Conservation Plan for Freshwater Mussels of the Upper Mississippi River System

Prepared by the

Mussel Ad Hoc Committee

of the

Upper Mississippi River Conservation Committee
4469 48th Avenue Court
Rock Island, Illinois 61201

Revised May, 2004

Conservation Plan for Freshwater Mussels of the Upper Mississippi River System

Prepared by the

Mussel Ad Hoc Committee

of the

Upper Mississippi River Conservation Committee
4469 48th Avenue Court
Rock Island, Illinois 61201

INTRODUCTION

The Upper Mississippi River System (UMRS) includes the Mississippi River from the mouth of the Ohio River upstream to the Twin Cities in Minnesota. It also includes the Illinois River and other major tributaries in the five states of Minnesota, Wisconsin, Iowa, Illinois and Missouri. Historically 51 species of freshwater mussels lived in the UMRS; today, 44 species have been found in mussel surveys conducted in the past 35 years (Havlik and Sauer 2000). In North America, it is estimated that 55 percent of the nearly 300 species of freshwater mussels are in danger of extinction and only 25 percent are considered stable (Williams et al.1993). No other group of animals in North America is in such grave danger.

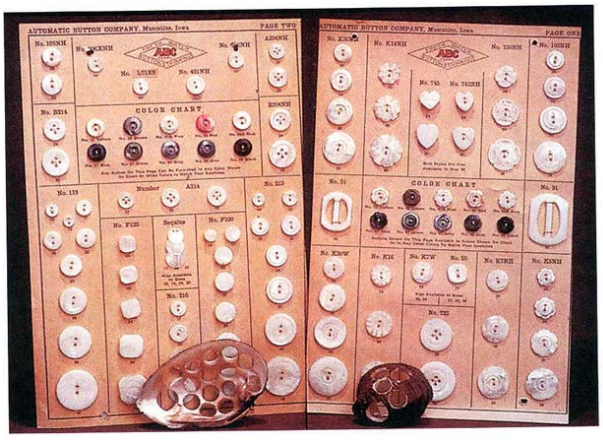
The goal of this Conservation Plan for Freshwater Mussels is to return a healthy, self-sustaining native freshwater mussel fauna to the UMRS. Specifically, the purposes of this document are to (1) identify the research, management, and conservation actions necessary to maintain and recover the mussel fauna; (2) increase government and public awareness of the plight of these animals and their essential ecosystems and garner support, including adequate funding, for species and habitat protection programs; (3) foster creative partnerships (working and funding) among federal, state, tribal, and local governments and the private sector to restore the mussel fauna and environmental quality to our rivers; (4) document the many problems which are barriers to effective mussel resource management efforts; and (5) prescribe a strategic plan of action, which if implemented, will restore the valuable freshwater mussel resources of the UMRS. Common and scientific names referenced in this plan are from Turgeon et al.(1998).

HISTORY

It was not until the mid-1850s when a large gem-quality pearl was found by a New Jersey shoemaker in his evening meal of mussel meats that any particular attention was given to freshwater mussels. This incident set off a wave of “pearl fever”, which gradually spread south and westward.

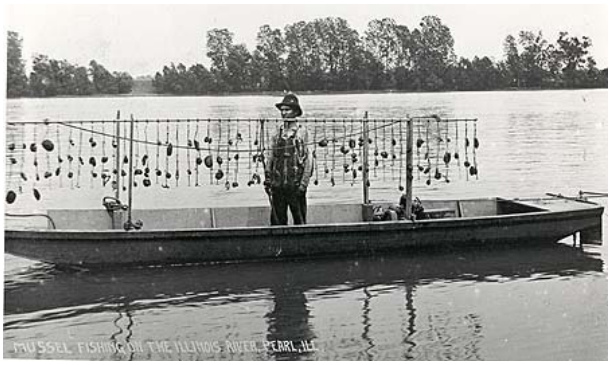
Finding a pearl inside a freshwater mussel. Source: Muscatine Art Center, Iowa. The photo on the right shows the many different shapes, sizes and colors of natural pearls. Source: Mississippi River Pearl Jewelry Company, Alma, Wisconsin.

In 1891, another industry was born that would have an even greater impact on the river's mussel resources. John Boepple, a German immigrant, using mussel shells as the raw material, initiated the first production of "pearl" buttons in the basement of his Muscatine, Iowa home. Within a few years, there were three button factories in Muscatine. This industry grew rapidly; by 1908 it had a capital investment of over two million dollars. By 1912, there were 196 plants involved in one phase or another of manufacturing buttons or novelty items from mussel shells along the Upper Mississippi River and its tributary streams.



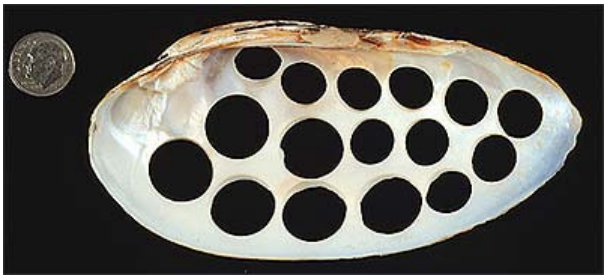
Pearl button factory at Muscatine, Iowa. Round sections were cut from mussel shells and processed into finished pearl buttons. Source: left photo U.S. Bureau of Fisheries; right photo Richard Sparks, Illinois Natural History Survey, Havana, Illinois.

Mussels were harvested by various methods including methods including wading, shallow diving, hand rakes and forks, scissor tongs, hand (pole) dredges, crowfoot bars or brail. It was soon learned that mussel beds subjected to intensive harvest were often depleted within a few years.



Harvesting mussels on the Illinois River with a crowfoot bar (brail). Source: Marshall County Historical Society, Illinois. The right photo shows a close-up of the "crow feet" that mussels attach to. Source: Gary Andrashko, Illinois State Museum

Ten years after the button factory began production, the mussel beds near Muscatine were severely depleted by excessive, unregulated harvest. To meet the increasing demand for shells, the mussel fishery quickly spread to other portions of the river and its tributary streams in Minnesota, Wisconsin, Missouri, and Illinois. By 1920, shell tonnage harvested from these regions also began to decline sharply.



Commercial mussel fishermen standing in a large pile of mussel shells which will be used to make pearl buttons (circa 1911). Source: U.S. Bureau of Fisheries. The photo on the right shows a mussel shell (yellow sandshell) that has been drilled for button blanks. Source: Gary Andrashko, Illinois State Museum.

Concerned that the economic stability of their communities would suffer if dependable supplies of mussel shells were not maintained, industry and local businessmen sought federal and state agency assistance to restore depleted mussel stocks as early as 1905 (Pritchard 2001). The U.S. Bureau of Fisheries responded by establishing a biological research station at Fairport, Iowa in 1914 to conduct fish and mussel research. Mussel propagation soon became an important part of the station's work.

The Fairport Biological Station on the Upper Mississippi River at Fairport, Iowa, 1920. The Fairport State Fish Hatchery and University of Iowa Mississippi Riverside Environmental Research Station now occupy this site. Source: Iowa Department of Natural Resources.

Although the harvest of mussels from the UMRS continued to decline, an adequate supply of shells from southern states within the river basin allowed the pearl button industry to flourish until about 1940. The development and production of plastic buttons caused the collapse of the pearl button industry by 1945. The loss of thousands of jobs had a devastating economic impact on numerous small river communities within the UMRS.

Cessation of mussel harvest from mid-1940 to mid-1960 resulted in a partial recovery of the mussel populations in some stretches of the Upper Mississippi River. However, full recovery was thwarted by the cumulative impacts of additional habitat loss and increased pollution due to domestic growth and expanded agricultural, industrial and navigational activities. Because few people anticipated a renewed demand for mussels, concern for the welfare of these animals declined, resulting in a discontinuation of virtually all research and management efforts.

Expansion of the Japanese cultured pearl industry after World War II, coupled with the earlier discovery that mussel shells from the Upper Mississippi River drainage basin were the finest of all pearl implant materials, lead to the resumption of intensive mussel harvest within the UMRS. Thousands of tons of mussel shells were shipped annually to Japan. During the 1980s, mussel harvest increased sharply as a result of the Japanese having increased their production and marketing of cultured pearls. From 1983 to1987, mussel fishermen from the five UMRS states harvested shells with an estimated value of more than one million dollars.

Kokicki Mikimoto, founder of the cultured pearl industry. These cultured pearls are from the Mikimoto Company in Japan. The nucleus of the pearls is from shell of freshwater mussels from the Upper Mississippi River. Source: Kyodo and Mikimoto Company, Japan.

Since 1978, several events have occurred within the UMRS which resulted in further degradation of mussel stocks. Depletion of commercial mussel stocks in other regions of the Upper Mississippi River basin and higher prices being paid for shells caused a significant increase in harvest pressure by the five states' resident and non-resident mussel fishermen. The net result was extensive harvest in old and newly found mussel beds for all species and sizes of mussels of commercial value.

In 1982, numerous mussel fishermen and several biologists noted a large die-off of mussels had occurred during the summer. (Upper Mississippi River Conservation Committee 1988, Blodgett and Sparks 1987, Havlik 1987, Thiel 1987). The following year, mussel divers from La Crosse to Keokuk reported finding large quantities of shell of the commercial species that had died the previous year, far in excess of that normally found. They also indicated the die-off was still in progress based on the numerous dead mussels (meat still intact) and dying mussels being harvested. Specimens of live and dying mussels, and substrate samples from which they were collected, were sent to several laboratories to be tested for chemical contaminants and bacterial infestations. No causative agent(s) for the mortality could be identified. Die-off investigations conducted by Wisconsin and Illinois researchers indicated mussel mortality rates ranging from 20 to 40 percent.

Although no reports were received of mussel mortality during the summer of 1984, conversations with mussel fishermen later in the year disclosed that a limited die-off had indeed occurred (Upper Mississippi River Conservation Committee 1988). Reasons given for not reporting the die-off were that it was not as severe as the previous two years and they were fearful state natural resource agencies would halt mussel harvest. Inasmuch as knowledge of continued mortality was not learned until late fall, no additional mussel samples were taken for diagnostic purposes.

By the third week of June 1985, biologists from several UMRS states had received reports that the die-off had resumed. Several samples of live and moribund mussels were again collected and sent to fish and mussel pathologists. Their analysis revealed that the animals appeared to have been healthy (in good body condition with normal gametogenesis in progress) right up to the

time of death. No causative agent(s) could be identified in these samples or others collected and submitted to different pathology labs later during the year.

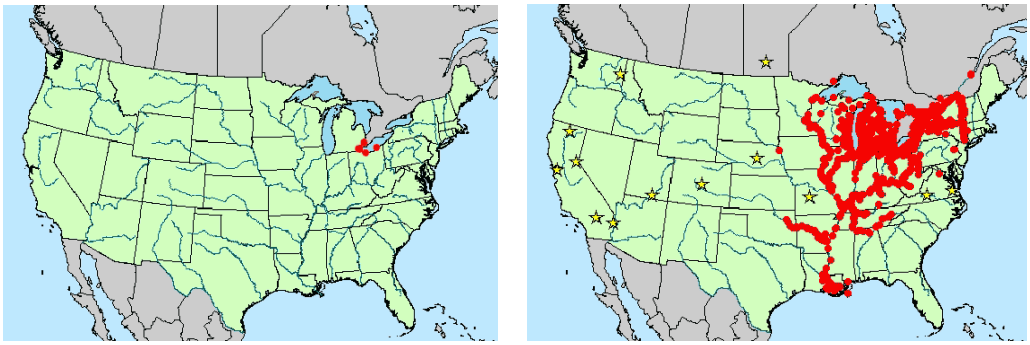
Of the Upper Mississippi River commercial mussel fishermen interviewed during 1985, many were of the opinion that 40 to 75 percent of all washboard (*Megalonaias nervosa*) and threeridge (*Amblema plicata*) had been killed in the beds they harvested upstream of Keokuk, Iowa (Upper Mississippi River Conservation Committee 1988). While the die-off may not have been as devastating as believed, a survey by Illinois biologists of a Pool 15 mussel bed did indicate an overall mortality rate of 17.9 percent for the 25 species collected. Mortality rates found for individual species were 21.9 percent for washboard, 25.8 percent for pimpleback (*Quadrula pustulosa*), 22.8 percent for threeridge, and 28.8 percent for fawnsfoot (*Truncilla donaciformis*). The severity of the die-offs was also reflected in the commercial harvest; more that 60 percent of the washboards harvested by Illinois mussel fishermen from Pools 12 to 19 were recent-relic shells.

ZEBRA MUSSELS: A SIGNIFICANT THREAT TO NATIVE MUSSELS

Since the mid to late 1980s, a new, more serious threat to native mussels appeared. In 1988, a small, bivalve mollusk of European origin appeared in the Laurentian Great Lakes. The zebra mussel (*Dreissena polymorpha*) and quagga mussel (*D. bugensis*) presumably were brought over from Europe in ballast water of ocean-going vessels. These freshwater and brackish water tolerant bivalves quickly spread in the Great Lakes and made their way to the upper Illinois River system. In 1991 the zebra mussel was found first in the Upper Mississippi River near La Crosse, Wisconsin (Sparks et al. 1994).

Zebra mussels (*Driessena polymorpha*). Byssal threads used by zebra mussels to attach to hard surfaces can be seen in the right photo. Source: Ohio Sea Grant.

Since their appearance in the Upper Mississippi River, zebra mussel populations have expanded exponentially, sometimes reaching population densities of 60,000 per square meter. By 1999, very low population densities occurred in Navigation Pool 2 downstream to Lake Pepin, and high densities have occurred from Lake Pepin downstream to the open river reach downstream of the Melvin Price Lock and Dam at Alton, Illinois.



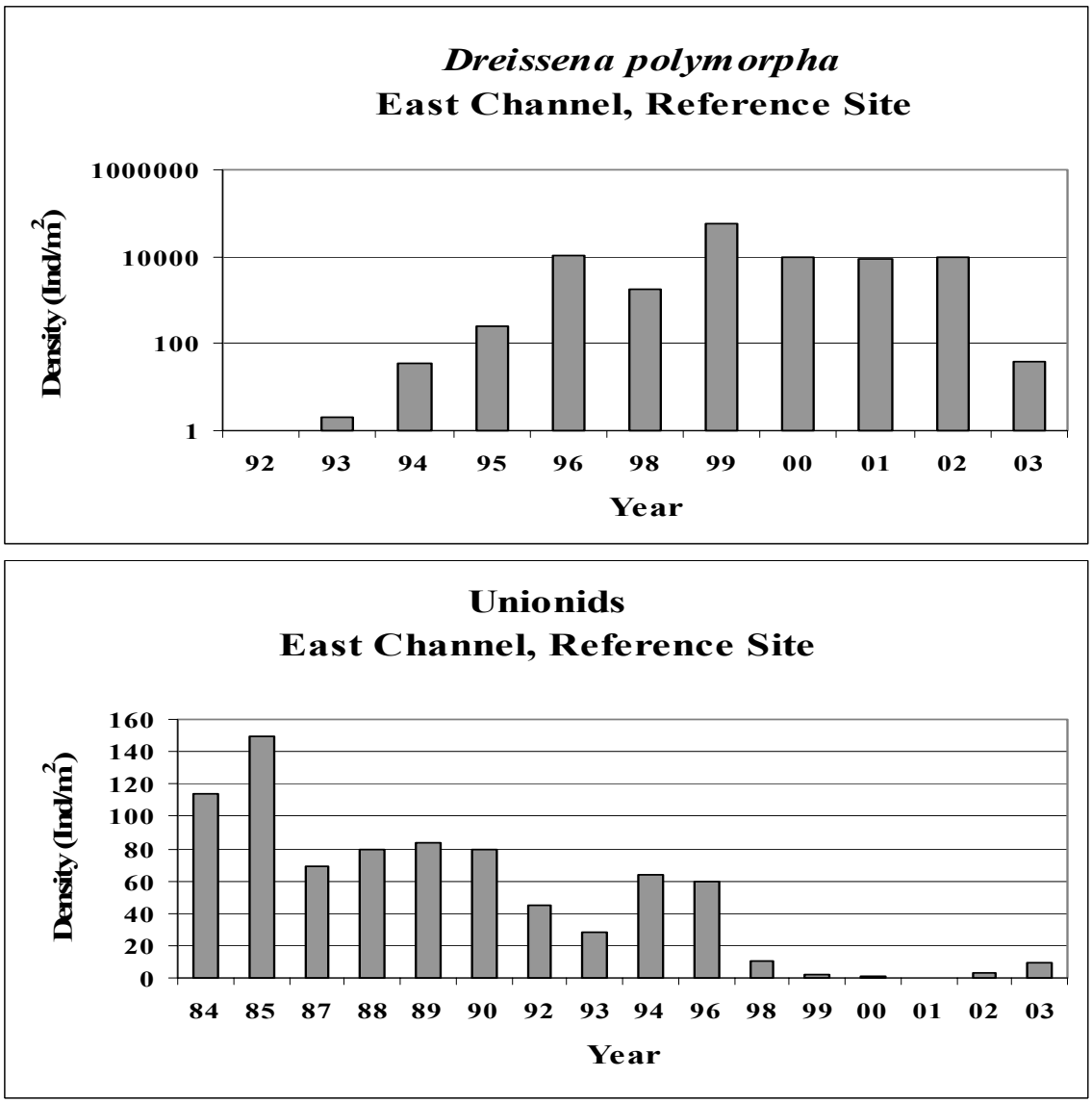
1988 2002

Distribution of zebra mussels (*Driessena polymorpha*) in 1988 and 2002. Source: U.S. Geological Survey

The native mussel community of the Upper Mississippi River at Prairie du Chien, Wisconsin, (East and West Channels) was valuable and well known to biologists and commercial mussel fishermen (Havlik and Stansbery 1978, Duncan and Thiel 1983). In particular, this area was considered to be the most valuable Essential Habitat Area for the federally endangered Higgins eye pearlymussel (*Lampsilis higginsii*) (U.S. Fish and Wildlife Service 1982; 2003). Abundance of native mussels in the East Channel declined during the early 1990s, possibly due to increased barge traffic (Marian Havlik, personal communication). However, in the late 1990s, the native mussel community at Prairie du Chien was devastated by zebra mussels.

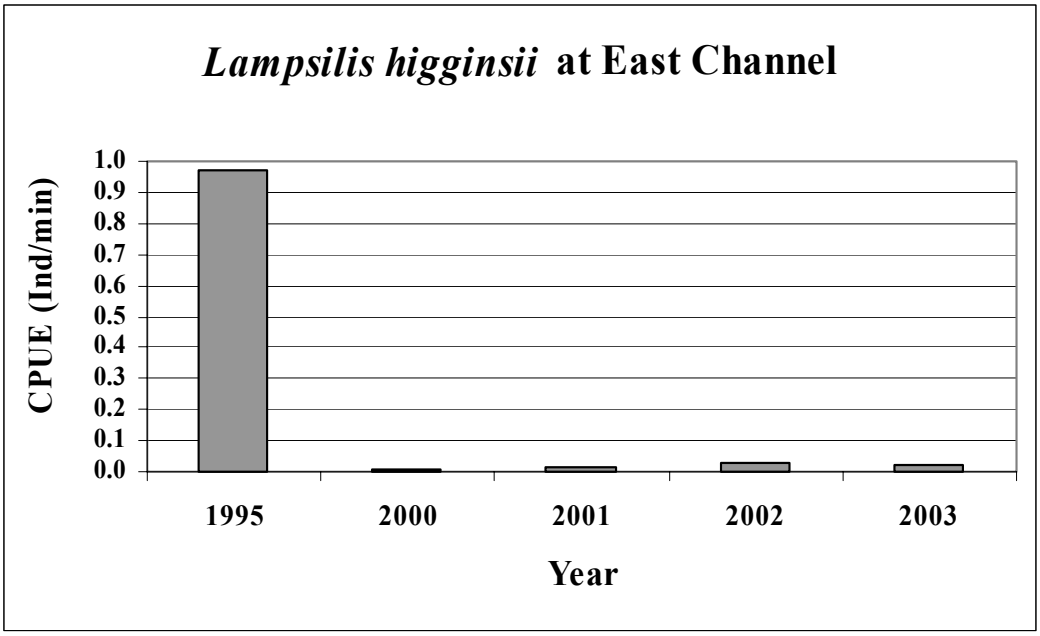
Photo on left shows zebra mussels scooped from the bottom of Lake Pepin (UMR Pool 4) by a diver; they formed a "carpet" on the river bottom. They also covered individual mussels. This fat mucket (*Lampsilis siliquoidea*) was removed from the bottom sediment by a diver. All exposed areas were covered by zebra mussels. Source: Minnesota Department of Natural Resources.

Zebra mussel densities in the East Channel rose dramatically from 2 per square meter in 1993 to 56,507 per square meter in 1999. Consequently, density of native mussels in the East Channel fell from 59.2 per square meter in 1996 to 1.7 per square meter in 1999; no juvenile native mussels were found between 1999 and 2001. Based on North America studies, zebra mussels are believed to impact native mussels by interfering with siphoning, feeding, gamete release, reproductive displays, and respiration (U.S. Fish and Wildlife Service 2000a).



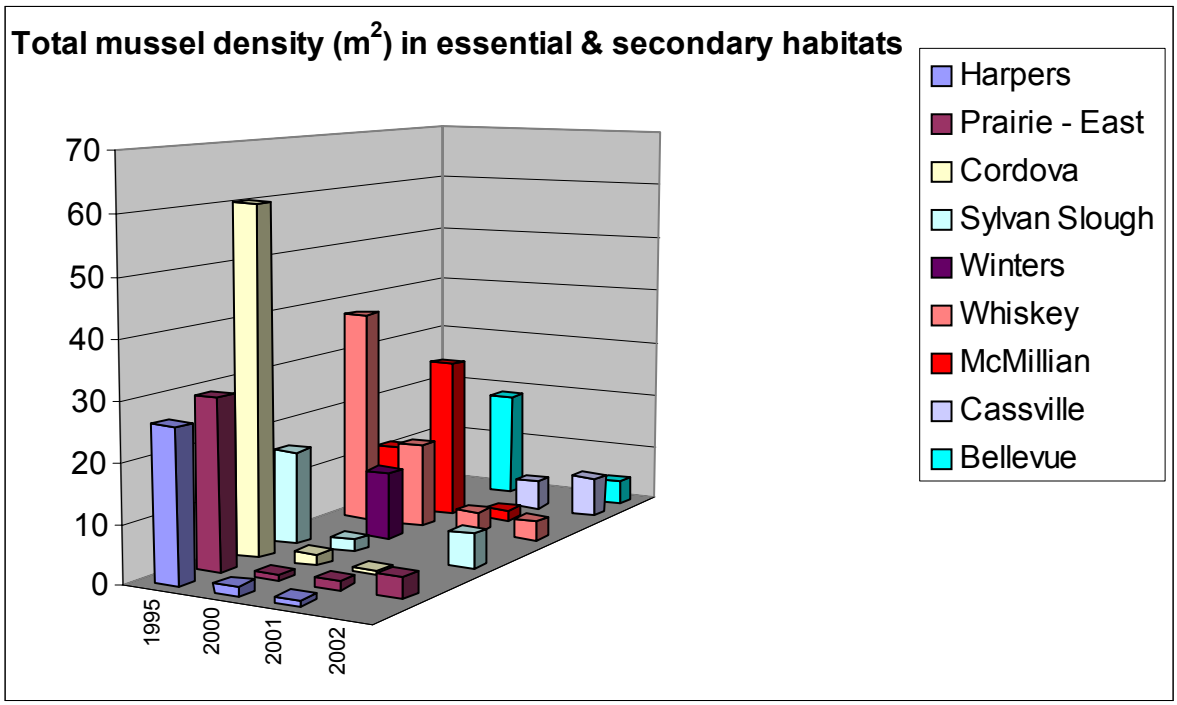
Density (number per square meter) of zebra mussels (*Dreissena polymorpha*) and native mussels at the East Channel Reference Site within the Prairie du Chien Essential Habitat Area, Pool 10, Upper Mississippi River, Wisconsin. Source: U.S. Army Corps of Engineers (2004).

Like the rest of the mussel community there, the abundance of Higgins eye in the East Channel significantly declined with the expanding zebra mussel population.



Catch per unit effort of Higgins eye pearlymussels (*Lampsilis higginsii*) at the East Channel Reference Site within the Prairie du Chien Essential Habitat Area, Pool 10, Upper Mississippi River, Wisconsin. Source: Unpublished 2003 data from the U.S. Army Corps of Engineers.

This phenomenon also occurred elsewhere on the Upper Mississippi River; density of native mussels declined significantly between 1995 and 2000 at some historically important mussel beds (Mussel Coordination Team 2003).



Density (number per square meter) of native mussels at Essential Habitat Areas and secondary habitats on the Upper Mississippi River. Source: Mussel Coordination Team (2003) based on unpublished 2002 data from the U.S. Army Corps of Engineers.

AN EXAMPLE OF MUSSEL CONSERVATION ON THE UMRS

After the decline in mussels at the Prairie du Chien Essential Habitat Area, state and federal river biologists took action to save the Higgins eye pearlymussel from extinction. In particular, they evaluated mussel propagation and relocation techniques. A mussel culture facility was quickly constructed at the Genoa National Fish Hatchery in Wisconsin.

Genoa National Fish Hatchery in Pool 9, Upper Mississippi River, near Genoa, Wisconsin. The building in the right photo was constructed to propagate the federally endangered Higgins eye pearlymussel (*Lampsilis higginsii*). Source: U.S. Fish and Wildlife Service.

In the spring of 2000, biologists obtained five gravid female Higgins eye from the St. Croix River and inoculated host fish (592 largemouth bass and 752 walleye yearlings) with glochidia. Their efforts were successful in producing approximately 92,000 juvenile Higgins eye; 4,800 were subsequently released into the Lower Wisconsin River in 2000 (Steingraeber 2002).

Stocking juvenile Higgins eye pearlymussels into the Lower Wisconsin River, Wisconsin. Juvenile in right photo was produced at the Genoa National Fish Hatchery, Wisconsin. Source: U.S. Fish and Wildlife Service

They also installed two propagation cages in Pool 4 of the Upper Mississippi River that produced 3 juvenile Higgins eye (Davis 2001).

One of two mussel propagation cages placed in Lake Pepin (UMR Pool 4) in June, 2000. The cage filled with sediments and was difficult to monitor; three subadult Higgins eye pearlymusseds (*Lampsilis higginsii*) were collected in June 2001. Source: Minnesota Department of Natural Resources.

During this time, the U.S. Army Corps of Engineers (Corps) and U.S. Fish and Wildlife Service (Service) entered into formal consultation under section 7 of the Endangered Species Act for the Upper Mississippi River – Illinois Waterway System Navigation Study. In April, 2000, the Service provided a Biological Opinion to the Corps on operation and maintenance of the existing 9-Foot Channel Project for another 50 years which would establish baseline conditions for the navigation study (U.S. Fish & Wildlife Service 2000a).

Zebra mussels are transported by towboats and other large craft using the locks and dams to upstream areas on the Upper Mississippi River. The Service determined in the Biological Opinion that operation and maintenance of the project for an additional 50 years would jeopardize the continued existence of the federally endangered Higgins eye pearlymussel because it provides for a steady upstream transport of zebra mussels on the Upper Mississippi River. In order to avoid jeopardy, the Service recommended that the Corps establish populations of Higgins eye in areas with few zebra mussels, and implement a zebra mussel control program.

Zebra mussels (*Driessena polymorpha*) attached to a barge in the Twin Cities, Minnesota, and the hull of a houseboat in La Crosse, Wisconsin. Source: Minnesota Department of Natural Resources.

The Corps accepted the Service's recommendations, developed a Higgins Eye Pearlymussel Relocation Plan, and established an interagency Mussel Coordination Team to assist in implementing the Biological Opinion requirements (U.S. Army Corps of Engineers 2002). Since 2000, a variety of conservation measures have been implemented including genetics studies, mussel culture at the Genoa National Fish Hatchery, cage culture in the Upper Mississippi River and tributaries, stocking juveniles, relocating adults, stocking glochidia inoculated fish, cleaning and stockpiling adults, and survey/monitoring activities (Mussel Coordination Team 2003). A reconnaissance report by the Corps recommended a feasibility study be conducted to evaluate potential measures for managing zebra mussels in the Upper Mississippi River Navigation System (U.S. Army Corps of Engineers 2003).

Juvenile and subadult Higgins eye pearlymussels (*Lampsilis higginsii*). Mussels in the upper left photo are approximately three months old; the diver is holding them by their byssal threads. The juvenile in the upper right photo is less than one-millimeter long and is shown next to the head of a pin for comparison. Subadults shown in the bottom photos are approximately 16 and 28 months old, respectively. Source: Minnesota Department of Natural Resources and U.S. Fish and Wildlife Service.

THE CONCERN FOR MUSSELS WIDENS – DEVELOPMENT OF A NATIONAL STRATEGY FOR THE CONSERVATION OF FRESHWATER MUSSELS

In 1988, the Upper Mississippi River Conservation Committee produced "A Strategic Plan for the Management of the Freshwater Mussel Resource of the Upper Mississippi River" (Upper Mississippi River Conservation Committee 1988). The plan was prepared in response to the increase in harvest of mussels for cultured pearls and a large die-off of native mussels in the River from 1982 to 1985.

With the arrival of zebra mussels in the Great Lakes in 1988 and Upper Mississippi River System in 1991, the concern for mussel conservation became national in scope. In 1995, representatives from several federal

and state natural resource agencies, the commercial mussel industry, academia, and private agencies met to gather information on the status of freshwater mussel populations, research, and recovery activities. As a result of the magnitude and immediacy of the nationwide threats to the freshwater mussel fauna, the group agreed that a coordinated effort of national scope was needed to prevent further mussel extinctions and population declines. To address this need, the group drafted a "National Strategy for the Conservation of Native Freshwater Mussels" and established a national ad hoc committee with broad-based representation from state, tribal, and federal agencies, the mussel industry, private conservation groups, and the academic community to help implement mussel conservation at the national level. In 1997, the National Native Mussel Conservation Committee was formed and a National Strategy was developed (National Native Mussel Conservation Committee 1998).

BRINGING THE NATIONAL STRATEGY HOME – A CONSERVATION PLAN FOR MUSSELS OF THE UPPER MISSISSIPPI RIVER

The "ecological health" of the UMRS has declined over time for many species and habitats including native freshwater mussels (U.S Geological Survey 1999). Successful restoration of fish and wildlife depends on restoring the River's ecological health to a condition that sustains their life requirements.

An Ecosystem Restoration Plan for the UMRS must include a variety of measures to restore ecological health. Given the scale and complexity of the UMRS ecosystem, development and implementation of a restoration plan will require a significant investment of funds and personnel by state and federal agencies, non-governmental organizations and other partners over a long period of time.

The Upper Mississippi River – Illinois Waterway System Navigation Study is a significant federal investment under the leadership of the U.S. Army Corps of Engineers. Planning assistance is provided to the Corps by a variety of state and federal natural resource agencies and non-governmental organizations along the UMRS. In addition to commercial navigation improvements, the Upper Mississippi River – Illinois Waterway System Navigation Study proposes to include a variety of ecosystem restoration measures and represents a significant opportunity to restore ecological health of the UMRS.

Without implementation of a large-scale ecosystem restoration plan for the UMRS, state and federal natural resource agencies are unable to adequately address the present mussel management crisis. They have neither adequate funding, the professional staff, nor specific on-going programs to insure the sound management of their mussel resources. Little is known about the biology and population dynamics of mussels, or how commercial exploitations and human-induced environmental changes impact these animals. One major concern is the long-term impacts from zebra mussels and other non-indigenous species entering the UMRS.

The management of the UMRS mussel resource is further complicated by the fact that it is a shared system resource. Thus, independent management efforts on the part of one or two states cannot in total safeguard such a valued resource. Such requires that all states, although autonomous by nature, jointly adopt and cooperatively initiate a realistic plan of action to achieve common management goals.

This is such a plan. It is an updated version of the "Strategic Plan for the Management of the Freshwater Mussel Resource of the Upper Mississippi River" prepared by the Mussel Ad Hoc Committee of the Upper Mississippi River Conservation Committee in 1988 (Upper Mississippi River Conservation Committee 1988). It also incorporates the broader goals and objectives of the

National Strategy. Presented herein are the major issues and objectives that must be addressed if sound management of the UMRS mussel resource is to be achieved. The strategies indicate what is required to achieve the specific objectives within the next ten years.

Conservation Plan for Freshwater Mussels of the Upper Mississippi River System

Goal = Restore and sustain the native mussel community of the Upper Mississippi River System

Objectives

1. Implement a long-term survey and monitoring program to assess the distribution, abundance, recruitment and health of native mussels.

Strategies

1.1 Status of Mussels

1.1.1 Include native mussel monitoring as a component of the Environmental Management Program, Long Term Resources Monitoring Program (LTRMP).

1.1.2 Increase sampling effort to determine location, density, species composition, and status of existing mussel communities in the UMRS. Many reaches and tributaries need basic or current survey information. Knowledge of the condition and location of mussel resources is critical to understand a species' status and develop proper management actions. Basic sampling standards should be developed and implemented.

1.1.3 Compile historic mussel distribution data to facilitate its use. Many historic collections exist in museums, universities, and private collections. However, some specimens have been misidentified, and many of the collections have not been catalogued or the data are not readily available. This historic information is critical to understanding the current status of many mussel populations. The information also may be useful for identifying potential reintroduction sites and locating unknown populations.

1.1.4 Develop a central database on the status and location of native mussel populations. Information should be categorized based on U.S. Geological Survey hydrologic unit maps and mapped using a geographic information system (GIS). The database can be used by resource managers to track mussel populations and should include absence data.

1.1.5 Continue development of protocols for evaluating the health of mussels and establish a central database for mussel health data. The U.S. Fish and Wildlife Service Fish Health Center, La Crosse, Wisconsin, should provide leadership in developing these protocols on the UMRS. River managers need standard techniques to assess the health of individual mussels and populations, and major mortality events (die-offs). Baseline conditions for mussel health should be described and diseases noted as endemic to native mussels, or new to the UMRS ecosystem.

1.1.6 Develop a mussel distributional atlas. In the early 1980s, the U.S. Fish and Wildlife Service funded the production of an Atlas of North American Freshwater Fishes (Lee et al. 1980). This document provides a distribution map for all North American freshwater fishes and includes information on the species' habitat and biology. The fish atlas has been a valuable tool for fisheries managers and biologists; a similar atlas on native mussels would benefit mussel conservation efforts.

2. Describe the life history, taxonomy, genetics and population dynamics of native mussels.

Strategies

2.1 Life History

2.1.1 Conduct life history studies. Unlike many other animal species, little is known about the basic biology and habitat requirements of most species of mussels. A basic knowledge of life history and ecological requirements is critical to the conservation of mussels in the UMRS.

2.1.2 Conduct studies on reproductive biology. River managers need to know more specifics about how native mussels reproduce, when and where reproduction occurs and what environmental conditions are critical for reproduction and recruitment. Certain species of fish and amphibians are an important link in the reproductive cycle of freshwater mussels; they serve as intermediate hosts in the transformation of glochidia into juvenile mussels. Studies to identify glochidial hosts are critical for future propagation and restoration of mussel species and populations. Host information is available for some mussels (available on the Internet at Ohio State University website http://128.146.250.63/musselhost) and needs to be completed and validated for UMRS species.

In addition to native species, river managers need to better understand the reproductive biology of non-indigenous species like zebra and quagga mussels, and black carp (*Mylopharyngodon piceus*) to develop management strategies.

2.1.3 Conduct studies on habitat requirements. What habitat conditions (biotic and abiotic) are needed by mussels to sustain their populations and communities? This information is needed by river managers to maintain, restore or create mussel habitats on the UMRS. Likewise, it is important for river managers to understand the habitat requirements of non-indigenous species like zebra and quagga mussels to develop effective management strategies favoring native mussels.

2.2 Taxonomy

2.2.1 Develop and implement molecular genetics techniques to help identify mussel species. Historically, mussels have been described primarily on the basis of shell characteristics. This method has been very reliable, and there is little question regarding the taxonomic distinctiveness of most mussel species. However, molecular genetic analysis has shown

that some species are comprised of complexes of distinct species (Kat 1983a, 1983b, Lydeard et al. 1996, Mulvey et al. 1997). Thus some species believed to be widespread may be unknowingly lumped with species that are rare and in need of protection. Molecular genetics research should help clarify the taxonomic relationships within these complexes.

2.3 Genetics and Population Dynamics

2.3.1 Conduct studies on genetics. Information is needed by river managers to evaluate genetic variability between individuals and populations. This information is important in developing mussel propagation and relocation activities.

2.3.2 Conduct studies on population dynamics. Information is needed on the dynamics of mussel populations and communities in the UMRS. What environmental and population factors affect growth, mortality and recruitment? How do different species interact within mussel beds? How many adults and juveniles are needed to establish a new population or restore a former one? How close should they be placed to each other to optimize reproduction and recruitment? How do non-indigenous species like zebra mussels affect the diversity and abundance of native mussels? This information is important in restoring mussel populations and monitoring their long-term viability on the UMRS.

3. Determine how changes (man-made and natural) to the ecological health of the Upper Mississippi River System affect native mussels.

Strategies

3.1 Environmental Changes

3.1.1 Determine how and to what extent various habitat alterations affect mussel species and populations. The impacts to mussels from habitat alterations, such as impoundment and dredging of mussel beds, are fairly well understood. However, the links between the decline or loss of many mussel populations and the causative agent(s) are generally unknown. Research is needed to determine how and to what extent the following factors affect mussels (this list is not intended to include all of the potential mussel perturbation agents that need research): (1) pesticides, herbicides, and fungicides; (2) wastewater discharge of various pollutants; (3) siltation; (4) stream-flow modifications; and (5) modifications in water temperature, dissolved oxygen levels, nutrients, and pH; water level management activities associated with operation of the 9-foot channel project. A better understanding of how environmental factors affect mussel will enable resource agencies to better manage and conserve mussel communities.

3.1.2 Review early literature to determine what historic factors may have caused the decline or extirpation of mussel populations. The loss or decline of some mussel populations in specific rivers is the result of historic rather than current conditions. A review of historic literature may reveal the reasons for the current depressed status of mussel communities. If the original cause of the loss has been eliminated or minimized, mussel reintroduction

may be feasible. An example of historical documentation is a report by Pritchard (2001) "An Historical Analysis of Mussel Propagation and Culture: Research Performed at the Fairport Biological Station".

3.1.3 Develop and implement biomonitoring protocols using freshwater mussels. These monitoring activities should complement fish and other macrionvertebrate biomonitoring protocols presently used to evaluate the integrity of a stream. Fish and macrionvertebrate biomonitoring protocols have been developed to score and ranks lotic system for their health based on numbers and presence of sensitive species. Freshwater mussels are a very logical monitoring component for the biotic health of a system since they are generally long-lived and sedentary. This would provide valuable information for linking environmental threats to presence or absence of specific species, more adequately assess the integrity of streams, and provide a valuable tool to biologists and resource managers.

3.1.4 Encourage the U.S. Environmental Protection Agency to set standard bioassay protocols as a basis to set water quality standards that would protect mussel populations.

3.1.5 Encourage state agencies to adopt water quality standards that protect freshwater mussels.

3.2 Non-Indigenous Species

3.2.1 Continue development of predictive models on the spread of zebra mussels, black carp and other non-indigenous species and their likely impact on native mussels. Zebra mussels and other non-indigenous species have devastated native mussel populations in the Great Lakes (O'Neill and MacNeill 1991, Kelch 1994, Taylor and Kerschner 1995) and the UMRS, and they have now invaded inland rivers where they are likely to affect important mussel resources and protected species. Information is needed to predict the rate of movement of zebra mussels, black carp and other non-indigenous species into inland waters, the types of habitats they will invade, and the impacts they will have on native mussels in these habitats.

3.2.2 Develop and maintain a geographic information system (GIS) to monitor the spread of non-indigenous species relative to the location of native mussel populations. The spread of non-indigenous species should be monitored and the data reported in a readily available format. The U.S. Geological Survey Florida Caribbean Science Center at Gainesville, Florida, currently tracks the spread of zebra mussels and other non-indigenous species. That database should be reviewed to determine whether modifications are necessary to meet the needs of native mussel conservation and aquatic resource management.

3.2.3 Determine how non-indigenous species spread to new waters. Barge traffic has been the primary zebra mussel transport mechanism in large navigable rivers, and recreational boats are the likely vector into small rivers and lakes. Definitive information on non-indigenous species mode of transport could be useful in developing control procedures.

3.2.4 Investigate the feasibility of controlling the spread of non-indigenous species through technological means. The feasibility of a barrier between the Illinois Waterway and the Great Lakes should be investigated. Research on the physical, chemical and biological control of non-indigenous species is urgently needed. However, extreme care must be

taken to ensure that biological control methods for non-indigenous species do not jeopardize native mussels.

3.2.5 Develop measures to control the spread of black carp. Black carp are an Asian species whose primary foods are mollusks and crustaceans. Specimens have been found in the wild in the Mississippi and Red River Basins.

4: Implement measures to restore and sustain populations of native mussels on the Upper Mississippi River System.

Strategies

4.1 Propagation

4.1.1 Conduct a comprehensive review of foreign and related literature that could have application in mussel propagation research. Asian countries have a wealth of experience in freshwater mussel culture and their literature should be translated so techniques can be tested and implemented here.

4.1.2 Continue development of artificial propagation technology for native mussels. Artificially propagated juvenile mussels are needed for four primary purposes: (1) augment populations when population size of a rare species is too small, young, or old to support reproduction; (2) establish new populations when the translocation of adults is not possible; (3) maintain a captive population when the species' natural habitat is deemed unsuitable because of zebra mussels and other impacts; and (4) for bioassay research.

4.1.3 Determine the risk associated with mussels, their fish hosts, and associated disease escaping from the facility or propagation cages into non-historic habitat. Whenever species are moved into areas outside their historic range there is always a risk that they will escape and become established. If mussels and their associated fish hosts are to be propagated and held outside their historic range, an assessment should be made of the risk of escape and potential consequences. The Performance Standards for Safely Conducting Research with Genetically Modified Fish and Shellfish (available on the Internet at http://www.nbiap.vt.edu), and U.S. Fish and Wildlife Service and Department of Commerce Policy on Controlled Propagation of Species Listed Under the Endangered Species Act (U.S. Fish and Wildlife Service 2000b) will be considered in the course of propagation and containment activities. Mussel containment activities will not continue where the consequences of escape are likely and severe.

4.1.4 Develop a health strategy for captive mussel populations. This would include the development of techniques for disease diagnosis, determination of disease vectors, and disease control. If adult mussels are to be brought into active fish hatchery facilities, the effect of mussel disease on fish and fish diseases on mussels should be assessed.

4.1.5 Identify criteria for selecting federal, state, tribal, and private hatchery facilities that could be used for large-scale mussel propagation. Once artificial propagation technology is developed, existing hatchery facilities will be needed to produce juveniles for

reintroduction. If the facility managers know that they might be requested to propagate mussels, they could consider these criteria when planning modifications at their facility.

4.2 Reintroduction/Relocation

4.2.1 Develop protocols and techniques to relocate juvenile and adult mussels. Mussels are generally relocated for two reasons: to (1) remove them from an area when a development project or other factors threaten their survival; or (2) release them back into restored historic habitat or to non-zebra mussel impacted areas. Efforts to relocate adult mussels have met with varied success; nevertheless, this tool is essential to mussel conservation. For example, zebra mussels are currently threatening rare mussels in the Ohio and Mississippi River systems. To save some of these native species, it will be necessary to move some rare species to areas that will not be threatened by zebra mussels. Also, adult mussels can be relocated in order to reestablish extirpated populations when sufficient specimens are available in a donor population. The feasibility for releasing juvenile mussels into the wild and artificially infesting and releasing fish hosts needs to be tested. Additional research on such factors as habitat suitability, size and number of juveniles to release, method of release, and time of release are needed.

4.2.2 Develop criteria for mussel relocation. Develop a checklist of the physical, chemical, and biological parameters (e.g., habitat type, presence of other mussel species, and number of individuals needed for a self-sustaining population) to be considered before attempting to translocate mussels or hold them in refugia. This guidance should address moving species between watersheds and introduction into nonhistoric habitat. The guidance should also stress the need to monitor and fully report project results.

4.2.3 Develop protocols to ensure that zebra mussels and other non-indigenous species are not inadvertently introduced into new waters when native mussels are relocated. Because of the dire threat posed by zebra mussels and other non-indigenous species, some mussel species will be moved into hatchery facilities or to locations where these non-indigenous species do not exist.

4.2.4 Identify streams for reintroduction and augmentation of mussel populations. Federal and state natural resources agencies should form partnerships to develop a prioritized list of streams that can be used for reintroduction and augmentation of mussel populations.

4.2.5 Develop mechanisms for the long-term monitoring of transplanted mussels. Once released into the wild, individual mussels are difficult to relocate, complicating the assessment of release success. Use of radio telemetry should be explored along with other tagging methods (Lemarie et al. 2000). Other avenues of relocating and monitoring transplanted mussels should be investigated as well.

4.3 Refugia and Cryopreservation

4.3.1 Continue development of protocols and technology to maintain adult mussels in captivity. Many species are so rare or so threatened by habitat destruction or other factors like non-indigenous zebra mussels that they are likely to become extinct in the wild in the

foreseeable future. As mussels are long-lived, it may be possible to maintain some species in captivity for extended periods. When habitat is restored or suitable habitat is located, these individuals or their propagated offspring could be returned to the wild. The technology for the long-term maintenance of captive mussel populations is not fully developed. Research on the feeding and habitat requirements of captive-held adults is crucial.

4.3.2 Develop guidelines with thresholds (triggers) to assist managers in determining when individuals of a mussel species should be brought into captivity. Many factors threaten the continued existence of native mussels.

4.3.3 Develop criteria for selecting an appropriate facility to be used for captive mussel holding and identify specific facilities that could be used in this effort. These criteria will assist managers in determining if their facilities are suitable for captive holding. If the facility managers know they might be requested to hold mussels, they could consider these criteria when planning modifications to their facilities. Secure appropriate commitments from agencies or organizations for facility space in areas where there is an imminent need for captive holding.

4.3.4 Develop mussel cryopreservation technology. Cryogenic preservation could maintain mussel genetic material (much like seed banks for endangered plants) until such time that the habitat is suitable for reestablishing the species. Additionally, if a mussel population was lost to a catastrophic event, such as a toxic chemical spill, cryogenic preservation could allow for the eventual reestablishment of that population using preserved genetic material. As cryopreservation techniques for other faunal groups are developed, the technology should be adapted and tested on native mussels.

4.4 Habitat Restoration

4.4.1 Develop and implement projects to restore mussel habitats. The magnitude of the mussel conservation challenge is great, but staff and funding resources available for mussel conservation is small. Managers should concentrate their efforts, within their area of responsibility, on those key habitats, research programs, and protection / enhancement activities that will achieve the greatest benefit to mussel conservation.

4.4.2 Develop a list of case studies that identify and summarize successful habitat restoration and protection projects and make the information available to the mussel conservation community.

4.4.3 Construct habitat projects that provide flow and substrate conditions more favorable to native mussels than non-indigenous zebra mussels.

4.5 Species and Habitat Protection

4.5.1 Encourage state and federal agencies to use their regulatory authority to strengthen their enforcement capabilities to reduce or abate pollution and habitat loss on the UMRS, establish effective harvest restrictions and violation penalties, and optimize enforcement activities. Those few reaches that still harbor diverse mussel populations should be

protected from further habitat degradation to the extent possible. It is much more cost-effective to protect existing quality habitat than to restore.

4.5.2 Determine if current laws and regulations protect freshwater mussels. Many existing laws and regulations are aimed at protecting aquatic resources. However, information is needed to determine if they provide sufficient protection for rare mussels.

4.5.3 Determine if current water quality criteria protect all life stages of freshwater mussels. Bioassays should be conducted to evaluate the sensitivity of all life stages of mussel relative to the sensitivities of standard bioassay organisms. Surrogate species should be selected to be protective of most sensitive mussel species or appropriate buffers should be built into protective criteria models.

4.5.4 Determine if current Best Management Practices (BMPs) protect mussel populations and their habitat. Great strides have been made in the development and implementation of BMPs for agriculture, silviculture, road and bridge construction, and other activities, and these practices have benefited aquatic resources. Research is needed to determine if these practices adequately protect mussel populations and how they might be modified to be more effective. Information is also needed about the degree of voluntary compliance with BMPs.

4.5.5 Use federal and state legislation such as the Endangered Species Act to formally list mussels as endangered, threatened or other appropriate designation.

4.6 Endangered Species Act Recovery Plans

4.6.1 Implement recovery plans for federally endangered mussels of the UMRS. Four mussel species that reside in the Upper Mississippi River System receive federal protection under the Endangered Species Act. They are listed as endangered species and include the winged mapleleaf (*Quadrula fragosa*), Higgins eye pearlymussel, fat pockbook (*Potamilus capax*) and scaleshell (*Leptodea leptodon*).

5: Educate people (private, public and political) on the ecological and economic value of native mussels, threats to their continued existence, and restoration opportunities.

Strategies

5.1 Public Education

5.1.1 Compile an annotated list of existing freshwater mussel-related outreach material. Considerable educational material relating to freshwater mussels and the value of protecting natural stream ecosystems already exists.

5.1.2 Identify target audiences, evaluate the need for outreach material for these audiences, and develop appropriate media to strategically convey focused mussel conservation messages to specific audiences. Identify target groups that can assist with mussel conservation and

those that could be, or perceived they could be, impacted by the program. Where needed, develop specific outreach material for these target groups.

5.1.3 Identify and develop specific educational/informational material and mechanisms to assist field biologists with implementing this plan. This includes items such as an annotated bibliography of existing freshwater mussel literature, a database on the historic and current distribution of mussels, videos and other materials, and an effective information transfer system on current mussel research, management, and conservation issues.

5.1.4 Inform the public about the threat zebra mussels and other non-indigenous species pose to native aquatic species and other resources (e.g., sport fisheries, water supply facilities, and power plants). Public support will be needed to stem the invasion of these species into other waters. The public should be informed of the economic and ecological threat posed by non-indigenous species and provided with information as to what they can do to reduce the species' dispersal rate. If the spread of non-indigenous species can be slowed, increased opportunities will be available to develop native mussel protection strategies.

5.1.5 Request the U.S. Fish and Wildlife Service National Conservation Training Center develop training and educational coursework on freshwater mussel conservation.

5.1.6 The U.S. Fish and Wildlife Service and U.S. Geological Survey should continue to operate and maintain the Internet mussel web site "Freshwater Mussels of the Upper Mississippi River System" (http://midwest.fws.gov/mussel) to assist with implementation and outreach strategies.

5.1.7 Revise and reprint the 1985 identification booklet "Freshwater Mussels of the Upper Mississippi River" on waterproof paper (Wisconsin Department of Natural Resources 1985).

6. Develop strategies to implement the Conservation Plan for Freshwater Mussels of the Upper Mississippi River System.

Strategies

6.1 Plan Implementation

6.1.1 Ensure that new federal programs on the UMRS include conservation of native mussels as a project objective and implement appropriate portions of this plan. Recommend that this Conservation Plan for Freshwater Mussels on the Upper Mississippi River System be included as a project feature of the Upper Mississippi River – Illinois Waterway System Navigation Study.

6.1.2 Encourage federal, state and tribal natural resource agencies to establish new mussel conservation positions on the UMRS.

6.1.3 Use the interagency Mussel Coordination Team (MCT) to coordinate mussel conservation activities under this Plan. The role of the MCT may include, but not be

limited to, such activities as establishment of priority mussel research and management needs; collection and publication of mussel statistics; review of critical environmental issues; providing professional consultation services to the Corps and other agencies; development of uniform mussel investigation, propagation and relocation procedures, and public education programs and materials.

6.1.4 Foster and create new partnerships that facilitate the development of formal agreements (e.g., memorandums of agreement) among government agencies and private entities to help implement this plan. The mussel conservation community is small and, by itself, cannot significantly alter the factors that threaten this faunal group. However, most of the strategies that benefit mussels and their habitat quality also significantly benefit other aquatic fauna and resource user groups (commercial mussel industry, sport fisheries, water supply industry, canoeists, birders, etc.). Partnerships with other entities are essential to the success of this mussel conservation program, and these partnerships should be actively pursued.

6.1.5 Develop partnerships and seek funding from government agencies, private organizations, foundations, industries, and individuals. No one agency or organization has sufficient funds or expertise to conserve and recover the UMRS mussel fauna. Partnerships, cooperative ventures, and funding from within and outside government are essential to program success. Additionally, mussel conservation will not succeed unless it is integrated with other aquatic ecosystem conservation efforts. The benefit of mussel conservation must be linked to other aquatic resource benefits.

6.1.6 Seek funding for mussel conservation from agencies or organizations that have activities that impact mussel communities. Many regulatory agencies oversee programs that secondarily benefit mussels; they should strengthen their programs to improve the protection of mussel resources. Pursue cooperative funding that satisfies an agency's needs and promotes mussel conservation. Consider establishing mitigation trust funds to help compensate for the loss of mussel resources caused by development projects. A trust was established to mitigate for the loss of a mussel bed on the Ohio River. This trust now provides funds for mussel conservation projects that benefit Ohio River mussels (Marshall et al. 1993).

6.1.7 Evaluate funding alternatives, such as a tax on exported shells, commercial mussel harvest fees, or a tax on the import of products made from native shells. Some states already impose a tax on harvested shells, and the funds are used for mussel conservation efforts. A federal tax on domestic shell exports or the foreign import of mussel-derived products should be considered.

6.1.8 Seek funding assistance from non-government agencies and organizations, businesses, and foundations. Many organizations fund conservation projects or provide in-kind support. If one organization provides funding, other organizations are often more willing to match the original funds. Solicit the support of such organizations and build cooperative efforts among these groups.

SUMMARY

This plan presents an outline of goals, objectives and strategies for a UMRS mussel conservation program. These strategies do not encompass all the conservation activities that are currently under way nor do they identify all activities that will be needed for the long-term conservation of mussels. They are offered as guidance to provide a regional mussel conservation perspective and help various organizations identify the types of conservation tasks that could be implemented to assist in the greater conservation effort.

Furthermore, the Conservation Plan for Freshwater Mussels of the UMRS is intended to be a dynamic document that will be revised periodically as new information becomes available and new strategies are developed. The authors welcome any comments and suggestions that would help enhance short- and long-term mussel conservation goals.

ACKNOWLEDGEMENTS

This report was prepared by Gary Wege (U.S. Fish and Wildlife Service). Other members of the writing team included Dave Heath (Wisconsin Department of Natural Resources), Pam Thiel, Roger Gordon and Tony Brady (U.S. Fish and Wildlife Service), Dan Kelner (U.S. Army Corps of Engineers), and Mike Davis (Minnesota Department of Natural Resources). Special thanks to Marian Havlik (Malacological Consultants), Doug Blodgett (The Nature Conservancy), and Susan Rogers (U.S. Fish and Wildlife Service) for their review, suggestions and comments.

BIBLIOGRAPHY

Blodgett, K.D., and R.E. Sparks. 1987. Documentation of a mussel die-off in Pools 14 and 15 of the Upper Mississippi River. Pages 76-88 in R. J. Neves, editor. Proceedings of the workshop on die-offs of freshwater mussels in the United States. Upper Mississippi River Conservation Committee, Rock Island, IL.

Davis, M. 2001. Emergency conservation, relocation and reintroduction of Higgins eye pearlymussel (*Lampsilis higginsii*) and other mussel species from zebra mussel affected areas in the Upper Mississippi River. Minnesota Department of Natural Resources, Lake City, MN. 17pp.

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. 14pp.

Havlik, M.E., and D. H. Stansbery. 1978. The naiad mollusks of the Mississippi River in the vicinity of Prairie du Chien, Wisconsin. Bulletin American Malacological Union, 1977, pages 9-12.

Havlik, M.E. 1987. Probable causes and considerations of the naiad mollusk die-off in the Upper Mississippi River. Pages 91-103 in R. J. Neves, editor. Proceedings of the workshop on die-offs of freshwater mussels in the United States. Upper Mississippi River Conservation Committee, Rock Island, IL.

Havlik, M.E., and J.S. Sauer. 2000. Native freshwater mussels of the Upper Mississippi River System. Project Status Report 2000-4, U.S. Geological Survey, Upper Midwest Environmental Sciences Center, La Crosse, WI. 2pp.

Kat, P.W. 1983a. Genetic and morphological divergence among nominal species of North America Anodonta (Bivalvia: Unionidae). Malacologia 23:361-374.

Kat, P.W. 1983b. Genetics, morphological divergence, and speciation among *Lampsilis*. Journal of Molluscan Studies 49:133-145.

Kelch, D.O. 1994. Slow the spread of zebra mussels and protect your boat and motor, too. Ohio Sea Grant Publication FS-054.

Lee, D.S., C.R. Gilbert, C.H. Hocutt, R.E. Jenkins, D.E. McAllister and J.R. Stauffer, Jr. 1980. Atlas of North American freshwater fishes. Publication #1980-12 of the North Carolina Biological Survey. 854pp.

Lemarie, D. P., D. R. Smith, R. F, Villella and D. A. Waller. 2000. Evaluation of tag types and adhesives for marking freshwater mussels (Mollusca: Unionidae). Journal of Shellfish Research 19(1):247-250.

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 DNA sequences. Proceedings of the Royal Society (London) Series B:351:1593-1603

Marshall, J.H., W.L. Davis and B.L. Huff. 1993. The mussel mitigation trust: a different type of mussel mitigation. pp. 123-125. In: K.S. Cummings, A.C. Buchanan and L. M. Koch (eds.). Conservation and management of freshwater mussels. Proceedings of a UMRCC symposium, 12-14 October 1992, St. Louis, MO. Upper Mississippi River Conservation Committee, Rock Island, IL. 189pp.

Mulvey, M., C. Lydeard, D.L. Pyer, K.M. Hicks, J. Brian-Box, J.D. Williams and R.S. Butler. 1997. Conservation genetics of North American freshwater mussels Amblema and Megalonaias. Conservation Biology 11:868-878.

Mussel Coordination Team. 2003. Saving the Higgins eye pearlymussel (*Lampsilis higginsii*) from extinction: 2002 status report on the accomplishments of the Mussel Coordination Team. St. Paul District Corps of Engineers, St. Paul, MN. 14pp.

National Native Mussel Conservation Committee. 1998. National strategy for the conservation of native mussels. Journal of Shellfish Research 17(s):1419-1428

Neves, R.J. 1997. Keynote address: A national strategy for the conservation of native freshwater mussels. pp 1-10. In: K.S. Cummings, A.C. Buchanan, C.A. Mayer, and T.J. Naimo (eds.). Conservation and management of freshwater mussels II: initiatives for the future. Proceedings of a UMRCC symposium, 16-18 October 1997, St. Louis, MO. Upper Mississippi River Conservation Committee, Rock Island, IL.

O'Neill, C. Jr. and D.B. MacNeill. 1991. The zebra mussel (*Dreissena polymorpha*): an unwelcome North American invader. New York Sea Grant, FACT SHEET November 1991, SUNY College at Brockport, Brockport, NY. 12pp.

Pritchard, J. 2001. An historical analysis of mussel propagation and culture: research performed at the Fairport Biological Station. December 2001. Clear Creek Historical Research, Ames, IA. 76pp.

Sparks, R.S., S. Whitney, J. Stoeckel, E. Ratcliff, S. Stenzel, R. Sparks, D. Blodgett, E. Marsden and D. Schneider. 1994. Gateway to invasion. Illinois Natural History Survey Report 330:12.

Steingraeber, M. 2002. Propagation and restoration of Higgins eye pearlymussels in the Upper Mississippi River Basin; partnership efforts and achievements in 2000 – 2001. June 2002. U.S. Fish and Wildlife Service, Onalaska, WI. 14pp.

Taylor, R.M. and Kelly Kershner (eds.). 1995. Sea Grant zebra mussel report: an update of research and outreach. Ohio Sea Grant College Program, The Ohio State University, Columbus, OH. 54pp.

Thiel, P.A. 1987. Recent events in the mussel mortality problem on the Upper Mississippi River. Pages 66-75 in R. J. Neves, editor. Proceedings of the workshop on die-offs of freshwater mussels in the United States. Upper Mississippi River Conservation Committee, Rock Island, IL.

Turgeon, D.D., A.E. Bogan, E.V. Coan, W.K. Emerson, W.G. Lyons, W.L. Pratt, D.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, 526pp.

Upper Mississippi River Conservation Committee. 1988. A strategic plan for the management of the freshwater mussel resource of the Upper Mississippi River. Upper Mississippi River Conservation Committee. Rock Island. IL. 10pp.

U.S. Army Corps of Engineers. 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. July 2002. U.S. Army Corps of Engineers, St. Paul District, MN. 56pp.

U.S. Army Corps of Engineers. 2003. Mississippi River between the Missouri River and Minneapolis, 9-foot channel project – measures for managing zebra mussels, reconnaissance report. August 2003. U.S. Army Corps of Engineers, St. Paul District, MN. 32pp.

U.S. Army Corps of Engineers. 2004. Biological assessment of the Upper Mississippi River-Illinois waterway system navigation study. April 2004. U.S. Army Corps of Engineers, Vicksburg, MS. 193pp.

U.S. Fish and Wildlife Service. 1982. Higgins eye mussel recovery plan. U.S. Fish and Wildlife Service, Fish and Wildlife reference Center, Rockville, MD. 98pp.

U.S. Fish and Wildlife Service. 2000a. Final biological opinion for the operation and maintenance of the 9-foot navigation channel on the Upper Mississippi River System. April 2000. U.S. Fish & Wildlife Service, Region 3, Fort Snelling, MN. 240pp.

U.S. Fish and Wildlife Service. 2000b. Controlled propagation of species listed under the Endangered Species Act. U.S. Fish and Wildlife Service and Department of Commerce, Federal Register, September, 2000.

U.S. Fish and Wildlife Service. 2003. Higgins eye pearlymussel (*Lampsilis higginsii*) draft revised recovery plan. U.S. Fish and Wildlife Service, Region 3, Fort Snelling, MN. 115pp.

U.S. Geological Survey. 1999. Ecological status and trends of the Upper Mississippi River System 1998: A report of the Long Term Resource Monitoring Program. U.S. Geological Survey, Upper Midwest Environmental Sciences Center, La Crosse, WI, April 1999, LTRMP 99-T001, 236pp.

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(9):6-22.

Wisconsin Department of Natural Resources. 1985. Freshwater mussels of the Upper Mississippi River. Wisconsin Department of Natural Resources, Madison, WI. 63pp.