha*, on *L. higginsii*. Determine the feasibility of reestablishing *L. higginsii* into historic habitats, particularly streams that are at lower risk for zebra mussel colonization. (see Tasks 1.1, 1.1.1, 1.1.2, 1.1.3, 2.3, and 2.3.1)

Listing Factors:
A. The Present or Threatened Destruction, Modification, or Curtailment Of Its Habitat or Range
B. Overutilization for Commercial, Recreational, Scientific, Educational Purposes
C. Disease or Predation (not a factor)
D. The Inadequacy of Existing Regulatory Mechanisms
E. Other Natural or Manmade Factors Affecting Its Continued Existence

Appendix D. Public Comments on the 2003 Higgins Eye Pearlymussel Draft Recovery Plan: First Revision.

The Service published a notice of availability of a second draft revised plan on August 15, 2003 (68 FR 48933) and transmitted the document for public review and comment shortly thereafter. The Service received substantial formal and informal comments addressing a variety of points of the second draft. The Service carefully considered all comments received. As a result of the comment period on the second draft plan, the Service was able to further improve the revised plan.

Following is the list of individuals and agencies that submitted comments on the second draft of the Higgins' Eye Pearlymussel Draft Recovery Plan: First Revision. All comments have been reviewed and incorporated, as appropriate, into this recovery plan. Comments are on file in the Service's Twin Cities Ecological Services Field Office, Bloomington, Minnesota. Review and responses to comments received from the peer reviewer are included below.

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Comment: EPA and other state and federal agencies are called upon to take specific actions under the Plan, specifically in the conservation section. We agree that this is appropriate, but are unsure if the Recovery Plan is "binding" or how it would affect budgets, etc. Also, we were wondering how recovery tasks in this plan and the GLI BO (Great Lakes Initiative Biological Opinion) could be coordinated between funding agencies and work plans. It seems like this plan could benefit from close coordination with other activities, but this was not mentioned.

Response: The identification of specific agencies or states as Responsible Parties for actions in the recovery plan and the assignment of cost estimates for the related tasks does not constitute a mandate for action by those parties. All federal agencies, however, are required by section 7(a)(1) of the Endangered Species Act to utilize their authorities in furtherance of the purposes of the Act. Federal agencies and other parties willing to participate may benefit by being able to show in their own budgets that their funding request is for a recovery action identified in an approved recovery plan. When implementing the plan, the Service will work to determine how recovery tasks in this plan might benefit through coordination with the Great Lakes Initiative (GLI) and other activities.

Comment: In regards to Task 1.5, the development of a toxicity database could be coordinated with EPA databases like Ecotox or the GLI Clearinghouse. Other efforts such as development of toxicological testing methods and determining which life stage is most sensitive should also be coordinated with EPA to ensure that the methods will be suitable for use by EPA.

Response: The Service will work to see how development of a toxicity database mentioned in Task 1.5 could be coordinated with EPA databases, such as Ecotox, or the GLI clearinghouse. The Service will also plan to coordinate with EPA when implementing this task and its associated sub-tasks. EPA is identified as a Responsible Party for each of the sub-tasks.

Comment: I feel the major obstacle to determining if water quality is affecting Higgins' eye is the lack of toxicity information for mussels in general. The plan does point this out, but it does not clearly point out that the best way to protect mussels from ammonia/metal (at least within the current framework of the Clean Water Act and EPA regulations) is to develop and implement protective water quality criteria. The real limitation, currently, is the fact that sediment and pore water quality do not have associated criteria. In the future, the effectiveness of the criteria may be bolstered through collection of additional information which could lead to the development of a "translator" from water column to sediment concentrations which would prevent toxic buildup of contaminants in the sediments.

Response: We added a new sub-task (1.5.2.2) that states: "Develop and implement water quality criteria that would conserve Higgins' eye; these criteria should be directly or indirectly protective of sediment and pore water quality, as necessary to conserve Higgins' eye. We assumed that this task would rely on the review and analysis of data collected and analyzed under the prior task (1.5.2.1) and would cost approximately $10,000 over three years to accomplish.

Comment: EPA provided information to FWS associated with the GLI BO that shows that juveniles and glochidia are similarly sensitive overall. Thus, the statement on page 12 may not be completely accurate.

Response: We reviewed the available literature on ammonia and other contaminants that may affect *L. higginsii*, updated the information on these topics in the plan, and reviewed this text to ensure that the information accurately reflected the current literature.

Comment: The ambient water quality and sediment quality information could be more effectively utilized in the analysis, but this would require reporting the pH, temperature, and hardness associated with the data. This would allow a more robust comparison between in situ water quality and water quality criteria. For example, if pH, temperature, and hardness were reported, the ambient levels could be compared to applicable criteria values. This would strengthen any conclusions about the possible impacts of water quality on Higgins' eye survival. Also, the plan compares instream ammonia to the 1985 criteria. However, the plan was updated in 1998 and 1999, so these values should be added or the applicable state standards should be compared. Also, the ammonia mussel toxicity levels cited in the plan may be inconsistent with the numbers reported in our database, so this is a point to follow up.

Response: We added the following statement to the narrative description of tasks 1.5.1.4 and 1.5.2.1 to address the first part of this comment: "Report pH, temperature, and hardness associated with data collected in *L. higginsii* Essential Habitat Areas to allow for a robust comparison to existing or proposed water quality criteria." We also provided an updated (1999) EPA acute ammonia criterion and updated information on the effects of ammonia on mussels, most of which was taken from a recent published review of this topic.

Comment: It also may be worthwhile to compare instream ammonia concentrations with host fish toxicity data. An initial analysis indicated that host sensitivity is within a factor of 5 from the current 1999 criteria.

Response: EPA provided data on acute toxicity values of ammonia to species that have been identified and marginal or suitable hosts for *L. higginsii* and we summarized these data in the plan.

Comments (two similar comments):

(1) Essential Habitat Areas. This section references nine locations as potential secondary habitats but does not mention the location of those sites either in text or in Table 6 in Section IV. Those locations need to be included. What is the value placed on secondary habitats, and how do those habitats play into meeting the outlined tasks and subsequent measurement criteria for Goal 1?

(2) Nine potential "secondary habitats" are actually listed in Table 2, page 76, not Table 6, in Section IV. Those locations need to be described, and the basis for their inclusion cited in the text, including which six were sampled, when and how (p. 5). Furthermore, "secondary habitats" merit definition, including the qualifying criteria for future consideration of these, or other areas upon further study. And, is the site actually nearer RM 444 or 446, Bogus or Barkis Island?

Response: All references to "secondary habitats" in the draft revised plan summarize the use of this term in the original (1983) plan. The term "secondary habitats" has no specific function in the current recovery plan, which relies on the term *Essential Habitat Area* only. The plan outlines

criteria that allow for the evaluation and addition of new Essential Habitat Areas. Federal agencies should attempt to conserve any areas that possess features that may justify their addition to the list of Essential Habitat Areas for *L. higginsii*. Areas that the original recovery plan identified as "secondary habitat areas" for *L. higginsii* are likely to be among those that the Service and other agencies will continue to assess against the current plan's criteria for Essential Habitat Areas.

Comments (two similar comments):

(1) Essential Habitat Areas. The Recovery plan is very clear about designation requirements for essential habitat areas. The Corps of Engineers relocation plan for *L. higginsii* will likely include at least two sites that are not essential habitat areas. If relocations were successful in these areas, based on the existing recovery plan, these populations would not count towards the recovery Goal #1. The discrepancies between these two plans needs to be addressed.

(2) The draft Recovery Plan offers very detailed criteria for essential habitats. If the Corps of Engineers Mussel Coordination Team relocation plans for *L. higginsii* include sites that are not essential habitat areas, would these populations count towards recovery Goal #1? Any discrepancies between these plans merit reconciliation.

Response: The Service may designate additional areas as an Essential Habitat Areas for *L. higginsii* using the guidelines contained in the plan. Therefore, successful relocation of *L. higginsii* into an area that meets the Essential Habitat Area guidelines could contribute to reaching the plan's recovery goals.

Comments (two similar comments):

(1) Non-human predators. This section needs to include discussion on the potential impacts on the *L. higginsii*, and other freshwater unionids, from the introduction of black carp (*Mylopharyngodon piceus*). The species has already been collected in a Mississippi River backwater lake in Illinois.

(2) Under Recovery Goal 1- 5 and Pg. 34- Goal 2-1. We request that the sentence in each of these paragraphs be changed from "... not threatened by zebra mussels" to "...not threatened by invasive aquatic species such as the zebra mussel." The round goby and black carp have both been identified as mollusk eaters. We also believe that a section should be added to the plan that identifies known potential threats to Higgins' eye such as the black carp and round goby, species now known to inhabit the Mississippi drainage. We believe tasks should be identified in the plan to assess and address impacts from these potential threats.

Response: We agree that each of these may threaten Higgins eye and have added relevant information about each species to the Threats section of this plan. We have also modified some aspects of the plan (e.g., recovery criteria) to reflect the threat posed by invasive species in addition to zebra mussels.

Comment: Zebra Mussel Survivability. The Comprehensive Conservation Plan (CCP) for the Mark Twain National Wildlife Refuge cites a study by Tucker *et al.* 1997, which concludes that a 24

hour exposure during the summer caused high mortality in zebra mussels while having minimal impact on native mussels. This study would seem to contradict the statement in the subject paragraph concerning survival of zebra mussels for days out of water.

Response: It is clear from this study (Tucker *et al.* 1997) that zebra mussels exposed to air and substrate temperatures of 25.6-35.6° and relative humidity of 40-52% for 24 hours are very likely to die unless they are relatively protected (e.g., on the underside of native mussels). Zebra mussels are presumably transported between water bodies attached to aquatic vegetation picked up by boats or boat trailers. Zebra mussels attached to aquatic vegetation on boats or trailers would likely be exposed to more moderate temperatures and higher relative humidity than in this study, thus prolonging the number of hours or days they may survive outside of water. This comment addressed the following sentence in the draft, which is part of the discussion of overland transport of zebra mussels between water bodies: "Zebra mussels attach to nearly anything submerged and can survive for days out of water." We changed the sentence as follows (emphasis added): "Zebra mussels attach to nearly anything submerged and can survive for days out of water, depending on the temperatures and relative humidity to which they are exposed."

Comment: Development of Uniform Regulations Concerning Clam Harvesting Methods. This entire section is outdated, referencing that new rules will not be in place till 1998, which was five years ago. The existing status of state mussel regulations needs to be addressed.

Response: We worked with the states to update this information.

Comment: Recovery Goals and Interim Recovery Criteria. Goal 1 (1.c.) Zebra mussel numbers vary greatly by year. We are now seeing larger numbers of small zebra mussels, after seeing a large die off of adult zebra mussels. The criteria for this measure is that zebra mussel densities have not increased over 5 years. This criteria needs refinement. A similar number of small juvenile zebra numbers and large adult zebra mussels (i.e. the same density) would have substantially different impacts on native mussels.

Response: We refined this criterion in a way that should address this concern.

Comment: (three similar comments)

(1) Recovery Goals and Interim Recovery Criteria. It appears that the stated conditions for recovery may well be unobtainable. With the major infestation of Lake Pepin, it is reasonable to expect significant periodic re-infestations of the Essential Habitat Areas, perhaps several times, within the twenty year requirement for *L. higginsii* population establishment. Therefore, in the absence of highly significant sustainable reduction or complete eradication of all populations of zebra mussels upstream of the essential habitat areas, recovery cannot, by definition, take place. I suggest that the recovery team take a closer look at the recovery goals and objectives and not define recovery based solely on the Essential Habitat Areas concept.

(2) The criteria for Reclassification and Delisting are not realistic because the Prairie du Chien Essential Habitat Area must be one of the 5 Essential Habitat Areas. Prairie du Chien is severely

infested with zebra mussels, and *L. higginsii* is experiencing severe impacts at this location. So, short of a miraculous disappearance of zebra mussel from this location, how can the *L. higginsii* population at this site ever achieve a "reproducing, self-sustaining population not threatened by zebra mussels"?

(3) The volatile and unknown nature of zebra mussels should be discussed.

Response: Recovery of *L. higginsii* will depend on populations of the species in five Essential Habitat Areas, including the Prairie du Chien Essential Habitat Area and at least one Essential Habitat Area each in the St. Croix River and in Mississippi River Pool 14. This does make recovery dependent on at least one specific (Prairie du Chien) and two general (St. Croix River and Pool 14) areas, whereas the other two Essential Habitat Areas may occur anywhere within the range of the species. Given the historical significance of the Prairie du Chien Essential Habitat Area to *L. higginsii*, the recency of its demise, and some uncertainty regarding the future distribution and abundance of zebra mussels in the range of the species, we will maintain the focus on this particular area in the recovery plan. Moreover, the Service and the recovery team think that it is important that recovery depend on the conservation of *L. higginsii* populations that occur in relatively disparate portions of the species' range. Therefore, we will retain the dependence on recovery of at least one population in the St. Croix River and Pool 14 of the Upper Mississippi River. We have found Essential Habitat Areas to be a useful concept for assessing the recovery status of a species that is largely sedentary as an adult and whose populations are relatively discrete. Recovery cannot be obtained for any species under the Endangered Species Act until the factors that threaten or endanger it are resolved. Zebra mussels are clearly a major threat to *L. higginsii*. Therefore, the species will not be recovered until the they are no longer a pressing threat to the species in a significant portion of its range.

Comment: I think the habitat section in the original plan should be changed to reflect what we have noted in recent years. Specifically we have been consistently finding *L. higginsii* in the littoral areas of river channels. That is, in areas 2-4 feet deep that are colonized by rooted submersed aquatic plants. At both Cordova, IL and at Cassville, WI we have collected more animals from this habitat than in the gravel/sand channel areas of deeper flowing water. As currently written, the recovery plan describes the required habitat as this deeper channel condition and specifically excludes the vegetated shoreline areas.

Response: We modified the plan to recognize this recent discovery of the potential importance of these types of habitats to *L. higginsii*. We removed wording that specifically described habitats with rooted plants as being unsuitable for *L. higginsii* and summarized this recent information.

Comment: According to Turgeon *et al.* (1998) the name should be Higgins (no apostrophe) -- or, alternately, the use of Higgins' should be discussed and explained.

Response: The commenter is correct – Turgeon *et al.* (1998) uses Higgins eye without the apostrophe. We have modified the plan accordingly.

Comments: (three similar comments)

(1) The East Channel (at Prairie du Chien) should not be closed to commercial clamming and yet continue to allow up to 1000 barges/year in that Essential Habitat Area. I am not aware of any evidence that commercial clamming by divers is harmful to this endangered mussel. The shortage of funds and personnel gets worse yearly, so it remains very difficult to know what is going on with Upper Mississippi River mussels if hardly anyone is looking at the river, zebra mussel impacts etc. Clammers could help biologists. Commercial clamming should be regulated some other way, such as limiting the number of licenses in each state, so that a Clammers can be assured of a living wage. However, if the low demand for mussel shells for export continues, then this issue becomes a moot point.

(2) Is the decision to preclude mussel harvest based on scientific data or a political decision? We have not seen evidence of endangered species decline resulting from harvest of commercial species in the Tennessee River. Is there evidence of cause-effect at a population level?

(3) Under Commercial Harvest- last paragraph. It states that little is known regarding the direct impacts of commercial harvest on *L. higginsii*. However, in the Recovery Section under Goals 1 and 2 (pages 34 and 36 respectively), downlisting and delisting requires that commercial harvest MUST be prohibited by law or regulation. Again, a threat should be identified before it is dealt with. Recovery Task 1.7 (pg. 41) says nothing about determining whether harvest is causing an impact. It simply goes directly to closure within all identified Essential Habitat Areas. The states that currently allow commercial harvest that will be affected by this recovery plan will likely need data to demonstrate a negative impact of harvest on *L. higginsii* before closure can occur. Therefore, this sub-task should be added under this section and in the Task Table (as a new 1.7.1) on pg. 41. Existing Task 1.7.1 should change to 1.7.2 and be modified to read, "If warranted, develop regulations to prevent mussel harvest in all Essential Habitat Areas." We also believe that the requirements for closure under the Recovery Goals (pg. 34 & 36) should be modified to require closure if harvest is demonstrated to cause an impact on *L. higginsii.*

Response: Although there may be little or no available data to support the contention that commercial clamming is specifically harmful to *L. higginsii* populations, it is reasonable to conclude that clamming would threaten the species if it is allowed in Essential Habitat Areas. Hart (1999), for example, found that commercial harvest depressed threeridge (*Amblema plicata*) populations in Lake Pepin in the early 1990s. He found that if harvest exceeded "5% of the population or if *D. polymorpha* infestations continue at the current rate" threeridge populations were in danger of local extinctions. Threeridge is one of four species that Heath (1995) found to be very common at all known *L. higginsii* sites. Although it is morphologically distinct from *L. higginsii*, it is reasonable to assume that clammers in pursuit of *A. plicata* would inadvertently collect or harm *L. higginsii*. In addition, some commercially harvested mussels (e.g., pocketbook, hickory nut) are similar in appearance to *L. higginsii*.

The Service will monitor the status of populations and threats to their continued existence at and outside of Essential Habitat Areas. Barging or other activities cannot take *L. higginsii* without

proper authorization from the Service and the Service may not authorize such take if it would appreciably reduce the likelihood of survival and recovery of the species.

Comment: There are no D. Helms references listed in the casino discussion on page 24 (of the draft); he has done many studies at this site.

Response: The draft plan contained only one reference to floating casinos -- i.e., as an example of large vessels that may crush *L. higginsii*. Floating casinos could pose a risk to *L. higginsii* in certain areas, but we do not think that the recovery plan needs further information regarding the specific effects of casinos.

Comment: Leave the '?' indicated for the Ohio River; it is just that – a questionable location for the specimen.

Response: We inserted the '?' for the Ohio River record to indicate that this represents a questionable location for *L. higginsii*.

Comment: If a self-sustaining population in Pool 14 is a minimum requirement for recovery, then some plan should be developed about the use of the Cordova bed. Collection for relocation and other purposes is relatively easy at this bed and it may get over-exploited.

Response: In July 2001, biologists found that *L. higginsii* at the Cordova site were subject to high fouling densities of zebra mussels and decided that as many as possible should be cleaned and moved to a location where they would not be refouled. As a result, they cleaned and moved 271 *L. higginsii* to two locations in the Mississippi River in and near St. Paul/Minneapolis, MN. In 2002, biologists returned to Cordova to determine if further relocation would be warranted. At that time, biologists found more than 371 *L. higginsii* and removed attached zebra mussels, but did not remove any *L. higginsii* from the Cordova area. In 2003, several females were temporarily removed from the Cordova bed, used to infest fish at Genoa National Fish Hatchery for reintroduction of glochidia-infested fish, and returned to the Cordova bed. The Service will continue to review proposed relocation and propagation activities on a case-by-case basis to ensure that these activities do not harm the population in Pool 14.

Comment: Why are the Essential Habitat Areas not designated as critical habitat?

Response: In the June 14, 1976 final rule to list *L. higginsii* as endangered, the Service stated, "(N)o critical habitat is presently being determined for United States species. That action, if and when it occurs, will be a separate rulemaking." The Wisconsin Department of Natural Resources petitioned the Service on October 6, 1980 to designate critical habitat for *L. higginsii*. Although the Service found that the petition contained substantial information to indicate that designation of critical habitat may be warranted, it has not formally addressed critical habitat for *L. higginsii*. Under current regulations, when the Service lists species under the Act it must determine whether designation of critical habitat is prudent and, if so, whether it is feasible to determine what is critical habitat for the species. Although *L. higginsii* is already listed as an endangered species, the Service could propose a separate rule in the Federal Register to designate critical habitat for *L.*

higginsii. The number of critical habitat designations that the Service may propose and finalize in any year, however, is limited by available funding. In recent years, court-ordered critical habitat designations or court-approved settlement agreements have used all available critical habitat designation funds, thereby precluding the ability of the Service to designate critical habitat according to its own conservation priorities. If a proposal for critical habitat is prepared in the future, it would be based on the habitat features essential to the conservation of the species, similar to those used to identify essential habitat areas in the recovery plan.

Comment: The statement regarding the transplanting of adults assumes it is a beneficial action rather than an experimental strategy. It also is not consistent with recovery of parent sites as "essential habitat".

Response: In general, the plan simply states the facts with regard to translocation of adult *L. higginsii*. The inclusion of this practice under Conservation Measures may imply that the Service views this is a beneficial action. The Service has approved the translocation of adults from two locations in the Mississippi River to avoid catastrophic mortality as a result of fouling by zebra mussels – at Cassville, WI (September 2000) and Cordova, IL (July 2001). This practice could be viewed as both beneficial and experimental. The benefits of these two actions likely include reduced harm or mortality of relocated *L. higginsii* caused by fouling by zebra mussels and the reintroduction of the species into two locations within its historical range (one site each in Pools 2 and 3 of the Mississippi River). The former assumes that the survival of the cleaned *L. higginsii* would have been lower if left in the source locations (Cassville and Cordova) and the latter depends on the successful establishment of *L. higginsii* populations at the reintroduction sites. Biologists evaluated the evidence at each site before relocating the mussels and decided that their survival was likely to be higher if relocated to areas with few or no zebra mussels. Evidence of survival and reproduction at the relocation site, which is presented in the plan, suggests that the relocated mussels have not experienced unusual mortality or adverse sub-lethal effects as a result of being relocated. Continued monitoring for several years will be necessary to determine whether this relocation will result in established populations of *L. higginsii* at the relocation sites. There are also risks of adult relocation. It is possible that survival of the relocated *L. higginsii* would have been equaled or exceeded if they had been left in place after they were cleaned of attached zebra mussels. This may have occurred if zebra mussel densities had declined to non-threatening densities shortly after relocation or if teams of biologists returned frequently enough to effectively remove attached zebra mussels. When we consider relocating adults, we will assess the current and expected conditions at the threatened sites, resources for repeated cleanings, etc., and the likely benefits of relocation to determine the appropriate course of action. This was done in each case thus far and the Service will ensure that no relocations occur that would not help to conserve the species. This will be considered at all sites whether or not they are designated as Essential Habitat Areas by the Service.

Comment: (two similar comments)

(1) The following should be changed from a recovery criterion to a recovery task: "The use of double hull barges is required at and upstream of each of the identified Essential Habitat Areas that may otherwise be threatened by spills from commercial barges."

(2) Executive Summary, item D, bottom, page ix and Narrative outline, item 1.6.1, Page 41. There is a significant difference between the phrases "Require the use of...." vs "Promote the use of...." A phase-in period is needed for any double-hulled barge requirement, and then may need to be phased in by the relative toxicity of the bulk commodity in transit.

Response: We modified this recovery criterion to the following: "The use of double hull barges or other actions have alleviated the threat of spills to each of the identified Essential Habitat Areas." If means other than double hull barges alleviate the threat of spills to the identified Essential Habitat Areas, then this criterion will be met. Therefore, the criterion focuses on the alleviation of the threat of spills and allows for some flexibility in addressing the threat.

Comment: As with commercial harvest, restrictions on the collection of *L. higginsii* at Essential Habitat Areas for propagation or relocation of the species should be in place as a criterion for reclassification and delisting.

Response: This type of collection is done to conserve the species. Moreover, females collected for propagation are returned to the area from which they were removed, usually within a few weeks of collection. The Service does not think that this type of activity is a threat to the continued existence of ths species. Therefore, it would be inappropriate to address it with a recovery criterion.

Comment: Do not offer translocation of *L. higginsii* as acceptable mitigation for adverse effects caused by construction in Essential Habitat Areas.

Response: The plan states that "(M)itigation, including translocation, may be an acceptable alternative in limited instances." The Service will review such proposals on a case-by-case basis and shall not allow any action to proceed that would appreciably reduce the likelihood of the survival and recovery of *L. higginsii.*

Comment: The revised Plan needs to acknowledge *L. higginsii* population changes since the initial 1983 Recovery Plan. Weren't some of the goals of that plan accomplished? If so, revised recovery goals should recognize whatever progress has been made relative to the revised evaluation period.

Response: The recovery goals and criteria in the revised recovery plan are based on the current species' status and the current environmental baseline within its historic range. Therefore, it incorporates changes that have occurred since the original recovery plan.

Comment: The recovery strategy proposes the removal of *L. higginsii* from areas where zebra mussels pose an imminent risk, but I don't see comparable narrative for the three Essential Habitat

Areas where zebra mussels have had severe impacts. Of the ten Essential Habitat Areas, three are experiencing severe impacts and two are under imminent threat. I don't understand why removal is proposed for the latter but not the former.

Response: The plan states that the alleviation of impacts to "infested populations" ... "may consist largely of removing *L. higginsii* from areas where zebra mussels pose an imminent risk to the persistence of the population and releasing them into suitable habitats within their historical range where zebra mussels are not an imminent threat." "Infested populations" refers to populations that zebra mussels have already severely affected (e.g., populations in the three Essential Habitat Areas where zebra mussels have had severe impacts). Under recovery task 1.1.3, the Service plans to "Develop and implement an emergency response plan in the event of a demonstrable impact of zebra mussels on *L. higginsii* in Essential Habitat Areas." The Service has the discretion, in cooperation with any affected states, to also remove *L. higginsii* from locations where severe effects are imminent and cannot be prevented. This was the case in the three adult relocations that the Service and the states carried out in 2000 and 2001. No adult relocations have occurred since 2001.

Comment: The lack of quantifiable criteria makes Goal 1a subjective. For example (5a), "a sufficient number of strong juvenile year classes" is complete avoidance of the need to make a decision based on best available science at this time. The reality is that this criterion will never be fully measurable (p. 34), so delaying the decisions on what constitutes 'strong year class' or 'number of year classes' for adequate reproduction is not a substitute for current uncertainty to provide an answer. Other recovery plans have made such decisions based on best available data and expert opinion and the recovery team for *L. higginsii* should do the same. Those decisions can be revised in subsequent years, should new data become available to better quantify this criterion.

Response: The Servicé and the Recovery Team decided that the best available information at this time would not sufficiently reduce the uncertainty associated with selecting measurable criteria for each goal. Therefore, we decided to complete this plan revision and develop measurable criteria as part of its implementation.

Comment: In 1b (p. 33), how was the 20 years decided? Does the Recovery Team really believe that they can measure e.g. a 10% increase or decrease in the population at any site, short of a huge and unrealistic sampling effort to reduce confidence intervals?

Response: *L. higginsii* typically comprises a small portion of mussel communities in which it occurs. Therefore, as this commenter pointed out, the detection of population trends with acceptable power and precision would require a sampling efforts that may not be feasible. Therefore, we have modified the recovery criteria to ensure that the sampling required to assess the status of *L. higginsii* populations would be feasible.

Comment: In 5c (p. 33-34), I disagree that a five year status quo population of zebra mussels constitutes a 'no threat' to the resident *L. higginsii*. Zebra mussels at constant moderate densities likely pose a chronic threat to resident unionids because of physiological stress, food competition, space limitations, etc., such that the persistence of *L. higginsii* at that site is at some low level of

jeopardy and negatively affected. What evidence exists that a constant, moderate density of zebra mussels poses no threat to *L. higginsii* at a site? I have yet to see such data for any unionid species.

Response: We agree that this criterion in isolation would not be sufficient to determine that zebra mussels pose no threat to a population of *L. higginsii* and have removed the words "not threatened by zebra mussels" from the criterion. When the Service determines whether *L. higginsii* may be reclassified or delisted, it will evaluate the status of the species against all criteria (three for reclassification and six for delisting). For example, the species' populations must be stable or increasing for at least twenty years for the Service to consider them for reclassification or delisting. We do not think that *L. higginsii* populations and associated mussel communities under chronic stress are likely to have stable or growing populations over a twenty year period. Moreover, the zebra mussel criterion includes a fallback measure to ensure that populations that are not currently stressed by zebra mussels are not likely to become infested in the foreseeable future. The change in wording should avoid the perception that one portion of the criteria would be used to evaluate the potential zebra mussel threat for any population.

Comment: There are too many subjective narrations under this goal, such that delisting will never be achieved. Phrases such as, "reasonably likely to occur in the foreseeable future" and "appreciably reduce the likelihood of", are unquantifiable now and likely twenty years from now. The best scientific data now will not be much different from the best scientific data twenty years from now, because the cost of data collection will only escalate to infeasible levels, even more so than today. The Recovery Team seems to be unwilling to make biological decisions based on best available data on *L. higginsii* and data on other endangered mussel species. Unless those decisions are made, no matter what the level of uncertainty, the section on Recovery is one of procrastination, with a false expectation that answers will be forthcoming in the future. None have appeared in the last ten years, nor will they in the next ten years.

Response: The phrases, "reasonably likely to occur in the foreseeable future" and "appreciably reduce the likelihood of", were used in the delisting criteria reference to potential human actions that would cause significant adverse impacts to L. *higginsii* habitat in Essential Habitat Areas. There will always be some uncertainty when assessing the likelihood of future human impacts to these habitats. Nevertheless, we have modified these criteria to reduce subjectivity and ambiguity in their interpretation.

Comment: I have no problem with the concept of Essential Habitat Areas. The following statement (p. 5) supports my concern expressed earlier: "Moreover, it is unclear how long zebra mussels will continue to suppress native mussel communities at these sites." This seems to contradict the requirement of stable population density of zebra mussels for 5 years to achieve a 'no threat' status.

Response: It is unclear whether zebra mussels will return to the high densities that devastated populations of native unionids in some *L. higginsii* beds (e.g., at Prairie du Chien). Moreover, we are unconvinced that these beds do not retain the ability to recover from zebra mussels. Given the historical importance of the beds at Harpers Slough and Prairie du Chien and uncertainty about the

future nature of zebra mussel impacts there, we will keep them as Essential Habitat Areas for now and have retained the importance of Prairie du Chien in this plan's recovery criteria.

Comment: Several of these sections are outdated, with no recent citations in the last five years. For example, Tom Augspurger has an excellent paper on un-ionized ammonia that summarizes recent data on unionids. There are several recent papers on Cu, Cl, and other contaminants that are not cited. It doesn't appear that the contaminants section was updated in the last 7 years.

Response: We have reviewed the recent literature on the effects of ammonia and other contaminants to freshwater unionids and have updated the recovery plan with the relevant information.

Comment: The statement is made (p. 4) that two sites in Pools 2 and 3 have zebra mussel densities below threatening levels. What is that threshold level and how was it determined?

Response: Malacologists inspected the current unionid communities and zebra mussel densities in the two reintroduction sites and also evaluated the available information on zebra mussels upstream of these sites. Zebra mussels were sparse in each reintroduction area, unionid communities were relatively diverse, and there were no upstream concentrations of zebra mussels likely to produce significant numbers of veligers that would drift and settle into the reintroduction sites. No threshold level was evaluated, per se. Monitoring of these sites and of upstream areas thorough 2003 indicates that zebra mussels are still not a threat at these sites.

Comment: I am pleased to see the efforts being made to propagate this species. This section (p. 30) acknowledges that there are no data to evaluate the success of infested fish releases. This then brings up the question of how to objectively determine whether the populations at any of the 10 Essential Habitat Areas are stable or increasing in abundance. Release of infested fish or propagated juveniles may be adding to the population at a site, while zebra mussels, water quality, sediment contaminants, etc. are subtracting from the population. How does the Recovery Team expect to decide whether the criteria under Reclassification or Delisting are achieved when releases of undetermined numbers and unknown success will affect the overall status of the species throughout its range? For example, the use of infested fish in cages in the St. Croix River should be adding juveniles of unknown number to the population in that river. So if that population increases to the yet undefined "self-sustaining" level, will that population be declared to be recovered? Will augmentation of that population stop, such that 'self-sustaining' status can be determined? There doesn't seem to be a clear rationale that incorporates the release of fish, juveniles, and relocations (Table 1, p. 74) with the subjective criteria under Recovery. Is there any strategy to augment some sites and not others to monitor measurable effects of these attempted augmentations on population size? Is the goal to simply release as many as possible, even if there is no way to determine how many and survival rate? I do not see a cohesive plan to mesh the induced propagation efforts and their evaluation with the vague criteria proposed for the two stages of recovery.

Response: The plan states that, "(T)here are no data to evaluate the success of the free-swimming fish releases."

At this time, reintroduction and relocation of *L. higginsii* is being done primarily by the Corps of Engineers as part of its action to operate and maintain the nine-foot navigation channel in the Upper Mississippi River. The Corps' is carrying out these *L. higginsii* conservation actions as part of their operations to avoid jeopardizing the continued existence of the species and has developed a plan to guide these activities (U.S. Army Corps of Engineers 2002). The Corps plans to establish new *L. higginsii* populations at ten sites within the species' historical range. Its plan does have measurable criteria to determine whether viable populations have become established; after determining that a new population has met these criteria, the Corps will monitor for an additional twenty years to ensure that the population continues to meet its viability criteria. The Corps has released artificially propagated *L. higginsii* at a few sites at which the species already exists to refine its propagation techniques. Such augmentation of existing populations is not the primary focus of these activities. Any propagation that the Service carries out in addition to the Corps' conservation program will likely also focus on establishing new populations within its historical range where the species has been extirpated or greatly reduced in numbers. Like the Corps', the Service would allow for a lag in time between the release of fish infested with *L. higginsii* and a final evaluation of the new population's viability.

Comment: On p. 74, it would be more useful to see the number of glochidia rather than the number of fish caged or free-ranging, as that is a better indicator of attempted population augmentation.

Response: Gordon (2002) estimated the number of juveniles that transformed per fish for three species used -- smallmouth bass, largemouth bass, and walleye. We included those estimates to give the reader a rough idea of the number of juvenile mussels that may be produced for each fish released.

Comment: I would recommend three items: 1. Determination of potential contamination of essential habitat from groundwater. 2. Identification of endocrine disrupters at essential habitat. 3. Identification of hydrologic parameters at essential habitat.

Response: Completion of task 1.5.1.6 should address potential adverse effects of contaminated groundwater to *L. higginsii*. Under 1.5.2.1, the plan calls for the collection of "sediment and pore water from areas identified as currently supporting viable *L. higginsii* populations" and to analyze that water "for a range of organic and inorganic contaminants." If warranted, endocrine disrupters would be included in this analysis. Hydrologic parameters may be assessed at Essential Habitat Areas in conjunction with the identification of contaminants at Essential Habitat Areas.

Comment: It was good to see the inclusion of significance levels and power for sampling of zebra mussels and *L. higginsii* that are found on pages vi and 35. There is only one issue unresolved with this -- to construct a sampling regime, the magnitude of the trend must be specified. For the *L. higginsii* sampling the Service can figure this out when it defines "self-sustaining populations." The plan also states, however, that for Essential Habitat Areas the Service will consider them not to be threatened by zebra mussels if densities have not increased for five consecutive years. So, it will be important to state what is meant by "have not increased." I would suggest that if zebra mussels have not increased by more than 5% per year for 5 consecutive years, then the Service should conclude that their populations "have not increased."

Response: When finalizing the plan, we considered this comment and also considered changing the 'zebra mussel criterion' to reflect a density, as opposed to a trend, that would indicate that zebra mussels were not a threat to *L. higginsii* at any of the identified Essential Habitat Areas. The best available information seems to indicate that native mussels, such as *L. higginsii*, may survive in the presence of zebra mussels at some (low) densities. The information from published and unpublished sources, however, falls well short of quantifying such 'safe' densities. Therefore, if we specified an absolute density that would be safe for *L. higginsii* we would run too great of a risk of the density being impractically and unrealistically low or unacceptably high. In addition, we did not think that it would be prudent to suggest that any increasing trend (e.g., 4%, see above) in zebra mussel densities would indicate that they were not a threat. Therefore, we decided to use a criterion that would allow for a site-specific assessment of the potential threat of zebra mussels to any of the identified Essential Habitat Areas (see Recovery Criteria) without specific numeric criteria.

Comment: A note should be added that the apparent increased density of Higgins' eye associated with wing dams might be the result of both substrate suitability for mussels and their host fishes. The host fishes may spend more time in these locations, potentially depositing higher densities of glochidia in these habitats.

Response: We inserted a sentence to point out that the distribution of mussels is likely influenced to some degree by the distribution of their host fish.

Comments (three similar comments):

(1) We believe that many of the tasks under 1.5 should be considered as separate projects and should not be included in the recovery plan unless there have been specific toxins associated with Higgins' eye mortality. A toxicity database would benefit all mussel species and should be expanded beyond the Upper Mississippi basin. Costs under 1.5 comprise more than 51% of the total three-year budget and could be better used to evaluate mussel populations, evaluate habitat – including other potential habitats for reintroduction -- and to mitigate current and pending threats (round goby for example) to Higgins' eye.

(2) Page 24. Under Water Quality- Sentence one of paragraph 1 is contradicted by sentence one of paragraph 2. If there is no documentation that water quality issues are adversely impacting *L. higginsii*, then how can the plan make the statement, "The lack of information or documentation is itself the most significant water-quality related threat." An impact must be demonstrated before its significance can be evaluated. It would read more clearly to state that, "While no water-quality related issues have been documented to impact *L. higginsii*, our lack of knowledge does not preclude water quality as a threat. Therefore, we need to determine whether any impacts can be demonstrated. Then continue with the second sentence in paragraph two of this section.

(3) We believe that many of the tasks under 1.5. should be considered as separate projects and should not be included in the recovery plan unless there have been specific toxins associated with Higgins' eye mortality. A toxicity database would benefit all mussel species and should be expanded beyond the Upper Mississippi basin. Costs under 1.5 comprise more than 51 % of the

total three-year budget and could be better used to evaluate mussel populations, evaluate habitat -- including other potential habitats for reintroduction and to mitigate current and pending threats (round goby for example) to Higgins' eye.

Response: The Service decided that the potential for contaminants to be a threat to *L. higginsii* is significant despite the lack of evidence that specific toxins have killed or harmed this species. Contaminants that may threaten *L. higginsii* are likely to also threaten other aquatic organisms, especially other mussels. Therefore, implementation of these tasks should occur in cooperation with other agencies and should not rely solely on the Service's endangered species recovery funds. Augspurger *et al.* (2003), for example, state that "A need exists to work toward standardizing the toxicity tests for early life stages of freshwater mussels." This is an example of a recovery need for *L. higginsii* that it shares with many mussel species.

Comment: What baseline population densities will be used to demonstrate stability and increasing densities at Essential Habitat Areas? Population levels in some essential habitats have been significantly reduced in recent years and stability at those low levels for 20 years should signal that something is still wrong there. Some level of population recovery, especially in essential habitat like the East Channel at Prairie du Chien, should be required before reclassifying the species to threatened or delisting it, unless most of the EHAs have experienced some "reasonable level" of population recovery. Recovery levels should be defined in this plan (perhaps defined by using recent-historical Higgins' eye densities for each EHA.) The level of recovery that is needed to consider downlisting or delisting should be identified.

Response: The baseline population density could be obtained at any point in time, depending on the sufficiency of the available data. In the scenario presented above, zebra mussels or some other factor has sharply reduced the density of a population of *L. higginsii* within an Essential Habitat Area – a scenario that resembles the current situations for the species in some areas on the Mississippi River (e.g., Prairie du Chien and Harpers Slough) – and monitoring has shown that the *L. higginsii* population has been stable for twenty years. For this population to contribute to the reclassification or delisting of the species, however, it must also have evidence of reproduction based on the presence of a "sufficient number of strong juvenile year classes" and meet the mussel density and diversity criteria for Essential Habitat Areas, persistence criterion, etc. Moreover, other threats (zebra mussels, adverse changes in habitat, water quality, etc.) must also be resolved to allow for such a population to contribute toward a reclassification or delisting decision. Therefore, we think that the criteria are sufficient to identify populations in Essential Habitat Areas that are viable and that should contribute to a reclassification or delisting decision.

Comment: Section on Historical and Present Distributions- para 2. It should be pointed out that the data presented are not based on comparable quantitative sampling since no standardized methods have been established for evaluating and monitoring freshwater mussel populations involving Higgins' eye.

Response: We inserted a sentence that indicates that the available data may not allow for robust quantitative comparisons among *L. higginsii* populations.

Comment: Habitat- Water and Sediment Quality Factors. At the end of paragraph 2, a sentence should be added that the decomposition of dead zebra mussels might also result in elevated ammonia levels. It should also be added somewhere in the larger Habitat section that the identified affects, such as water quality or flows, on habitats also may influence their suitability for Higgins' eye host fishes. Those affects should also be stated where known. Under Present Threats Section add a brief paragraph on the chemical and physical alterations that are caused by zebra mussels and their decomposition and remnant shells on host fishes. If nothing is known about this, the acquisition of this information should be identified in the Task Section of the plan as at least a Priority 2.

Response: We reviewed the literature relative to zebra mussels and ammonia and added some information about this issue (e.g., excretion of ammonia by zebra mussels). We also briefly reviewed the literature on the effects of zebra mussels to native fish populations in North America. This is an important area of study that we will continue to monitor relative to *L. higginsii.* We will not add the specific task recommended above, however, but will address effects of zebra mussels via host fishes under Task 1.1, "Assess and limit impact of the zebra mussel, *Dreissena polymorpha,* on *L. higginsii.*" Part of this task includes Goal 3 of the "Zebra Mussel Emergency Response Plan": "Minimize loss of *L. higginsii* in areas already infested by zebra mussels, including restoration of habitat suitability (i.e., reducing or removing zebra mussels), where feasible."

Comment: Paragraph 3 under Recovery should include language about the Corps' potential to improve conditions to benefit unionids and potentially reduce zebra mussel threats. We recommend developing an additional Task section (2.5) to address this as a recovery option as follows:

> 2.5 Examine alternatives to operation and maintenance of the 9-foot channel project to affect zebra mussel and unionid populations.
>
> > 2.5.1 Examine flow alteration on veliger distribution.
> >
> > 2.5.2 Explore creation of new habitats by altering existing wing dams and/or construction of new wing dams.

Response: Under section 7(a)(2) of the Endangered Species Act, federal agencies, such as the Corps, must consult with the Service on any action that they fund, authorize, or carry out that may affect endangered or threatened species. These issues are the subject of consultations between the Service and the Corps and we have chosen to not address them in detail in the recovery plan. The recovery plan and its goals, objectives, and criteria, however, will inform and help to guide these consultations.

Comment: Development of uniform protocols under 1.2.1 should be moved up to a priority 1 task. Standardized protocols are essential for determining mussel densities and long term trends in the populations. Much of the historical freshwater mussel work was conducted using simple random searches by various methods that provide little more than presence of species captured at site locations. Development of standardized protocols will facilitate answering questions in tasks 1.2.2

and conducting tasks1.2.4, 1.3.3 and 1.3.4. Standardized protocols for mussels and habitat will allow for valid statistical comparisons across time scales and among sites.

Response: We agree that the development of uniform protocols is important to be able to evaluate the status of *L. higginsii*, but we do not agree that it rises to the level of a Priority 1 task. In the (August 2003) draft recovery plan 1.2.2 was a Priority 1 task, but it is a Priority 2 task in the final plan.

Comment: Task 1.2. Consider adding a sub-task (1.2.5) -- develop criteria to define a stable attendant mussel community within essential habitat areas.

Add a sub-task (1.2.6) -- develop indices for growth and mortality to help define population status accurately.

Response: Essential habitat areas used as a basis for reclassification and delisting decisions must include a total mussel density of >10/m2 (Upper Mississippi River) or > 2/m2 (other rivers) and contain at least 15 other mussel species, each at densities greater than 0.01 individual/m2. Although these criteria may not be sensitive to trends in mussel abundance and diversity in EHAs, populations of *L. higginsii* must be stable or increasing in an EHA to contribute to reclassification or delisting of the species. Because L. higginsii is relatively rare, it is difficult to quantify population trends. Therefore, evaluations of the trends of *L. higginsii* populations will rely in part on trends of sympatric species' populations.

Comment: Under Tasks 2.2- We believe these tasks should be increased to priority 2. The plan does not mention any task to enhance natural contact between Higgins' eye mussels and natural fish hosts. One of the limiting factors may simply be lack of mussel/host contacts for glochidia transfer within their natural habitat. Comments by Miller and Payne (1996b) on the value of wing dams for Higgins' eye and other mussels may be more indicative of fish holding habitat than true mussel habitat preferences. Areas that concentrate and hold fish for extended periods of time will likely have more mussels due to glochidia released from fish.

There is no mention of developing strategies for host fish stability, protection or enhancement, such as the regulation of fishing tournaments or the creation of fish refuges. We believe this should be included as additional tasks- priority 3.

Response: Seven fish species from three families are suitable fish hosts for *L. higginsii* (Table 3). The diversity of these species and their relative abundance in the Mississippi River system does not support the contention that *L. higginsii* are threatened by limited availability to fish hosts.

Comment: Consider adding a task to develop an alternative preservation plan for Higgins' eye mussels either through hatchery salvage or introduction into non-historical locations as a safeguard measure if this plan's primary efforts to save and recover the species fail.

Response: Such an alternative plan does not seem warranted at this time. The Service will continue to monitor the status of species and of any new threats to its continued existence. If such

drastic measures seem warranted, the Service will act on the best available alternatives to prevent the extinction of the species.

Comment: Introduction (p. 3): The last sentence under "Taxonomy and Systematics" mentions that there is still some controversy surrounding the taxonomic status of *L. higginsii*. It is unclear how significant this controversy is when an earlier statement said that "most malacologists agree that *L. higginsii* is a valid species." A recovery action does suggest a need for further study. It would be helpful to provide additional explanation about the controversy as to what additional questions need to be asked, or whether a second review, similar to Johnson (1980) should be done.

Response: The Priority 3 task, "Examine the morphological, conchological and genetic differences between *L. higginsii* and *L. abrupt*", is sufficient to address any current uncertainty about the taxonomic status of *L. higginsii*.

Comment: There is no mention after the introduction about the threat of another flood. It would be helpful to address this threat again, even if there are few recovery actions that can be taken to prevent weather-created flooding. Since the impacts of the 1993 flood was a major factor in the revision of the plan as stated on page 1 of the document, it should be clarified as to what the recovery plan's approach to flood impacts are, i.e. is there a need for additional actions, or are no actions necessary because *L. higginsii* have survived OK as demonstrated by 1993 flood, etc.

Response: Floods are not generally regarding as a threat to *L. higginsii*, although they are likely to modify the species' habitat roughly in proportion to the magnitude of each event. The Service commissioned several studies after the 1993 floods due to the great magnitude of this event. These studies corresponded to the initial invasion and population growth of zebra mussels in the Upper Mississippi River. The severe impacts of this invasive species and other factors, not floods, are the recognized threats to *L. higginsii*.

Comment: Criteria #3 under Goal 2 (p. 36), use of double hull barges: There is little argument / documentation for the requirement of double hull barges earlier in the recovery plan. On p. 24, the plan states that "Harm to *L. higginsii* has not be documented as a result of a single contaminant spill or short-term contaminant episode, but such episodes have been strongly implicated in mussel die-offs elsewhere." Additional explanation of why double hull barges is a must should be added to the document or else this recovery criteria should be reworded. Perhaps, "the threat of spills from commercial barges has been minimized through regulation or other actions, i.e. use of double hull barges, upstream of each of the identified Essential Habitat Areas."

Response: We changed this criterion to: "The use of double hull barges or other actions have alleviated the threat of spills to each of the identified Essential Habitat Areas."

Comment: Narrative Outline (p.37-42): The Executive Summary and Introduction section of the plan state that the Twin Cities Field Office will retain an up-to-date list of Essential Habitat Areas and post it on the Internet, however there is no recovery action that cites this action.

Response: We added the following task (1.3.6): "Maintain an up-to-date list of Essential Habitat Areas and the supporting data for each at the Service's Twin Cities Field Office and make this information, or a summary thereof, available through the internet."

Comment: The recovery plan states that the list of seven Essential Habitat Areas identified in the original recovery plan will remain and an additional three EHAs will be added to a current list of ten EHAs (p. 5). It is unclear as to why action 1.3 is needed, "Confirm and modify the list of seven Essential Habitat Areas in the initial recovery plan". It seems that this action item should be retitled "Maintain a list of Essential Habitat Areas." Action 1.3.1 should be replaced with "Post the list of Essential Habitat Areas on the Internet so that is it easily available to partners and the public."

Response: We modified Task 1.3 to state: "Maintain a list and an ongoing evaluation of Essential Habitat Areas." Under this task, the ten Essential Habitat Areas recommended in this plan will be evaluated and additional areas will be added; the guidelines contained in the plan will be used to evaluate potential new Essential Habitat Areas.

Comment: (p. 37): It is unclear why the zebra mussel emergency response plan will "determine whether, and how, *L. higginsii* essential habitat areas should be redefined." This revised recovery plan is stating that it accepts the original 7 plus adds 3. What redefining is needed?

Response: The list of Essential Habitat Areas will not necessarily be static, but will include only those areas that the Service, in consultation with the Recovery Team, has determined are of utmost importance to the conservation of the species. Zebra mussels are one of the key factors to assess and monitor, including native mussel density and diversity, the geographic extent of the Essential Habitat, and other threats, to ensure that each site that we have designated as an Essential Habitat Area still maintains this importance to *L. higginsii.*

Comment: 1.3.2.1 (p. 38). It is unclear if this is one task or two? Could there be more than one EHA within Pool 10 or are the other areas to be identified as EHAs outside of pool 10?

Response: This task was changed to the following: "Survey Pool 10 to determine whether additional Essential Habitat Areas may be identified in this pool."

Comment: 1.7.2 (p. 42): 1.7.1 already recommends that mussel harvest no longer be permitted in EHAs so should this recovery action be to review existing harvest regulations for areas outside of EHAs?

Response: We changed this task to the following: "Review existing harvest regulations and make recommendations to the USFWS and the States on any regulations needed outside of Essential Habitat Areas."

Comment: 2.1 (p. 42): This action calls for ranking existing populations for enhancement but the step-down actions only look at non-EHAs. I recommend adding a recovery action to "prioritize existing EHAs based on data collected under 1.3."

Response: Task 2.1 is meant to apply to areas that do not meet the guidelines for Essential Habitat Areas. Therefore we changed it to read as follows: "Identify and rank potential sites of existing *L. higginsii* populations for enhancement." The sub-tasks are unchanged from the draft.

Comment: The Tumbling Creek cavesnail recovery plan (actions 6-8 and their subtasks) and the Lake Erie watersnake recovery plan (action 5 and its subtasks) include additional recovery actions such as revising the recovery plan when needed, convening a recovery implementation team, and developing a post-delisting monitoring plan. I recommend adding similar recovery actions to this revised recovery plan.

Response: We added the following tasks to the plan:

3 **Update, revise, or add to the plan to keep it current and useful.**

4 **Develop a plan to monitor *L. higginsii* after it is removed from the list of Endangered Species.**

We did not add a task to convene a recovery implementation team. An active recovery team is in place that will assist the Service with the implementation of the recovery plan.