Technical Report EL-97-12
August 1997

US Army Corps of Engineers
Waterways Experiment Station

# Measures to Minimize Harm to *Lampsilis higginsi* Caused by Passage of Commercial Navigation Vessels in the Upper Mississippi River

by Andrew C. Miller, Barry S. Payne, Fawn M. Burns







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Final report



Prepared for U.S. Army Engineer District, St. Louis
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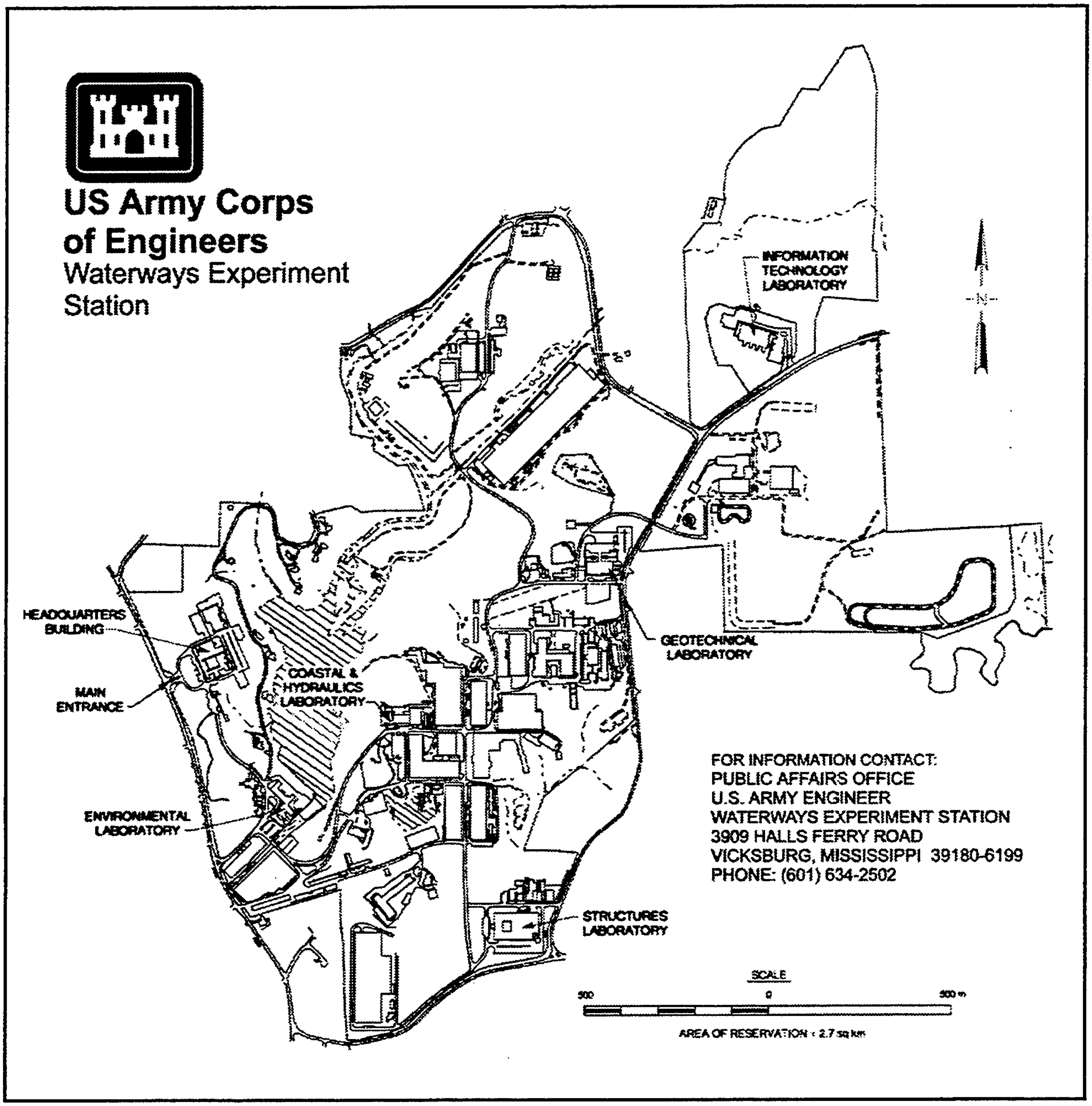


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# Contents

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# Preface

The U.S. Fish and Wildlife Service required, in the Incidental Take Statement, that a report be prepared that would recommend methods to reduce negative effects associated with increased commercial navigation traffic resulting from completion of the Second Lock of the Melvin Price Locks and Dam (formerly Locks and Dam 26). The document was to contain methods and plans that would help reduce navigation impacts associated with the increased use of the upper Mississippi River System. The U.S. Army Engineer District, St. Louis, requested that personnel of the U.S. Army Engineer Waterways Experiment Station (WES) prepare the document that would be reviewed by Federal and State agencies.

The following individuals assisted with cost estimates for environmental features in this plan: Mr. Steve Jones, U.S. Army Engineer Division, Mississippi Valley; Dr. Frank Neilson and Hollis Allen, WES; and Mr. Claude Strauser, U.S. Army Engineer District, St. Louis. Information on mussel beds was provided by Mr. Butch Atwood, Illinois Department of Natural Resources, and Messrs. Kevin Cummins and Douglas Blodgett, Illinois Natural History Survey. Personnel from the St. Louis District and the U.S. Fish and Wildlife Service reviewed early drafts of this report.

During the conduct of this study, Dr. John Harrison was Director, Environmental Laboratory (EL), WES; Dr. Conrad J. Kirby was Chief, Ecological Research Division (ERD), EL; and Dr. Alfred F. Cofrancesco was Chief, Aquatic Ecology Branch (AEB), ERD. Authors of this report were Drs. Andrew C. Miller and Barry S. Payne and Ms. Fawn M. Burns, AEB.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin.

This report should be cited as follows:

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# Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

| Multiply | By | To Obtain |
|---|---|---|
| feet | 0.3048 | meters |
| inches | 2.54 | centimeters |
| miles (U.S. statute) | 1.609347 | kilometers |
| tons (2,000 pounds, mass) | 907.1847 | kilograms |

# 1 Introduction

## Background

Native freshwater mussels (family: Unionidae), a resource with cultural, ecological, and economic value, reach their greatest abundance and richness in large and medium-sized rivers in the central United States. These organisms are long-lived, 30 or more years for many species, and feed on particulate organic matter in the water column. Immediately after being released from the female, immature mussels must spend approximately 10 days on the gills or fins of a freshwater fish. After the mussel drops off, it is virtually nonmotile and spends the rest of its life partially buried in stable sand/gravel or sand/silt substratum. When present at a site, freshwater mussels can be considered indicators of permanent water, stable substratum, and moderate to good water quality.

There are nearly 300 taxa of freshwater mussels in the United States and Canada. Williams et al. (1992) report that 71.7 percent are endangered, threatened, or of special concern. Various methods have been considered to protect mussels from water resource developments: relocating organisms, modifying project plans to minimize impacts, creating new or protecting existing habitat, and artificial propagation. All species of mussels are benefited by endangered species surveys and efforts to protect a single listed species. In addition to information on Federally listed organisms, endangered species surveys provide much needed information on the biology, ecology, and life history of nonlisted species. Implementation of plans to protect habitat for endangered species will benefit nonlisted species.

A species is considered "endangered" if it is likely to become extinct throughout all or a significant portion of its range and "threatened" if it is likely to become endangered within the foreseeable future. Organisms become extinct because of loss or conversion of appropriate habitat or competition by man or other organisms. Endangered or threatened species are usually uncommon, with highly specialized habitat requirements, and not widely distributed. Many species obtain Federal protection when it is determined that their historical range has greatly diminished. However, there are many uncommon, specialized species that are widely distributed and therefore not threatened or endangered.

The Higgins' Eye mussel, *Lampsilis higginsi* (Lea 1857), was listed as endangered in 1976 because of a reduction of approximately 50 percent of its range. As part of compliance with the Endangered Species Act of 1976, as amended, Federal and State agencies, as well as local municipalities, have sponsored numerous surveys for this species. This has resulted in much distributional and ecological information on *L. higginsi* and a commitment by many organizations to modify projects to help protect it and preserve its habitat. *Lampsilis higginsi* has been collected in the upper Mississippi River (UMR) between Lake Pepin, near River Mile (RM) 765[1] and RM 407 in Pool 17 (Cawley 1996) although it is most commonly collected in Pool 10. In addition, this species has been collected in the St. Croix, Rock, Wisconsin, and Minnesota rivers.

## Brief History of Melvin Price Locks and Dam Project

In 1978, the Inland Waterways Authorization Act (Public Law 95-502) authorized the U.S. Army Corps of Engineers to replace Locks and Dam 26 (now known as the Melvin Price Locks and Dam Project) at Alton, IL, by constructing a new dam and a single 1,200-ft[2] lock approximately 2 miles downriver of the existing dam. Public Law 95-502 also directed the upper Mississippi River Basin Commission to prepare a "Comprehensive Master Plan for the Management of the Upper Mississippi River System" in cooperation with appropriate Federal, State, and local interests. The Commission completed the Master Plan report and submitted it to Congress on 1 January 1982. The Master Plan recommended construction of a second lock chamber, 600 ft long, at the Melvin Price Locks and Dam Project.

The U.S. Army Engineer District, St. Louis, prepared an Environmental Impact Statement (EIS) for the second lock in compliance with the National Environmental Policy Act. As described in the EIS, the physical effects of commercial vessel passage associated with the second lock were of special concern. The EIS was published in July 1988. It included information on project design, environmental resources in the area, endangered and threatened species, and a discussion of overall impacts of the second lock.

## Authority

Pursuant to 50 CFR 402.14 (g)(7), the U.S. Fish and Wildlife Service (USFWS) must formulate a statement concerning the Incidental Take of a listed species if such take is likely to occur. Coordination on endangered species is part of a formal consultation process on endangered species. As part of this coordination, the level of take that is anticipated to occur due to the action must be considered. The USFWS is to develop, and the

[1] Personal Communication, 1996, Mike Davis, Minnesota Department of Natural Resources, Lake City, MN.

[2] A table of factors for converting non-SI units of measurement to SI units is presented on page vi.

Federal agency is to implement, reasonable and prudent measures that will minimize impacts of the action. In addition, the USFWS sets terms and conditions that must be met. If the level of Incidental Take is exceeded, formal consultation under Section 7 of the Act must be reinitiated.

On 20 November 1987, the USFWS completed their Biological Opinion, in accordance with Section 7 of the Endangered Species Act, on the second lock of the Melvin Price Locks and Dam project. The Biological Opinion and the attached Incidental Take Statement recommended an extensive 7-year baseline study of mussel populations in the UMR. The USFWS determined that increased commercial traffic, as a result of the second lock, would negatively impact *L. higginsi*. Since this species comprises a small percentage of the mussel community (usually 0.5 percent), and there was concern in disturbing this species, a surrogate species concept was incorporated. Mussel populations and communities would be studied and results applied to *L. higginsi*.

The Incidental Take Statement prepared by the USFWS provided a basis to evaluate traffic effects. A section in the Incidental Take Statement, titled "Reasonable and Prudent Measures to Minimize Impacts of the Taking," listed the following three goals:

*a.* *Monitoring mussel communities to detect changes in the various criteria described in the previous section "Level of Take."* The goal was to establish a baseline and to monitor the mussel community over a period of time that tow traffic was expected to increase due to the second lock. Changes in the mussel community were to be noted and compared with the previously discussed criteria. This lead to the development of navigation effects studies conducted by the U.S. Army Engineer Waterways Experiment Station (WES).

*b.* *Navigation effects studies to determine the nature and extent of tow impacts on mussels.* The goal was to determine the nature and extent of tow-induced physical impacts on mussels and *L. higginsi* so that appropriate action could be taken to minimize harm.

*c.* *A feasibility study of additional measures to minimize harm.* The goal was to determine specific activities that would reduce impacts caused by increased commercial navigation traffic.

Following the listing of these three measures, a study design to evaluate the effects of commercial navigation traffic was prepared. The design included information on site selection, methods to be used for physical and biological sampling, and the type of data to be collected. Study design was based on information in the Incidental Take Statement. The study was conducted from 1987 through 1994 (see Miller and Payne 1996a).

## Agency Involvement

The present document was based on information in a recovery plan prepared by the Higgins' Eye Recovery Team (USFWS 1982), other published information on *L. higginsi*, and results of studies in the UMR conducted by WES from 1988 to 1994. Information was also obtained from "Design Memorandum No. 24, Avoid and Minimize Measures," prepared by the St. Louis District (U.S. Army Corps of Engineers 1992).

A draft of the present document was used in an interagency meeting in late spring 1996. The report was reviewed and suggestions were provided by attendees. The final version of this report was then prepared based upon all comments and suggestions. In addition to WES personnel, the following agencies participated in this process: the USFWS, the Wisconsin Department of Natural Resources, the St. Louis District, and the American Waterway Operators.

## Purpose

The purpose of this report is to review pertinent aspects of the biology and ecology of *L. higginsi* and to recommend measures to minimize possible harm to it caused by increased passage of commercial navigation vessels in the upper Mississippi River System.

# 2 Freshwater Mussels and *Lampsilis higginsi*

## Introduction

Freshwater mussels are atypical members of Phylum Mollusca and class Bivalvia because of their life-cycle patterns and nonmarine habitats. There are approximately 110,000 living molluscan species, and only the class Arthropoda is more numerous and more successful. Freshwater molluscan families are Unionidae, Corbiculidae, and Dreisseniidae. The native unionid mussels are found in the world's larger, more permanent river systems. Unlike marine bivalves, they require a life-cycle stage in which they parasitize specific fish species. All freshwater bivalves are lamellibranchs and have a distinctive pair of enlarged gills used for filter feeding. Particulate matter remains on the inhalant side of the gills, and mucus and cilial movement create chains that carry this food material to the mouth.

## Locomotion and Behavior

The blood filling the system of hemocoelic spaces in molluscs serves both for respiration and for locomotion. The blood serves as a hydraulic skeleton that transmits distant muscle contractions. The number of structures (tentacles, foot, siphons) that can be extended at one time is limited by constant blood volume and limited available contractor muscle force. A typical unionid is a burrower with a relatively large muscular foot, two pairs of pedal retractor muscles, and anterior and posterior adductor muscles. The burrowing cycle begins by extending the foot into the substratum with valves relaxed. Blood is used to dilate the foot, which provides anchorage. The clam buries deeper into the substratum by closing its valves and contracting its anterior and posterior pedal retractor mussels. The more globose unionids can contract anterior pedal muscles first, followed by the posterior, which facilitates burrowing by causing rotation of the mussel. Smaller mussels and juveniles can rebury more easily than larger mussels.

## Gut Function and Digestion

All unionids have a ciliated alimentary canal and a digestive tract designed for slow, steady processing. Food consists of fine plant or bacterial matter mixed with some organic matter and suspended in mucus. Both intracellular and extracellular digestion occur. The crystalline style of the molluscan gut is unique in its separation from the anterior intestine, and it functions both in chemical digestion (through enzyme release) and physical digestion (manipulating the stomach contents). The style must be regularly regenerated, since approximately 6 mm/hr wears off during normal feeding.

In a typical molluscan gut, the mouth leads into a short esophagus and then to a subglobular stomach, whose ciliated posterior caecum sorts food by size into the anterior intestine, style sac, and paired basal ducts of the digestive diverticula that lead from the stomach. The typhlosole of the anterior intestine forms a tube within each root of digestive diverticula for food sorting. The posterior intestine and rectum continue from the anterior intestine. Most food circulates through the sorting areas of the stomach at least twice before being passed to the hindgut. Any indigestible material is trapped in spirales of mucus and is expelled.

## Reproduction and Early Development

Unlike the free-swimming larvae released by many marine bivalves, unionids produce large numbers of specialized parasitic larvae (glochidia), an adaptation more suitable to their riverine habitats. During spawning, between $10^5$ and $10^6$ larvae are released with outgoing water from feeding. The newly spawned glochidia are never free-swimming. A parasitic stage is necessary for normal development, and many larvae are equipped with hooks or temporary byssal threads to facilitate attachment to their vertebrate hosts. Once attached, the fish host's epidermis encloses the glochidium. After the immature mussel's internal organs have been replaced by adult structures, it breaks free of its host and lives the rest of its life on the river bottom (Russell-Hunter 1979).

## *Lampsilis higginsi*

*Lampsilis higginsi* is characterized by a round to slightly elongated shape, a thick inflated shell, and a yellowish-brown color with green rays (Cummings and Mayer 1992). This species is sexually dimorphic, with posteriorly tapered males and posteriorly truncated females (USFWS 1982). This species belongs to the subfamily Lampsilinae and has a reproductive life cycle that is typical of unionid mussels. Females receive sperm during normal water siphoning. Fertilization and development occur in the gills of the female. Females of this species are bradytictic, and glochidia are expelled after they achieve maturity. Glochidia of *L. higginsi* are almost identical to those of *Lampsilis cardium* and *Leptodea fragilis* and are often misidentified as such under light microscopy. The species used as a host by *L. higginsi* include smallmouth bass, green sunfish, and bluegill (Holland-Bartels and Waller 1988) and sauger and freshwater drum (USFWS 1982).

*Lampsilis higginsi* is one of two Federally endangered mussels of the UMR and was given this designation because of a reduction of its original range. The historical range of this species as reported by Baker (1928) included the Mississippi River from Fairport, IA (RM 463), north to Lake Pepin, Wisconsin (RM 811.3), and from the mouth of the Illinois River (Illinois RM 0.0) upstream to Havana, IL (RM 120). Currently, this species is not in the Illinois River. Havlik (1981) reported that this species was collected in the UMR as far south as Louisiana, MO (RM 283), located just north of St. Louis. In 1995 this species was collected in Sylvan Slough near Rock Island, IL, near RM 485 (Miller and Payne, in preparation), and in 1996 it was collected in Lake Pepin, near RM 765.[1] Dr. Ed Cawley reported collecting *L. higginsi* in Pool 17 (RM 407) in 1984 (Cawley 1996). This later find would be the most southern part of its present range. Its present range is approximately 50 percent of its historical range (USFWS 1982).

Although the majority of the reports for this species are in the UMR, it has also been collected in the St. Croix, Rock, Wisconsin, and Minnesota rivers. Hornbach, Baker, and Deneka (1995) reported collecting this species near Prescott, WI, and Lakeland, MN, in the lower St. Croix River, which joins the UMR at RM 811.3. Cawley (1996) lists another four locations for this species in the St. Croix River. In 1926 this species was collected approximately 30 miles upriver of the confluence of the Rock River with the UMR (at upper Mississippi RM 479).[2] This species has been reported between RMs 45 and 50 in the Wisconsin River (Cawley 1996). Finally, in 1989 this species was collected at RM 32.5 in the Minnesota River (Cawley 1996). It is very likely that additional searches in the lower reaches of large and small tributaries to the UMR could yield additional finds of *L. higginsi.*

*Lampsilis higginsi* is typically found in the deep waters of wide rivers and most often inhabits sand, sand/gravel, gravel, or silt/sand in low-density populations. Based upon studies by Holland-Bartels and Waller (1988), *L. higginsi* was found along the main channel border of the UMR in a heterogeneous substratum consisting of mud, sand, and gravel. It was usually present in water 8-20 ft deep and in areas of moderate current.

In 1988, WES personnel, using funds provided by the St. Louis District, began an intensive study of *L. higginsi* at five historically prominent beds in the UMR (Miller and Payne 1990). The range in abundance of *L. higginsi* at four beds that were within its range varied from 0.09 percent (quantitative samples in 1989 from Pool 14) to 1.72 percent (qualitative samples in 1988 from Pool 10) (Table 1). Because this species is uncommon, usually

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[1] Personal Communication, 1996, Mike Davis, Minnesota Department of Natural Resources, Lake City, MN.

[2] Personal communication, 1996, Dr. Ed Cawley, Loras College, Dubuque, IA.

several hundred mussels have to be collected before it is found. At a mussel bed in Pool 17, this species was collected twice by Miller and Payne (1996a), in 1988 and again in 1994, but was not collected in 1990 or 1992. *Lampsilis higginsi* was collected in 2 of 4 study years at a bed in Pool 12. At beds in Pools 10 and 14, this species was collected during each survey year (Table 1, Miller and Payne 1996a).

## Important Habitat in UMR for *Lampsilis higginsi*

The Higgins' Eye Mussel Recovery Plan (USFWS 1982) identified essential and secondary habitats for *L. higginsi* and recommended methods to protect it from harm in the UMR (Table 2). Habitats were considered to be essential if *L. higginsi* was regularly collected and the overall community was dense and species rich. Sixteen locations in the UMR were evaluated, and sufficient information was available to designate six as essential. A seventh habitat, located on the St. Croix River near Hudson, WI, was also listed as essential. Areas that lacked enough data to be considered essential were designated secondary. Habitats designated by the Team as "Essential" are listed in Table 2 and shown in Figure 1. Mussel sanctuaries, where commercial collecting is prohibited, and beds that support dense and diverse assemblages of mussels are depicted on Figure 1 and listed in Table 3. The map was prepared by selecting the most valuable beds in the UMR, based on presence of *L. higginsi* as well as total density and species richness. Some beds that exhibited high density and species richness were included although they did not contain *L. higginsi*.

**Table 1**
**Numbers of *L. higginsi* Taken in Qualitative and Quantitative Samples in UMR, 1988-94**

| Year | Quantitative Samples | | | Qualitative Samples | | |
|---|---|---|---|---|---|---|
| | Total Mussels | *L. higginsi* | | Total Mussels | *L. higginsi* | |
| | | Total | Percent | | Total | Percent |
| **Pool 24 (RM 299.6)** | | | | | | |
| 1988 | 78 | 0 | 0.00 | 326 | 0 | 0.00 |
| 1989 | 1,143 | 0 | 0.00 | 648 | 0 | 0.00 |
| 1991 | 301 | 0 | 0.00 | 465 | 0 | 0.00 |
| 1992 | 107 | 0 | 0.00 | 184 | 0 | 0.00 |
| 1994 | 243 | 0 | 0.00 | 390 | 0 | 0.00 |
| **Pool 17 (RM 450.4)** | | | | | | |
| 1988 | 1,176 | 0 | 0.00 | 567 | 1 | 0.18 |
| 1990 | 651 | 0 | 0.00 | 506 | 0 | 0.00 |
| 1992 | 954 | 0 | 0.00 | 402 | 0 | 0.00 |
| 1994 | 773 | 0 | 0.00 | 801 | 1 | 0.12 |
| **Pool 14 (RM 504.8)** | | | | | | |
| 1988 | 253 | 1 | 0.40 | 734 | 8 | 1.09 |
| 1989 | 1,131 | 1 | 0.09 | 961 | 5 | 0.52 |
| 1991 | 1,247 | 6 | 0.49 | 815 | 6 | 0.74 |
| 1992 | 800 | 2 | 0.25 | 386 | 3 | 0.78 |
| 1994 | 903 | 4 | 0.44 | 789 | 6 | 0.76 |
| **Pool 12 (RM 571.5)** | | | | | | |
| 1989 | — | — | — | 98 | 0 | 0.00 |
| 1990 | 408 | 5 | 1.22 | 518 | 5 | 0.98 |
| 1992 | 558 | 1 | 0.18 | 376 | 0 | 0.00 |
| 1994 | 509 | 0 | 0.00 | 579 | 0 | 0.00 |
| **Pool 10 (RM 635.2 - Main Channel)** | | | | | | |
| 1988 | 845 | 2 | 0.24 | 699 | 12 | 1.72 |
| 1989 | 1,616 | 11 | 0.68 | 212 | 0 | 0.00 |
| 1991 | 861 | 2 | 0.23 | 690 | 4 | 0.58 |
| 1992 | 700 | 3 | 0.43 | 376 | 1 | 0.27 |
| 1993 | 905 | 4 | 0.11 | 404 | 1 | 0.25 |
| 1994 | 680 | 1 | 0.15 | — | — | — |

Note: See Miller and Payne (1996a).

**Table 2**
**Sites Listed by Higgins' Eye Recovery Team (1982) Considered to Be Essential or of Secondary Importance for *L. higginsi***

| |
|---|
| **Essential Habitats** |
| 1. Mississippi River at Whiskey Rock (RMs 658.4-655.8) |
| 2. Mississippi River at Harper's Slough, Pool 10 (RMs 641.4-639) |
| 3. Mississippi River Main and East Channel at Prairie du Chien, WI, and Marquette, IA, Pool 10 (RM 633.6) |
| 4. Mississippi River at McMillan Island, Pool 10 (RMs 619.1-616.4) |
| 5. Mississippi River at Cordova, IL, Pool 14 (RMs 505.5-503) |
| 6. Mississippi River at Sylvan Slough, Pool 15 (RM 485.5) |
| **Secondary Habitats** |
| 1. Guttenberg, Iowa-Goetz Island, Pool 11 (RM 613) |
| 2. Cassville, WI, Pool 11 (RM 607) |
| 3. Dubuque, IA, Pool 12 (RM 580) |
| 4. Adams Island vicinity, Pool 14 (RM 507) |
| 5. Rapids City, IL, Pool 14 (RM 496) |
| 6. Lower Sylvan Slough, Pool 15 (RM 482) |
| 7. Andalusia Slough, Pool 16 (RM 473) |
| 8. Bakris Island, Pool 17 (RM 444) |
| 9. Jonas Johnson Island, Pool 17 (RM 439) |

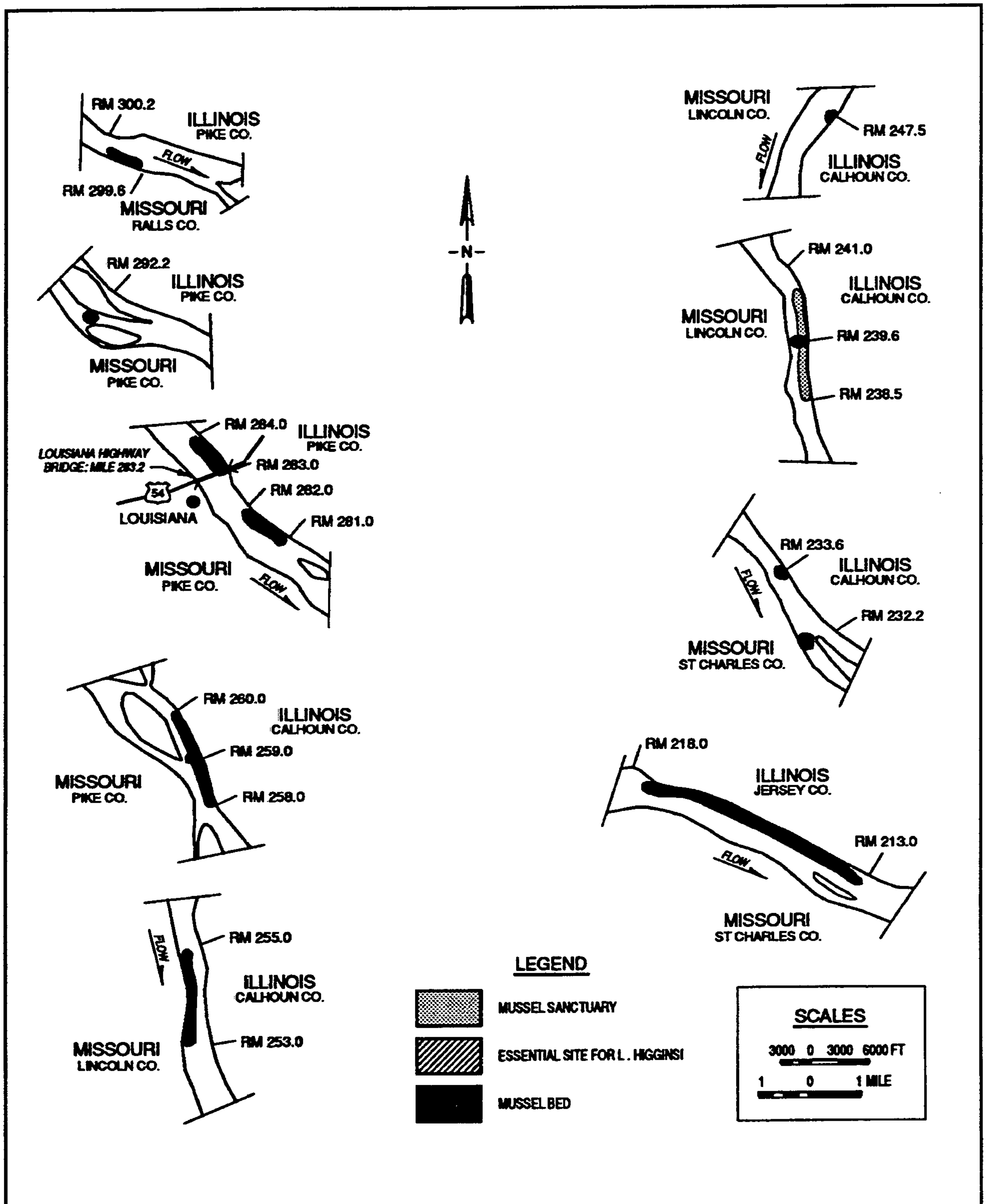


Figure 1. Valuable mussel habitats in UMR (See text for details) (Sheet 1 of 4)

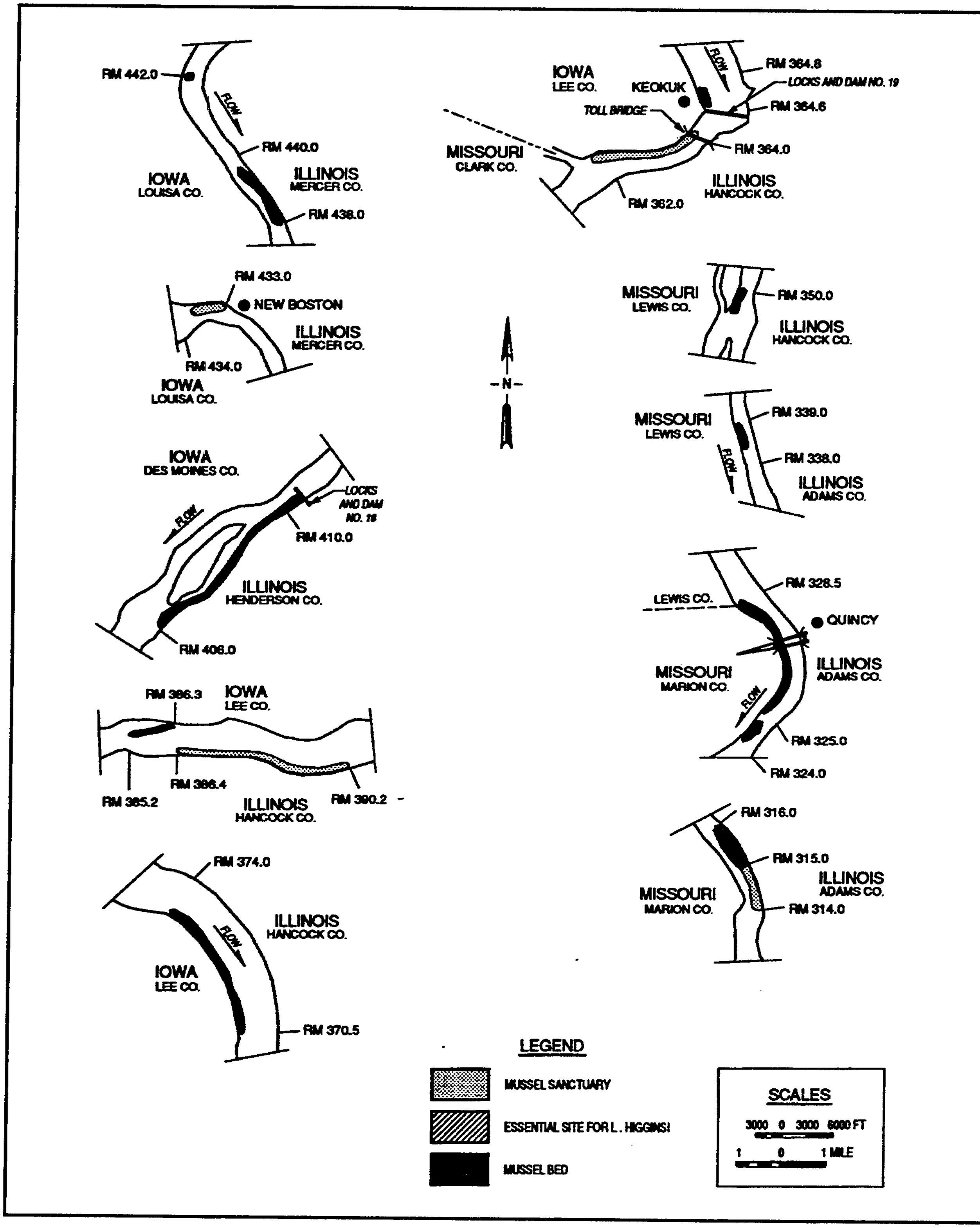


Figure 1. (Sheet 2 of 4)

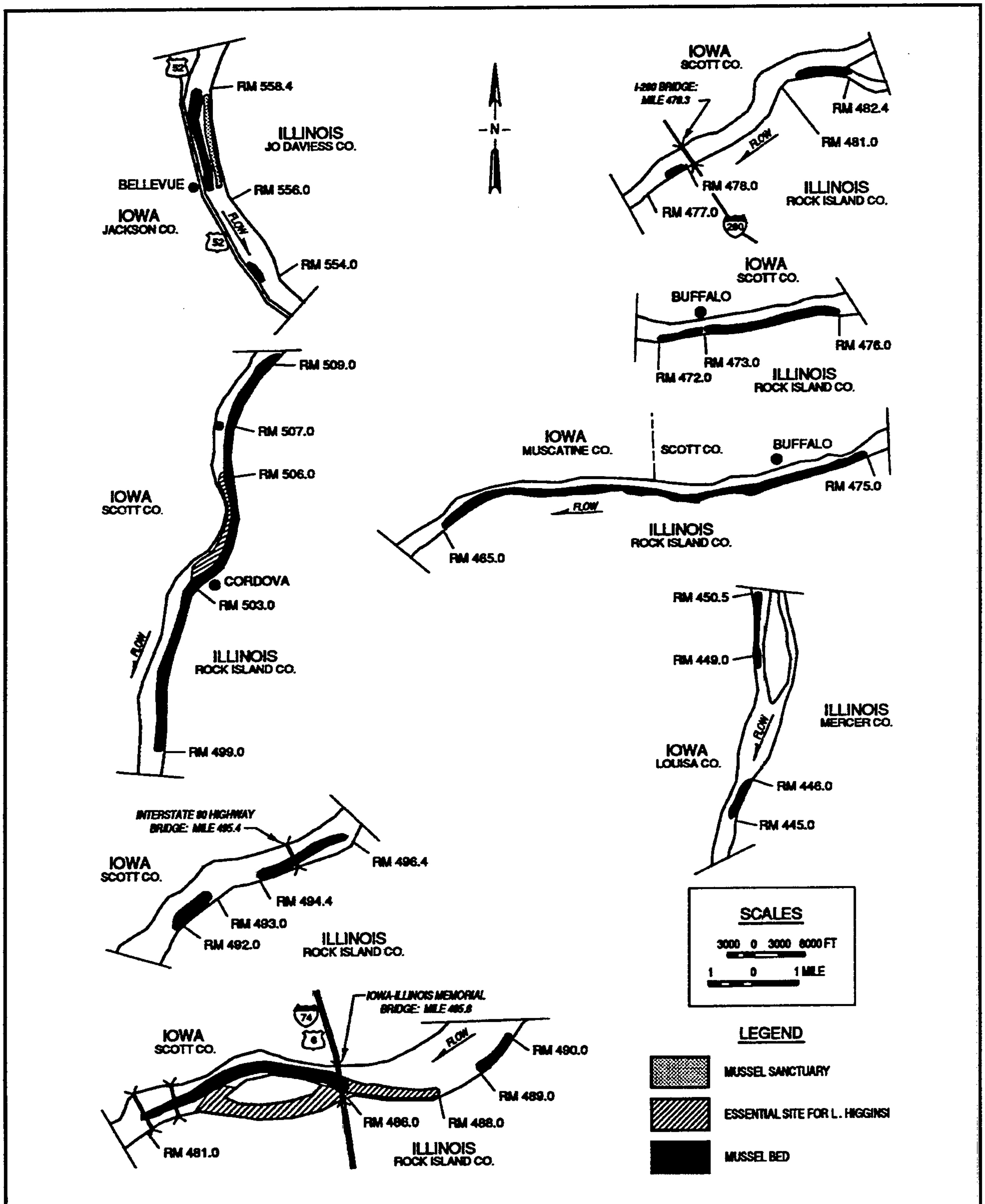


Figure 1. (Sheet 3 of 4)

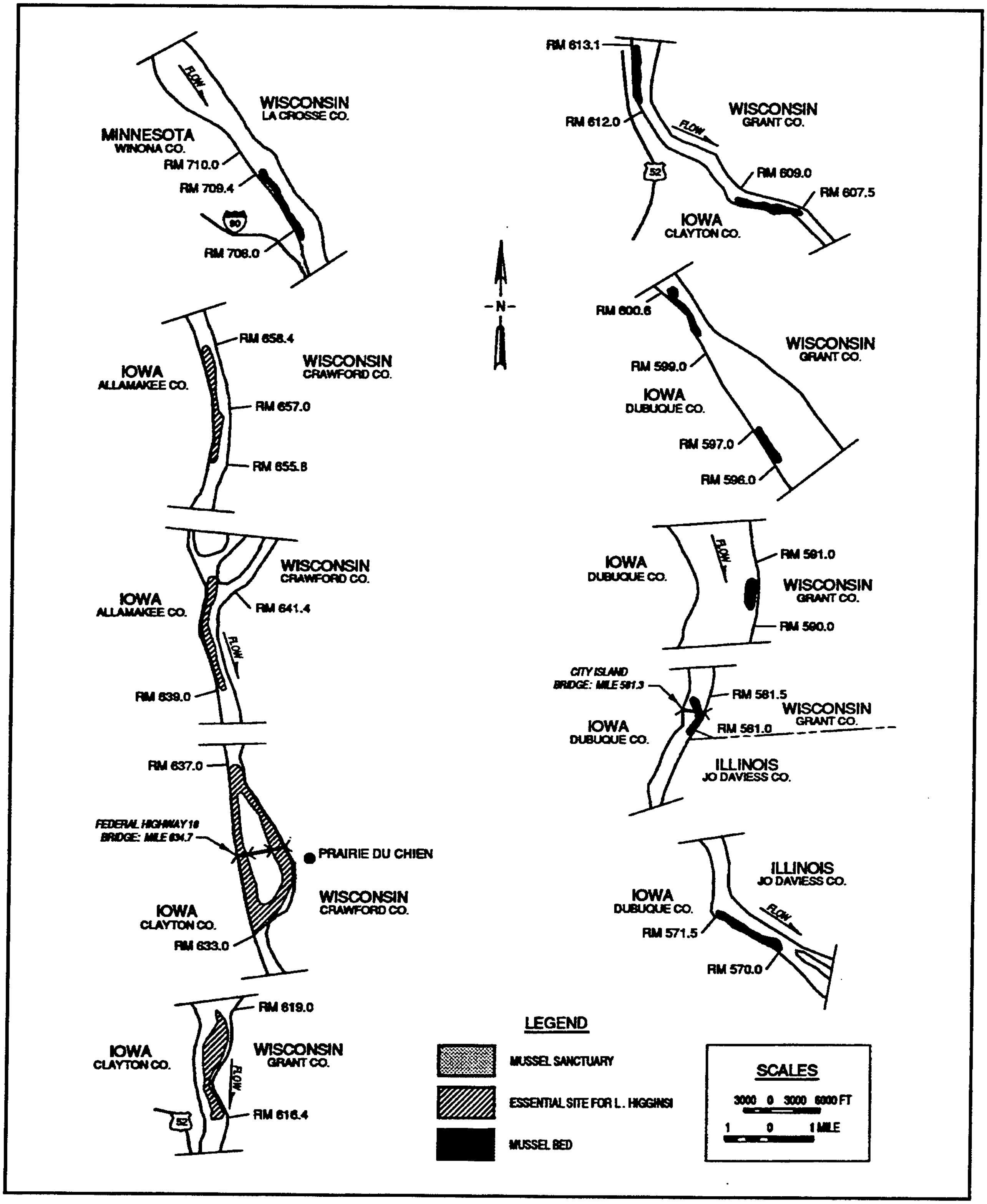


Figure 1. (Sheet 4 of 4)

**Table 3**
**Important River Reaches for Freshwater Mussels in UMR**

| Pools | | | | | |
|---|---|---|---|---|---|
| **26** | **25** | **24** | **22** | **21** | **20** |
| 213.0-218.0L | 247.5L | 292.2R | 281.0-282.0L | 325.2-328.5R | 349.0-351.0R |
| 232.2R | 253.0-255.0R | 299.6-300.2R | 283.0-284.0L | 338.2-339.0R | 361.5-364-MS |
| 233.6L | 258.0-260.0L | | 314.0-316.0L-MS | | |
| 238.5-240.6L-MS | 259.1-259.2L | | 324.2-324.9R | | |
| 239.6L | | | | | |
| **Pools** | | | | | |
| **19** | **18** | **17** | **16** | **15** | **14** |
| 364.6-364.8R | 433.0-433.8L-MS | 438.0-439.7L-SH | 472.0-473.0L | 485.5-486.0L-EH,SH | 494.0-496.4L-SH |
| 386.4-390.2L-MS | | 442.0-442.7R | 473.0-476.0L-SH | 489.0-490.0L | 503.0-506.0L-EH |
| 370.5-374.0R | | 445.0-446.0L-SH | 477.6-478.0L | 491.8-493.0L | 507.0R-SH |
| 406.0-410.5L | | 448.7-450.5R | 481.3-482.4-SH | 492.0-493.0L | |
| **Pools** | | | | | |
| **13** | **12** | **11** | **10** | **9** | **7** |
| 554.0-554.2R | 556.8-558.2L-MS | 590.2-590.4L | 616.4-619.1-EH | 655.8-658.4R-SH | 707.8-709.4R |
| 556.0-556.8R-MS | 570.0-571.5R | 596.0-600.6R | 633.0-637.0-EH | | |
| | 580.9-581.5L-SH | 607.5-609.0R-SH | 639.0-641.4R-EH | | |
| | | 612.2-613.1R-SH | 655.8-658.4R-EH | | |

Note: L-Left Descending Bank; R-Right Descending Bank; EH and SH-Essential and Secondary Habitat for *L. higginsi* (Higgins' Eye Recovery Team 1982); and MS-Mussel Sanctuary. Sources for this table include USFWS (1982), Miller and Payne (1996b), Peterson (1984), Illinois Natural History Survey, Illinois Department of Conservation, Missouri Department of Conservation, and Illinois Department of Natural Resources. See text for more details.

# 3 Effects of Commercial Navigation Traffic

Rasmussen (1983) summarized the physical disturbances to mussels in the UMR associated with passage of commercial tows. In that report he discussed the potential impacts of sediment resuspension and movement, wave heights and related actions, velocity and pressure changes, effects of navigation traffic on invertebrates, and correlation among UMR physical and biological variables. The information reported by Rasmussen is similar to that reported by Claflin et al. (1981) and Adams (1991). Based upon laboratory and field studies (Miller and Payne 1996a), the most severe negative effect of traffic on freshwater mussels can occur from physical disturbance to the substratum. Although negative effects of barges scraping the bottom are obvious, this impacts only individuals at a site and does not cause systemwide effects. Mussels appear to tolerate brief periods of turbulence and turbidity associated with vessel passage. Only if these actions occur continuously, such as in a fleeting area, is there a potential for long-term site-specific negative effects.

## Tow Traffic in UMR

Annual vessel passages (upriver and downriver combined) ranged from 2,014 tows in Pool 10 (in 1990) to 3,757 tows (in 1990) in Pool 24 (U.S. Army Corps of Engineers (USACE) 1995). Since 1990, there has been a gradual decline in daily passages at all locks (Figure 2). Low numbers of events in 1993 resulted from the temporary suspension of traffic during extremely high water in spring and summer.

The Master Plan provided commercial traffic projections for 1990, 2000, and 2040 with and without the second lock in place. For Pool 10, it was estimated that the second lock would cause one additional tow per day by the year 2040 (17-percent increase). By the year 2040 there would be an additional two tows per day in Pools 12 (29-percent increase). In Pools 14 and 17 there was a 17-percent increase, and in Pool 24 there was a 13-percent increase.

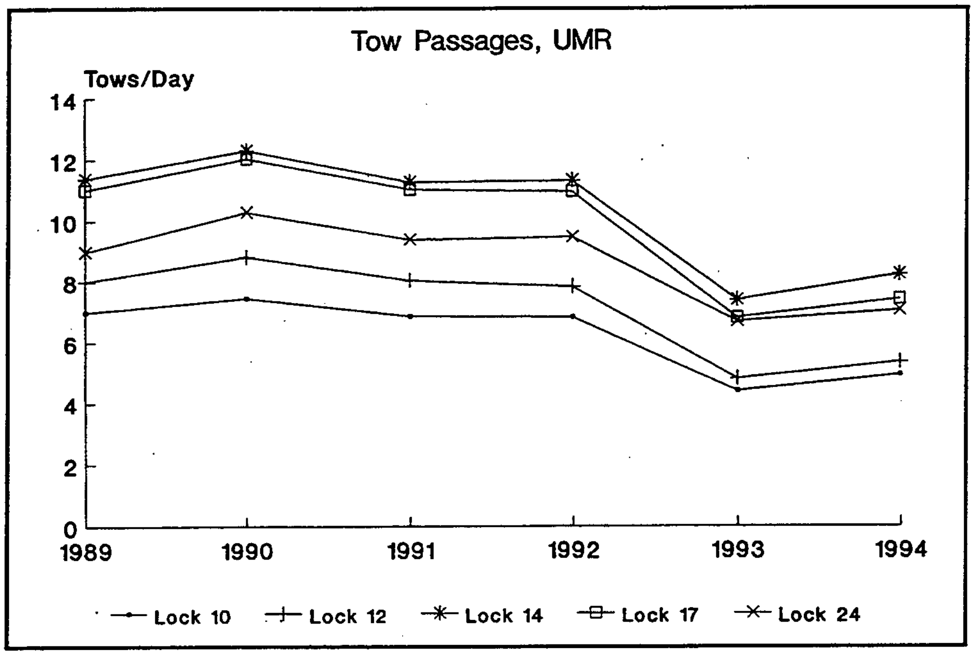


Figure 2. Number of tow passages per day at mussel beds in five pools of UMR, 1989-94

## Field Studies on *L. higginsi*

WES personnel studied physical and biological effects of commercial vessel movement between 1988 and 1994 using funds from the St. Louis District. The purpose was to collect detailed data at five mussel beds located at the following river miles:

| Pool | RM |
|---|---|
| 24 | 299.6 RDB (Right descending bank) |
| 17 | 450.4 RDB |
| 14 | 504.8 LDB (Left descending bank) |
| 12 | 571.5 RDB |
| 10 | 635.2 RDB |

Data were collected and then compared with six criteria established to measure the overall health of a mussel bed. The six criteria and a summary of results from the mussel study follows:

### Decrease in density of five common-to-abundant species

There was a significant density decline for nine species and a significant density increase for two species. However, this criterion was met since there was not a significant decline for five common-to-abundant species at a single bed sustained for at least 2 years.

### Absence of *L. higginsi*

Based on this criterion, beds in Pools 10 and 14 showed no negative effects. At the beds in Pools 12 and 17, *L. higginsi* was much less common and was not collected each year; this criterion was met at the bed in Pool 12, but was not met in Pool 17. *Lampsilis higginsi* was not found in Pool 24 and was uncommon in Pool 17.

### Decrease in live-to-recently dead ratios for dominant species

This criterion was met. Recently dead organisms were rarely collected and always made up less than 1 percent of the sample.

### Loss of more than 25 percent of mussel species

Although there was year-to year variation in this criterion, species richness remained relatively constant during the study. Annual variation in species richness results from collecting slightly different numbers of individuals each year.

### Evidence of recent recruitment

No indication of recruitment problems existed among UMR mussels, in terms of either species or total individuals. Depending on the bed studied, location of the site (nearshore or farshore), and the year, between 10 and 55 percent of all individuals collected in quantitative samples were less than 30-mm total shell length. Approximately 10 to 75 percent of species present showed evidence of recent recruitment in any particular pool, site, or year.

### A decline in the growth rate of two dominant species other than *A. p. plicata*

This criterion was not perused because of difficulty in retrieveing experimental organisms.

Results of field studies indicated that parameters such as total density, recruitment, and species richness exhibited considerable variation among beds and years, and from nearshore to farshore. There was no indication that these changes were the result of anything other than variation in hydrologic events, life cycles, and habitat requirements. The importance of long-term field studies, designed to regularly monitor key attributes of biotic populations and communities, cannot be ignored (Likens et al. 1983; Strayer et al. 1986; Likens 1987; Franklin 1987). They provide an opportunity to investigate the effects of waterway operation, introduction of nonindigenous species, or hydrologic events on a resource with ecological, economic, and cultural value. Perhaps the greatest value of the mussel monitoring program has been to establish a data base on UMR mussel populations.

As part of the mussel monitoring, physical effects of vessel passage were studied. A total of 60 passages by commercial vessels were examined; of these, 12 (20 percent) had a major effect on ambient conditions. A major effect caused ambient velocity 105 ft (32 m) from the bank to change from 0.348 ft/sec (10.6 cm/sec) to 0.720 ft/sec (21.9 cm/sec) for approximately 100 sec. In a minor but measurable event, combined downriver velocity changed from 0.80 ft/sec (24.4 cm/sec) to 0.56 ft/sec (17.1 cm/sec) immediately following passage. When a commercial vessel moves downriver, backflow causes velocity in the river to decrease briefly. Thirty-seven percent produced a minor effect, and 43 percent produced no measurable change. Many velocity changes were considered minor, especially when compared with ambient conditions during normal high water, between 2 and 3 ft/sec (61 and 91 cm/sec) in January through April for most years. Even the major events did not disturb mussels or their habitat.

Vessel-induced changes in turbidity and suspended solids at mussel beds in the UMR were minor, of short duration, and usually lasted no more than several minutes. Vessel motion increased these values more at the substratum-water interface than the surface. Typically, a vessel caused an increase in total suspended solids of no more than two times ambient conditions and had a measurable effect for several minutes. In one event, mean suspended solids changed from $20.4 \pm 5.3$ (standard deviation) to $21.1 \pm 5.7$ mg/ℓ and $37.4 \pm 12.4$ mg/ℓ at a near and farshore site, respectively. In the UMR, mussels are found in firmly packed substratum that is relatively free of recently settled sediments; therefore, movement of large vessels had minimal effects on ambient suspended solids and turbidity.

## Laboratory Studies on Molluscs

In a laboratory study conducted at WES in the early 1980s (Aldridge, Payne, and Miller 1987), metabolic rate and catabolic substrate shifts were measured for three species of mussels that were cyclically exposed to unnaturally high levels of turbulence and turbidity at two distinct frequencies. This experiment was designed to evaluate the importance of frequency of cyclic exposure to physiologically disruptive changes in hydrologic conditions and to assess the utility of food clearance, respiration, and nitrogen excretion rate measures as quantitative indices of stress. The following is a summary of the study.

Field studies of navigation effects on turbidity showed that levels of suspended solids (600-750 mg/ℓ) used in laboratory experiments designed to elicit physiological stress responses will rarely be encountered by natural populations of mussels during periods of normal flow as a result of navigation traffic. Laboratory studies indicated that there was a potential for disruption of normal feeding and metabolism due to exposure to high levels and frequencies of turbulence and suspended solids. The ecological significance of any shifts from food to body storage-based metabolism associated with stressful conditions of turbulence and suspended solids exposure ultimately depends on these shifts being translated into reduced growth, reproduction, or survival of individuals in naturally occurring populations.

The effects of continuous versus intermittent exposure to turbulence on the freshwater bivalve *Fusconaia ebena* were studied in a second laboratory experiment at WES (Payne and Miller 1987). Mussels were exposed to one of three conditions: continuous-low, continuous-high, and cyclic-high water velocity. The Tissue Condition Index (TCI) of juvenile *F. ebena* in the continuous-low and cyclic-high velocity treatments was 20 and 22 percent less than the TCI of field-fixed juveniles (control organisms). Continuous exposure to high velocity water caused a 34-percent reduction in TCI. Comparison of the mean TCI by Duncan's multiple range test indicated that weight loss was not significantly different ($p > 0.05$) between continuous-low and cyclic-high velocity treatments, but weight loss was significantly less in these two treatments than in the continuous-high velocity group. Respiration rates, measured in still water, did not differ significantly among mussels from the three treatments.

Juvenile *F. ebena* were not affected by 5-min exposure to high velocity water once per hour, a result directly relevant to evaluating the environmental effects of commercial navigation traffic. Commercial traffic rates do not often exceed one tow per hour. Thus, turbulence caused by routine traffic is not likely to deleteriously affect mussels. Conversely, at sites where barges are fleeted, towboats sometimes work continuously. Potential impacts to mussels by abrupt water velocity changes in fleeting areas need to be evaluated on a site-specific basis.

# 4 Basic Techniques to Minimize Effects of Commercial Traffic on *L. higginsi*

## Background

The St. Louis District, in cooperation with the USFWS, the navigation industry, the U.S. Coast Guard, and Rock Island and St. Paul Districts, developed and revised a list of avoid/minimize measures (see Table 4). These measures, taken from Design Memorandum No. 24, were not written specifically for mussels. Those measures dealt with methods to minimize impacts of increased navigation traffic due to completion of the second lock at Melvin Price Locks and Dam on aquatic organisms in general.

**Table 4**
**Avoid/Minimize Measures for Impacts of Operation of Second Lock at Melvin Price Locks and Dam**

| Group A - Operations of Locks and Navigation Channel |
|---|
| A1. Reduce navigation channel in biologically sensitive areas. |
| A2. Implement monetary fines for navigation outside marked channels, during hazardous conditions, and negligence in spills. |
| A3. Designate locks approach waiting areas or provide special mooring sites. |
| A4. Monitor channel depth more frequently in known problem areas. |
| A5. Limit and/or close navigation based on water stage, ice conditions, level of turbidity. |
| A6. Enforce a maximum 9-ft draft in channel. |
| A7. Restrict traffic until buoys are in place at the start of each towing season. |
| A8. Correct bridge design deficiencies. |
| *(Sheet 1 of 3)* |
| Note: Taken from Design Memorandum No. 24 (USACE 1992). |

| Table 4 (Continued) |
|---|
| **Group A - Operations of Locks and Navigation Channel (Continued)** |
| A9. Improve lock approach to avoid hazards. |
| A10. Reduce open-water dredge material disposal—create beaches. |
| A11. Reduce open-water dredge material disposal—create wetlands. |
| A12. Side channel dredging/create wetlands. |
| A13. Thalweg placement of dredge material. |
| A14. Comprehensive information program. |
| A15. Install lock guide wall extensions on selected UMR locks. |
| A16. Continue dike modification studies (i.e., notched, chevron, and bullnose dikes) and environmental monitoring. |
| A17. Field design and research of off-bank revetment placement on islands. |
| A18. Establish stable thalweg line with minimal regulation works. |
| A19. Construct bendway weirs. |
| A20. The dredge material placement team—continuing effort. |
| **Group B - Measures Related to Tow Operation** |
| B1. Improve tow and/or barge design. |
| B2. Reduce speed in sensitive areas. |
| B3. Limit horsepower to 4,500 above L&D 26. |
| B4. Passing and meeting regulations in sensitive areas. |
| B5. Employ a gradual increase in power when leaving a lock. |
| B6. Reduce draft in critical periods. |
| B7. Reduce tow size in critical periods. |
| B8. Develop nonstructural alternative to reduce waiting times. |
| B9. Accomplish design study of barge couplings. |
| **Group C - Measures Related to Induced Development** |
| C1. Require contingency plans at terminals and cargo-handling facilities. |
| C2. Strategically locate pollution response equipment throughout the UMR system. |
| C3. Require all fleeting to be located at mooring cells, deadmen, anchors, and/or in accordance with appropriate permits. |
| C4. Designate no fleeting in sensitive resource areas or in unpermitted areas. |
| C5. Where unregulated, establish fleeting regulations that take environmental planning into account. |
| C6. Complete waterfront development plans in urban areas. |
| C7. Complete shoreline management plans. |
| C8. Revise navigation pool Master Plans. |
| C9. Develop a Master Plan for resource management of Pool 27 lands and waters. |
| C10. Develop detailed operational management plans for all lands and waters under Riverlands jurisdiction. |
| ***(Sheet 2 of 3)*** |

| Table 4 (Continued) |
| --- |
| **Group D - Measures to Rectify Impacts** |
| D1. Shoreline protection in highly erodible areas to minimize erosion and enhance fish and wildlife habitat. |
| D2. Build diversion structures to reduce sediment input into backwater. |
| D3. Construct barrier islands to reduce wave impact to off-channel areas. |
| D4. Modify wing dikes to reduce accretion. |
| *(Sheet 3 of 3)* |

Some of the suggested measures would require virtually no funds to implement. For example, Measure A-1, "Reduce navigation channel within sensitive areas," would require no construction costs. A planning study would be required to implement some measures; for example, Measure B-8, "Develop non-structural alternatives to reduce waiting times," would require that individuals knowledgeable on sensitive resources and commercial navigation activities provide a list of alternatives.

The following is a list of measures of a specific value in reducing harm to mussels and *L. higginsi*. These measures are individually or in cooperation under the authority of the St. Louis District, Coast Guard, or towboat industry.

| Item | Measure |
| --- | --- |
| A-1 | Reduce navigation channel in sensitive areas |
| A-3 | Designate lock approach waiting areas or provide special mooring areas |
| A-4 | Monitor channel depth more frequently in known problem areas |
| A-9 | Improve lock approaches |
| A-10 | Reduce open-water disposal, create beaches |
| A-11 | Reduce open-water disposal, create wetlands |
| A-13 | Thalweg placement of dredged material |
| A-14 | Comprehensive information program |
| A-15 | Install lock guide wall extensions |
| A-16 | Modify dikes (chevron, notched) and monitor |
| A-17 | Design and research off-bank revetment placement |
| A-18 | Establish stable thalweg line with minimal regulation works |
| A-19 | Construct bendway weirs |
| C-3 | Reduce environmental effects of fleeting |
| C-8 | Revise navigation pool Master Plans |
| C-9 | Develop a Master Plan for resource management of Pool 27 lands and waters |
| C-10 | Develop detailed operational management plans for all lands and waters under Riverlands jurisdiction |
| D-1 | Stabilize erodible shoreline |
| D-2 | Build diversion structures to reduce sediment input to backwater |
| D-3 | Construct barrier islands |
| D-4 | Modify wing dams to reduce accretion |

Estimated unit costs for the majority of these measures appear in Table 5. These costs are not site specific, but were developed to provide an indication of funds required to implement a certain measure. For example, dredging costs are approximately $1 per cubic yard. This value will vary depending on availability of material and the distance it must be transported.

**Table 5**
**Cost Estimates for Selected Measures to Avoid and Minimize Harm to Freshwater Mussels**

| Item | Unit Costs | Notes |
|---|---|---|
| Improve lock approaches | Variable | Includes anything that would improve navigability at a lock |
| Create beaches | $250-500/ft | |
| Create wetlands | Variable | |
| Dredge side channels | $1/cu yd | Could be less or greater depending on distance material must be moved |
| Install lock guide wall | $2-5M | Needed for some locks to guide vessel into chamber |
| Modify dikes (notches, etc.) | $10K | |
| Construct bendway weirs | $7K | |
| Mooring cells | $5K | |
| Deadmen | $5K | |
| Anchors | $5K | |
| Stabilize erodible shoreline | $50-$250/ft | Depends on size of material (riprap), distance to transport, need for filter cloth, preconstruction engineering, etc. |
| Diversion structure to reduce sediment in backwaters | $7K | |
| Construct barrier islands | $25K | |
| Mussel relocation | $5K/day | Includes dive team, support personnel, and all equipment |
| Gravel bar | $50K | 300 ft by 100 ft by 1 ft thick |
| Modify wing dams to reduce accretion | $10K | |

Note: K = thousand; M = million

## Structural Methods to Reduce Effects of Commercial Navigation Traffic

Every effort should be made to protect river reaches with dense and diverse mussel populations where moderate to high numbers of *L. higginsi* can be collected. High-quality habitats that support dense and diverse mussel populations in the UMR appear in Table 3 and are depicted in Figure 1. This information was obtained from a set of annotated maps prepared by Peterson (1984), the original *L. higginsi* recovery plan (USFWS

1982), and studies by Miller et al. (1996a). Information was also obtained from the Illinois Natural History Survey and Illinois Department of Natural Resources. It will be necessary to identify sensitive areas before recommendations to improve or protect habitat can be implemented.

In the UMR, freshwater mussels are found in their highest densities along the channel border as compared with the navigation channel. When mussels are present, densities in the channel are about one-tenth those in the channel border (Duncan and Thiel 1983). Freshwater mussels become most abundant where water velocities are high enough to remove settled sediments yet not so high that the substratum erodes. A brief period of high velocity, greater than 1.5 ft/sec, is usually sufficient to remove settled silt and not disturb mussels. Such a brief period could occur only several times a year and still be effective in maintaining the mussel habitat.

Often *L. higginsi* is reported in high-density beds with many species present. This indicates that conditions suitable for all mussels are also appropriate for *L. higginsi*. High-density beds obviously attract host fishes and have suitable conditions of water velocity and substratum for adult and juvenile mussels. Techniques to protect these habitats will obviously be important to all molluscs as well as *L. higginsi*.

Based on review of the literature, information from participating agencies, and the authors experiences, the measures discussed below have been identified to reduce impacts of commercial vessel passage on freshwater mussels. Group letters and numbers from Table 4 have been included.

## Reduce navigation channel in sensitive areas (A-1)

Most valuable mussel beds are along the channel border and outside the thalweg and therefore not affected by vessel passage. However, if deemed necessary, buoys could be repositioned to keep commercial vessels from getting too close to sensitive areas. This would be a comparatively inexpensive protective measure. Funds would be required to evaluate the area and place buoys.

## Designate lock approach waiting areas or provide special mooring areas (A-3)

Areas immediately downriver of locks often support dense and diverse mussel assemblages. Special mooring areas could be located so there would be no interference with native mussels. A candidate area for this would be immediately downriver of Lock and Dam 24 where a valuable mussel bed is located along the RDB at RM 299.

## Monitor channel depth more frequently in known problem areas (A-4)

Areas where sediment deposition occurs naturally usually have to be dredged. If the deposited material is fine grained and stable, it could be colonized by mussels. Dredging these sites could negatively affect mussels. Bathymetry at these areas could be monitored frequently to determine if dredging would be required, and a survey might be required to determine if mussels were present. If frequent dredging was required, it could be necessary to devise plans to protect mussels if present.

### Improve lock approaches (A-9)

Locks could be improved by placing cells or other devices to temporarily hold commercial vessels before they enter the locks. This would reduce physical disturbances that could be caused by vessels scraping the river bottom.

### Reduce open-water disposal by creating beaches and wetlands (A-10, A-11, A13)

Disposal of dredged material at upland sites will reduce the negative effects of disposal in waterways. However, transportation costs could be prohibitive in some cases. In addition, disposal of dredged material in waterways probably would not affect mussel beds directly unless the material was placed directly on the mussels.

### Comprehensive information program (A-14)

A comprehensive information program can be prepared by the USACE, with input from other agencies, to provide the general public with information on commercial navigation traffic effects and the extent of the existing mussel resources in the river. This information program could consist of public service announcements on radio or television, information brochures, posters, or display booths at local or national meetings. Such a program would require the input of State and other Federal resource agencies.

### Install lock guide wall extensions (A-15)

Guide walls on locks could be extended to provide better approaches for entering and exiting commercial vessels. However, since there are no valuable mussel beds close to lock approaches in the UMR, this measure would be of limited value.

### Modify dikes (A-16)

A series of dikes along one side of the river will shunt water to the opposite shore during normal and low flow. During high water, dikes are usually overtopped and have a reduced effect on hydraulics. During low flow, dikes create depositional habitat and can provide habitat for freshwater mussels. Existing dikes provide appropriate habitat for freshwater mussels, and specific modifications for these organisms are usually not required.

However, any alterations that would improve stability and reduce the erosive characteristics of the substratum adjacent to dikes would benefit mussels.

Mussels have been collected on the dikes and in depositional areas between dikes. Dike construction, in conjunction with placement of suitable substratum (see below), could be used to create mussel habitat. Miller (1988) collected 23 species of freshwater mussels, including *L. higginsi*, on and between dikes between RMs 707.8 and 709.4 in the UMR. At a mussel bed near McMillan Island in Pool 10, mussels were collected on and immediately downriver of wing dams (Miller and Payne 1996b). It is recognized that not all dike fields will create habitat suitable for freshwater mussels. However, under appropriate circumstances, the value of dikes and dike fields for freshwater mussels should not be overlooked.

**Stabilize eroding shorelines (A-17, D-1).** An eroding shoreline negatively affects aquatic and terrestrial organisms. When soils erode, terrestrial plants and shrubs that provide food and cover for birds and small mammals are lost. Aquatic habitats are negatively affected by sediment deposition from erosion. Eroding shorelines can be stabilized with riprap or vegetation or a combination of both. When covered with water, riprap provides habitat for attached algae, macroinvertebrates, mussels, and fishes. Bank stabilization methods can be used in conjunction with placement of dikes or gravel bars to create or improve habitat for freshwater mussels. Typically, the cost to stabilize an eroding shoreline ranges between $50 and $250 per linear foot (Table 5).

## Establish stable thalweg line with minimal regulation works (A-18)

As with measure A-3 above, it is beneficial to restrict the navigation lane to specific parts of the river if there are sensitive resources present. Navigation works, such as dikes and other training structures, by causing depositional areas, can locally increase habitat value for mussels.

## Construct bendway weirs (A-19)

Bendway weirs provide a mechanism for altering the flow through bendways. This would provide the opportunity to improve aquatic habitat for mussels. This option could be of limited value in most of the UMR since most valuable mussel populations are along the border in the river proper.

## Reduce environmental effects of fleeting (C-3)

Mooring cells, deadmen, and anchors should be used to temporarily moor barges at selected sites. Use of these devices will reduce the likelihood of barges scraping the river bottom, crushing mussels and other aquatic organisms, and otherwise disturbing aquatic habitat. In addition, proper devices for mooring barges would reduce impacts associated with tying off to trees along the bank. Estimated costs for anchors, mooring cells, and deadmen appear in Table 5.

## Nonstructural Methods to Reduce Effects of Commercial Navigation Traffic

Methods can be implemented that do not require altering the physical characteristics of waterways or the operation of commercial vessels. The following methods could improve conditions for mussels in the UMR:

### Develop improved operational plans (C-8, C-9, C-10)

Any of the recommendations and projections that were part of the "Comprehensive Master Plan for the Management of the Upper Mississippi River System" or under Riverlands jurisdiction could be modified and are under the authority of the USACE. As deemed appropriate, these could be modified to improve conditions for *L. higginsi* and other mussels.

### Reduce environmental effects of vessel movement

Movement of a commercial vessel through a waterway with appropriate depth typically has little or no effect on mussel habitat. However, dredging, modification of the waterway for ports or other facilities, could negatively affect the mussels and should be avoided in areas that support valuable mussel habitat. A list of important mussel beds, some of which support *L. higginsi*, appears in Table 3.

### Mussel relocation

Relocation is one of several methods that can be used to protect freshwater mussels. Relocation can be used to recolonize areas where previous populations were extirpated, to remove mussels from proposed construction sites, to boost numbers of endangered species, or to protect against high densities of the zebra mussel, *Dreissena polymorpha*. The following guidance is based upon experiences of the authors and information in Cope and Waller (1995).

The survival of relocated mussels is closely tied to habitat quality. A relocation site should have the same conditions of substratum type and stability and water velocity as the original habitat. Substrate and water quality conditions should be assessed for an annual cycle or longer. An often overlooked aspect of relocation is the importance of fish hosts for the long-term survival of mussels. If mussels are relocated to a different river, the new habitat must be evaluated for its ability to support the fish hosts needed.

Cope and Waller (1995) examined 37 accounts of projects on mussel relocation involving almost 90,000 unionids. In 78 percent of all projects, follow-up monitoring was performed. Thirty-eight percent of projects were monitored for 1 year or less, and 16 percent were monitored consecutively for 5 or more years.

Mortality rates were calculated based on the percentage of mussels recovered versus the number of mussels relocated. In 32 percent of projects, mortality was between 0 and 20 percent. In 11 percent of the projects, the reported mortality was 21-70 percent, and in 30 percent, reported rates were greater than 70 percent. For some projects, reported mortality was 90 percent or greater, and for 27 percent there was no reported mortality. The average recovery rate was 43 percent. Minimal mortality (<12 percent) and high recovery rate (>88 percent) were shown when aerial exposure was less than 4 hr and when relocations were conducted in spring or autumn when air (12-28 $^{o}$C) and water temperature (15-23 $^{o}$C) was moderate.

Incomplete and inconsistent reporting of mortality data and inadequate monitoring of relocation projects prevented accurate assessment of relocation success. Long-term monitoring (4 years or more) was rare. Present assessment of relocation project success was based on recovery and presumed mortality rates. A determination of growth rates before and after relocation, reproduction and recruitment rates, and other physiological measurements would show the effect of relocation on mussels more completely (Cope and Waller 1995).

A major problem in assessing relocation success is the interpretation of dead or missing mussels at the relocation site. When recently moved mussels are found dead, no means exists to determine if cause of death was due to natural mortality, stress from rough handling during relocation, or an inappropriate relocation habitat. If mussels are not found at the relocation site, mortality is not the only feasible explanation; water currents could have carried them to another area.

Mussels can be relocated if their existing habitat will be affected by dredging, channel modification, or construction. A dive team can collect mussels, temporarily hold them in buckets, coolers, or in water, then move them to a new area. Mussels can then be introduced into the new habitat. Such work is time-consuming and expensive. A four-person dive crew can cost up to $5,000 per day. Depending on the density of mussels in the affected area, the crew could collect up to 1,000 mussels each day. If mussels are put in the substratum by hand, placement will take about the same time as collection. Additional time for transporting mussels, marking, and identifying (if deemed appropriate) must be included. Considering the expense of divers, support personnel on the shore, senior scientists, materials and equipment to hold and transport the mussels, a 1-week mussel relocation project could cost between $25,000 and $50,000 (Table 5).

## Construct artificial habitats or improve existing habitats (A-10, A-11, A-12, A-19, D-2, D-3, D-4)

If suitable substratum at a site does not exist, gravel or cobble could be brought in and placed at the area. Mussels are found in habitats where velocity during the summer is usually between 0.5 and 1.5 ft/sec. If extended periods of high-velocity water occur during certain times of the year, artificially placed substratum could be eroded away. Often plans for artificial habitats should include measures to stabilize banks or alter velocity with dikes or weirs. The appropriate particle size for an artificially placed shoal is typically between 1 and 2 in. in diameter. Larger particles reduce the available habitat for mussels, and smaller particles decrease the overall stability. The cost of constructing such a habitat depends mainly on the distance that materials and equipment must be transported; the cost of gravel is comparatively low. One ton of gravel delivered to a site could cost $15. This much gravel, spread 1 ft thick, would cover an area measuring 20 by 10 ft. A gravel bar 300 by 100 ft long could cost approximately $5,000.

Weirs can be placed at the entrance of bendways to divert specific quantities of water into these water bodies (A-19). This will reduce sedimentation and improve habitat for mussels, aquatic insects, and fishes. Diversion structures (D-2) can be built that would trap or deflect sediments from entering backwater habitats. Wing dams can be constructed that will reduce sediment accretion (D-4).

The success of artificial habitats is dependent on existing hydrologic conditions. As long as the substratum is not subject to extreme erosion or sedimentation, it should quickly recolonize with new organisms. A gravel bar placed in an abandoned channel of the Tombigbee River in 1984 was quickly populated with macroinvertebrates and is still stable and free of excessive sedimentation (Miller et al. 1988).

### Artificial propagation

Isom and Hudson (1982) developed a process for culturing freshwater mussels. Their work was based upon information in LeFevere and Curtis (1912) and Ellis and Ellis (1926). The procedure consisted of removing glochidia from gravid females and placing them in a culture media. The media contained all necessary amino acids, vitamins, and salts for the glochidia. Sterile procedures were required, and antibiotics were added to the media to reduce contamination. Isom (1983) reported that it was possible to rear up to 0.5 million glochidia in a two-compartment incubator.

Glochidia from uncommon or endangered mussels could be reared in the laboratory and then released to the field. Such work could be undertaken if there was the need to artificially increase the numbers of an important species of mollusc. If a laboratory could be found with the capabilities for doing this work, actual costs would consist mainly of materials, basic laboratory equipment (incubators, centrifuges), and technical personnel. Collecting and transporting organisms safely would be inexpensive if the laboratory was close to a suitable mussel habitat.

# 5 Recommendations

## Background

As a result of considerable field and laboratory studies and a review of the scientific and Government literature, it was determined that present levels of commercial navigation traffic in the UMR were having little or no effect on the freshwater mussels (Miller and Payne 1996a). However, negative effects could occur at selected high-use areas where barges are fleeted or unloaded. The following section describes a protocol that could be used to minimize the effects of commercial navigation traffic on freshwater mussels. Some of the reported negative effects of movement of commercial vessels and suggested remedies (from Table 4 and the list of measures provided earlier) are listed in the section below.

## Useful Methods to Minimize Effects of Vessel Passage

Any action that erodes or otherwise disturbs the substratum could potentially destroy mussels or damage their habitat. Vessels moving in the navigation channel that are near or even over the bed, as long as they do not scrape the bottom, will have little effect on freshwater mussels. Locating permanent or temporary fleeting sites directly on mussel beds should be avoided. In addition, vessel movement should be restricted from shallow areas where they could scrape the bottom.

Negative effects of vessels moving over mussel beds can be reduced by doing the following:

*a.* Reducing vessel speed.

*b.* Using the area only during high water so the vessel will not scrape the bottom.

*c.* Marking a distinct navigation lane so that negative effects are restricted to one area, thereby reducing overall impacts to the bed.

*d.* Reducing the number of barges so the tow is easier to control and less power is required.

As stated above, the major negative effects of vessel movement occur when the hull or propeller scrapes the bottom and erodes the substratum or dislodges mussels. However, a series of smaller impacts caused by vessel passage (creation of waves, drawdown, and sediment suspension) could negatively affect mussels. Although these are minor in comparison to forces that dislodge mussels or erode the substratum, these should be considered when evaluating the effects of commercial navigation effects. A list of these negative impacts and suggested methods for reducing their negative effects are listed below.

**Suggested Methods to Minimize Effects of Movement of Commercial Navigation Vessels on Freshwater Mussels**

| Physical Effect of Vessel Movement | Effect on Mussels | Possible Remedy (see Table 4 and list of measures provided earlier) |
|---|---|---|
| Waves | Could cause limited erosion and introduction of sediments in water | A-1, D-1, D-2 |
| Drawdown | Could expose mussels to the atmosphere for short periods | A-1, A-18 |
| Turbulence and velocity changes | Could cause mussels to close their valves temporarily | A-1 |
| Increased suspended solids | Could smother mussels or interfere with respiration, feeding | A-19, D-2, D-4 |
| Benthic scouring | Could dislodge or damage mussels | A-1, A-3, A-4, A-9 |
| Indirect effects (dredging, construction of loading facilities, or river training features) | Could dislodge, smother, or otherwise damage mussels | A-9, A-10, A-11, A-13, C-3, D-3, A-14, C-8, C-9 C-10 |

Appropriate mitigation features suitable for the UMR are listed below. For example, artificial propagation (AP) would most appropriately be used in sensitive areas, valuable existing habitat, and channel borders. The matrix is meant to suggest possible options to deal with selected areas of importance in the UMR. It would not be feasible to develop a matrix that would deal with every segment of the UMR. Site-specific problems, each with a unique set of issues, should be dealt with individually.

**A Generic Matrix That Relates Possible Mitigation Methods for Freshwater Mussels to Appropriate Application Areas in UMR**

| Method | Appropriate Application Area | | | | | |
|---|---|---|---|---|---|---|
| | SA | VH | LQ | MC | CB | SW |
| AP | x | x | | | x | |
| HI | x | | x | | x | x |
| AT | x | x | x | | x | |
| MR | | x | | | x | |
| AD | x | x | | | x | x |

**Abbreviations for Matrix**

| Method | Appropriate Application Area |
|---|---|
| AP - Artificial Propagation | SA - Sensitive Area |
| HI - Habitat improvement | VH - Valuable existing habitat |
| AT - Alter traffic patterns | LQ - Low-quality habitat |
| MR - Mussel relocation | MC - Main channel |
| AD - Avoid dredging | CB - Channel border |
| | SW - Slack-water habitat |

The following methods can be used to protect mussels and *L. higginsi* from the movement of commercial vessels. As described above, the major detrimental effect of traffic for mussels is disruption of the mussel bed or dislodging mussels.

## Alter traffic patterns

The navigation channel could be repositioned if it was determined that commercial vessel passage was having a negative effect on high-quality mussel habitat. Typically, this would be done with navigation buoys and in coordination with the U.S. Coast Guard. Depending on local conditions, it could require dredging or construction of dikes. If vessels were directed closer to a bank, then some protection could be required. Care should be taken that the new route for vessels does not cause some other negative effect.

### Modify navigation channel to protect resource

An existing bed could be protected by modifying the channel by altering depths or velocities over the mussel bed. In addition, dikes or levees could be constructed and placed in a manner to protect mussel habitat.

### Create new habitat for mussels

Using a mixture of coarse sand and 1- to 2- in.-diam gravel, mussel habitat can be created in large rivers. Care must be taken to ensure that the habitat is not placed in a river reach subjected to extreme sediment erosion or accretion. Usually the most expensive aspect of creating mussel habitat is transporting substratum since sand and gravel is inexpensive. Man-made habitats can be allowed to colonize naturally or they can be seeded with mussels collected at other locations. Habitat creation should be considered when there is a need for a demonstration project or it is not feasible to alter traffic patterns or the navigation channel.

### Mussel relocation

As described above, there have been numerous instances where mussels were moved to new areas. Because of the expense of doing this work, and since there is the possibility of mussel mortality when moved, this is often not a viable method. In addition, this action does not protect the habitat.

### Artificial propagation

As described earlier, the artificial propagation of mussels, first described by LeFevere and Curtis (1912) and Ellis and Ellis (1926) and recently developed by Isom and Hudson (1982), can be used to compensate for negative environmental effects. Although this method has been used successfully in the laboratory, it has not been used in a large-scale field demonstration. Although large numbers of glochidia can be produced in the laboratory, it is difficult to keep them viable until they are released. Once in the water, they will be subjected to the same stress from disease, predation, and localized poor water and sediment quality that affects naturally spawned mussels.

## Assessing value of Project Area for Mussels and *L. higginsi*

The previous section described techniques for protecting mussel habitat where *L. higginsi* is known to occur. The following section describes methods to conduct a survey to determine if *L. higginsi* or other valuable mussel assemblages are present. Once it has been determined that valuable mussel habitat is likely to be negatively affected by commercial traffic, then resources can be effectively used to protect this habitat.

### Preliminary site examination

The site should be located on navigation charts or topographic maps. Literature should be reviewed to determine if mussels have ever been found in the area. Based on published and unpublished information, the likelihood of finding mussels should be determined. An evaluation of hydraulic conditions at the site should be made. A site is more likely to support high-density mussel stocks if the current velocity is moderate (0.5 to 1.5 ft/sec) and the substratum is stable with little sediment erosion or accretion.

### Preliminary field evaluation

A preliminary evaluation of the site should be made. This would not necessarily require divers, but could be done with personnel knowledgeable on aquatic systems. The shore and shallow water should be examined for shells and appropriate substratum. If conditions appear to be appropriate for mussels, then more detailed studies should be conducted.

### Detailed site evaluation using divers

If conditions appear appropriate for mussels, then detailed quantitative or qualitative sampling should be done using divers. Sampling methods should follow those of Miller et al. (1993). The purpose would be to determine if mussel resources are present and to determine their relative value. A high-value mussel bed should contain moderate to high-density mussel population (at least 20-50 individuals/m) and demonstrate at least some evidence of recent recruitment (i.e., a minimum of 20 to 30 percent of the individuals should be 2-3 years old or less). Often presence of an uncommon or Federally listed species such as *L. higginsi,* a State-listed species, or fairly uncommon species such as *Plethobasis cyphyus* or *Cumberlandia monodonta* is considered to be an indicator of high value. If onsite studies demonstrate that valuable mussel resources exist in the area of concern and that movement of commercial navigation vessels could directly or indirectly affect the habitat, then a plan should be developed to protect mussels.

## Summary

### Environmental effects of commercial vessel movement

Results of previously conducted laboratory and field studies indicated that the increase in commercial navigation traffic resulting from the completion of the second lock at Melvin Price Locks and Dam will have minimal if any negative effects on freshwater mussels and the endangered *Lampsilis higginsi*. An exception could be certain high-use reaches such as near fleeting areas, ports, or in turning basins. Brief periods of increased turbulence and elevated suspended sediments in high-use areas that result from propeller wash, water displacement, and hull friction could dislodge mussels from the substratum and disrupt or destroy their habitat. However, in the river proper, mussels reach their highest density along the channel border away from the navigation channel. Vessel passage is infrequent, and the magnitude of disturbance at the mussel bed is not great enough to disturb mussels.

Results of field studies indicated that only about 20 percent of commercial vessel passages caused a major environmental effect, which was defined as a change in water velocity that was at least double ambient conditions (Miller and Payne 1996a). For example, in one such event, velocity changed from 0.348 ft/sec (10.6 cm/sec) to 0.720 ft/sec (21.9 cm/sec) for approximately 100 sec. Thirty-seven percent produced a minor effect, and 43 percent produced no measurable change. These velocity changes are minor, especially when compared with conditions during normal high water, which is usually between 2-3 ft/sec (61-91 cm/sec) in January through April for most years. In addition, vessel-induced changes in turbidity and suspended solids at mussel beds in the UMR were minor, of short duration, and usually lasted no more than several minutes. Typically, a vessel caused an increase in total suspended solids of no more than two times ambient conditions and had a measurable effect for several minutes. In the UMR, mussels are found in firmly packed substratum that is relatively free of recently settled sediments; therefore, movement of large vessels had minimal effects on ambient suspended solids and turbidity.

### Reducing effects of traffic on mussels and *Lampsilis higginsi* in the UMR

Negative effects of vessels movement could be reduced by lowering vessel speed, using the area only during high water so the vessel will not scrape the bottom, or marking a distinct navigation lane so that negative effects are restricted to one area, thereby reducing overall impacts. The number of barges being transported could be reduced so the tow is easier to control and less power is required. In addition, there are a series of smaller impacts caused by vessel passage that should be considered when evaluating the effects of commercial navigation effects. These minor effects include creation of waves, water drawdown, and benthic scouring. Other impacts that are indirectly related to commercial vessel passage include secondary impacts such as dredging, construction of loading facilities, or river training features.

Appropriate mitigation features to reduce impacts of traffic in the UMR could include the following: artificial propagation of valuable mussels including *L. Higginsi*, protection of sensitive areas or valuable habitat, improving existing habitat, altering traffic patterns, and relocating mussels to safer areas. Additional features include the following: avoiding dredging, altering traffic patterns, modifying the navigation channel to protect the resource.

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Results of previously conducted laboratory and field studies on navigation traffic effects have been reviewed. Projected increases in commercial vessel passage resulting from the completion of Melvin Price Locks and Dam will likely not have a measurable effect on freshwater mussels. However, certain high-use river reaches, for example, near fleeting areas or ports, could be negatively affected by commercial traffic. Various methods to reduce effects of traffic, such as altering traffic patterns, artificial propagation of mussels, relocating mussels, and creating or protecting mussel habitat, are reviewed and discussed. As an aid to reducing traffic effects, important mussel beds in the upper Mississippi River, some of which support the endangered *Lampsilis higginsi*, have been identified.

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