CHAPTER 11

Freshwater Mussels

John Tucker and Charles Theiling

Freshwater mussels (Unionidae) are large bivalve (two-shelled) mollusks that live in the sediments of rivers, streams, and to a lesser extent lakes. These soft-bodied animals are enclosed by two shells made mostly of calcium and connected by a hinge. They are variously pigmented, with some being uniform dark brown or black to bright yellow. Many species have distinctly colored rays and chevrons and bumps or ridges, or both (Figure 11-1).

The Long Term Resource Monitoring Program (LTRMP) does not sample freshwater mussel populations but has been active in supporting mussel research and the ecological factors that affect mussels. For example, when zebra mussels were first introduced into the Upper Mississippi River System (UMRS), the LTRMP participated in a multi-agency team to monitor their distribution. The Illinois Natural History Survey LTRMP Field Station on La Grange Pool has conducted extensive zebra mussel impact surveys on the Illinois River and the Pool 26 Field Station has conducted several studies. The history of the decline of freshwater mussels is important because it shows how a single resource can be affected by manifold influences.

There are 297 species of freshwater mussels in the United States, most of which occur in the Mississippi drainage (Turgeon et al. 1988). In the main stem of the UMRS about 50 species have been recorded, although only about 30 species are found at present. The high diversity of mussel species in the Mississippi drainage differs markedly with the low diversity of mussels found in North American lakes. This disparity has to do with the north–south orientation of the Mississippi River, which provided a warm-water southern refuge from glaciation in the northern reaches of the Mississippi River.

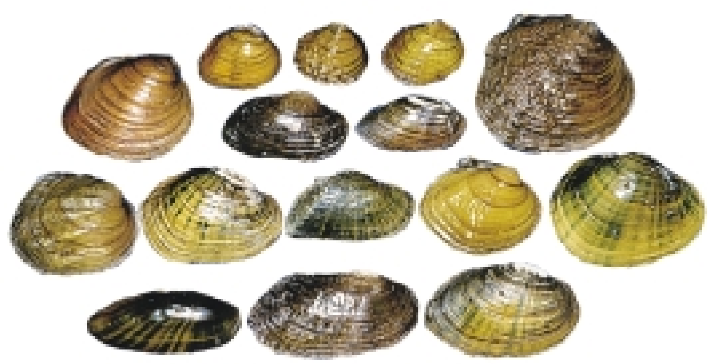

Figure 11-1. **Freshwater mussels show a high degree of shell variation. Different species have light or dark colors, smooth or ornamented shells, and a variety of rays and patterns (Source: Dan Kelner, Ecological Specialists, Inc., St. Peters, Missouri).**

Life History

Typically unionids are found anchored in the substrate, sometimes with only their siphons exposed. Mussels draw in river water from which they filter fine organic matter such as algae, detritus, etc. (Figure 11-2, following page). Many species are slow growing and long-lived animals, surviving for as long as 100 years (Neves 1993). Most species are sessile, moving only short distances their entire life. They maneuver by way of a muscular fleshy foot extended

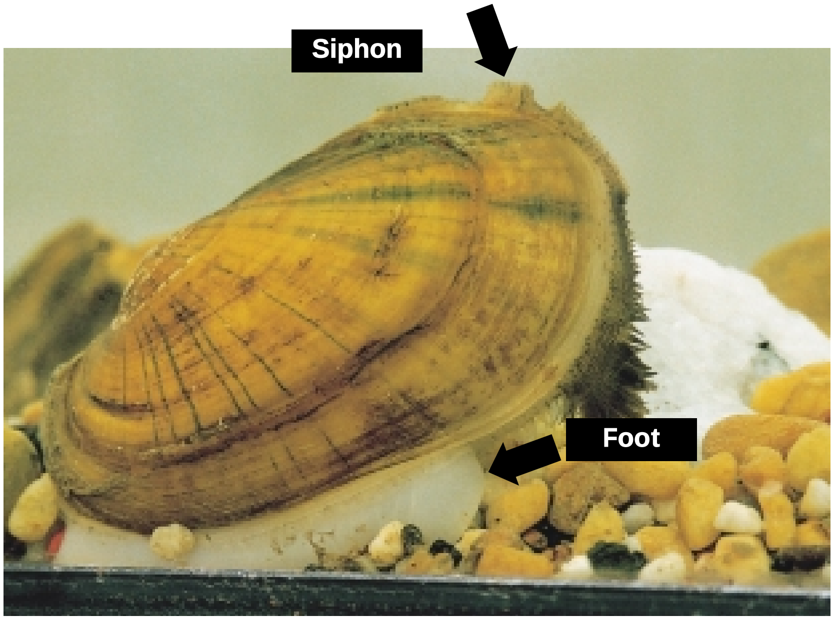

Figure 11-2. **A fat pocket mussel shows its fleshy foot at the bottom of the frame and its incurrent and excurrent siphons at the top. Mussels in the wild do not move much and typically are buried in the sediment with their siphons exposed (Source: Dan Kelner, Ecological Specialists, Inc., St. Peters, Missouri).**

from the shell (Figure 11-2). Movement often is triggered by changing water levels or other environmental conditions.

Quoted from Helfrich et al. 1997, and illustrated in Figure 11-3, this excerpt describes the unusual life cycle of Unionidae:

"The freshwater mussel has a unique life cycle, to include a short parasitic stage attached to a fish. The life of a mussel can be partitioned into five distinct life stages: (1) a larva (called glochidium) developing in the gill of a female mussel, (2) a free drifting glochidium expelled from the female mussel, (3) a parasitic glochidium attached to the gills or fins of a living host fish, (4) a free-living juvenile mussel, and (5) the adult mussel. Reproduction occurs when the male mussel releases sperm into the water column, which is siphoned into the female mussel to fertilize the eggs.

Reproduction may be triggered by increasing water temperatures and day length. Development and retention of larvae (smaller than a pinhead) within the female may last 1 to 10 months. Glochidia generally are released from the female in the spring and early summer (April to July). These tiny creatures drift in the water seeking a suitable fish host. Timing is critical for these larvae, for they cannot survive long outside of the female mussel or without a host fish. Unlike oysters and clams, [most] freshwater mussels require a fish host in order to complete their life cycle. As parasites, glochidia are dependent on fish for their nutrition at this part of their life. Some mussels may depend only on a single fish species, whereas others can parasitize many different fishes. The attachment of glochidia causes no problems for the host fish. If they find a host fish, they clamp onto the gills or fins and remain attached for one to four weeks while transforming into a juvenile mussel. As juveniles, they drop off the fish and begin their free-living life.

If glochidia do not find a suitable host fish within a few days of drifting in the water column, they die. To help ensure that they find a host fish, some species of mussels have developed special adaptations. Some adult female mussels have enlarged mantle tissue called mantle flaps that look like prey (worms, insect larva, or small fish) and which attract a fish looking for food. When fish nip at these structures, resembling potential food items, the female releases glochidia into the water column which clams onto the gills or fins of the fish host."

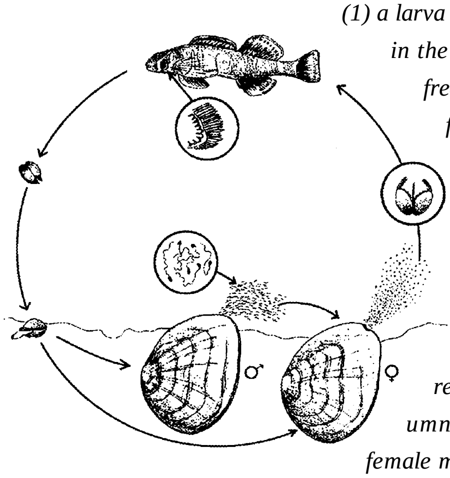

Figure 11-3. **The illustrated life cycle of freshwater mussels (Source: Richard Neves, Polytechnic Institute, Blacksburg, Virginia; Helfrich et al. 1997).**

Most mussel species require flowing water and coarse gravelly substrates, whereas others survive well in silty lake-like conditions in backwaters. Water and sediment quality are important habitat criteria. During periods of stress (e.g., temperature extremes, drought, pollutants), many species will burrow deep into the sediment and "clam up," sometimes surviving until the stressor has passed.

Mussels serve as good indicators of ecosystem health because they are relatively long-lived and sessile, and depend on good water quality and physical habitat (Fuller 1974; Williams et al. 1993). Municipal pollution (sewage) has been blamed for mussel die-offs below Minneapolis-St. Paul, Minnesota, on the Illinois River and below other urban areas. Most municipal wastes are now treated and mussels are returning to urban reaches of the Illinois River. Nonpoint pollutants, however, in the form of excessive siltation and agrichemical runoff continue to have an effect on habitat quality. A single mussel can filter several gallons of water per day, which means mussels can improve water quality by removing sediment and associated contaminants from water. Continued exposure to contaminants over many decades leads to bioaccumulation of toxins in mussel flesh (Goudreau et al. 1993; Havlik and Marking 1987).

Although mussels have not been widely used as human food since prehistoric times, they are an important source of food to other animals (Baker 1930; Parmalee and Klippel 1974). Adult mussels are eaten by muskrats, otters, and raccoons; young mussels are eaten by ducks, wading birds, and fish. Live mussels and relic shells also provide a relatively stable substrate in dynamic riverene environments for a variety of other macroinvertebrates (e.g., caddis flies, mayflies) and algae.

Present Status

Historically, as many as 50 species have been documented in the UMRS main stem, but only 30 species have been documented in recent surveys. Presently, two of the 30 species are listed as Federally endangered; five more are rare and their status is uncertain (Table 11-1, following page). Thus about 40 percent of the native species have been extirpated and 20 percent of the remaining species in the UMRS are at risk of extinction. Table 11-1 also shows that for the five states bordering the UMRS, many other species are considered threatened or endangered by state conservation agencies. Clearly, the current status of freshwater mussels is precarious.

The UMRS is a microcosm of the status of freshwater mussels in North America. Williams et al. (1993) found that 55 percent of North America's mussel species are extinct or threatened with extinction. Shannon et al. (1993) noted that 14 percent were Federally listed, 24 percent were candidates for listing, and 6 percent were already extinct. These are significant statistics considering that only 7 percent of the more intensively studied bird and mammal species are extinct or imperiled in North America (Master 1990). Also, because mussels are good indicators of ecological health, their decline reflects past abuse of the nation's waterways.

Change Over Time

Upper Mississippi River mussels have been subjected to several important human-made disturbances that greatly altered their abundance, distribution, and species composition. The effect on mussel populations is discussed below in reference to specific perturbations, but some background information on mussel communities is necessary for an understanding of that impact.

Mussels usually are found in dense aggregations called mussel beds. Mussel beds may be miles apart but also can cover large areas (e.g., several miles long). Because they are distributed in widely spaced clumps, site-specific impacts (e.g., spills, point source pollutants, dredging) can destroy the mussel fauna of large river reaches just by destroying a single bed. Repetitive disturbance (e.g., waste discharge, harvest, dredging) or continuous disturbance (dams) can limit both the distribution and abundance of some species by blocking host fish movement, altering habitat, poisoning, or over-harvesting the population (Neves 1993).

Upper Mississippi River mussels have been subject to several important human-made disturbances that greatly altered their abundance, distribution, and species composition.

Table 11-1. **The conservation status of mussel species (Family Unionidae) in the Upper Mississippi River System.**

Species	Federal	IL	IA	MN	MO	WI
Subfamily Cumberlandinae						
Spectaclecase *Cumberlandia monodonta*	C2	E	E	T	WL	E
Subfamily Ambleminae						
Washboard *Megalonaias nervosa*		SC		T		
Pistolgrip *Tritogonia verrucosa*			E	T	E	T
Winged mapleleaf *Quadrula fragosa*	E		E	E	E	
Mapleleaf *Quadrula quadrula*						
Monkeyface *Quadrula metanevra*			T		T	
Wartyback *Quadrula nodulata*			E	R	T	
Pimpleback *Quadrula pustulosa*						
Threeridge *Amblema plicata*						
Ebonyshell *Fusconaia ebena*		T		E	E	E
Wabash pigtoe *Fusconaia flava*						
Purple wartyback *Cyclonaias tuberculata*			T	T	T	E
Sheepnose *Plethobasus cyphyus*		E	E	E	R	E
Round pigtoe *Pleurobema coccineum*			E	T	E	SC
Elephant-ear *Elliptio crassidens*		T		E	E	E
Spike *Elliptio dilatata*		T		SC		
Pondhorn *Uniomerus tetralasmus*		T				
Subfamily Anodontinae						
Paper pondshell *Utterbackia imbecillis*						
Flat floater *Anodonta suborbiculata*					R	SC
Giant floater *Pyganodon grandis*						
Squawfoot *Strophitus undulatus*						
Elktoe *Alasmidonta marginata*				T	SC	SC
Rock-pocketbook *Arcidens confragosus*				E	R	T
Salamander mussel *Simpsonaias ambigua*	C2		E	T	E	T
White heelsplitter *Lasmigona complanata*					SC	
Fluted-shell *Lasmigona costata*			T	SC	SC	T
Creek heelsplitter *Lasmigona compressa*				SC		
Subfamily Lampsilinae						
Threehorn wartyback *Obliquaria reflexa*						
Mucket *Actinonaias ligamentina*				T		
Butterfly *Ellipsaria lineolata*		T	T	T	T	E
Hickorynut *Obovaria olivaria*						SC
Deertoe *Truncilla truncata*						
Fawnsfoot *Truncilla donaciformis*						
Scaleshell *Leptodea leptodon*	C2		X			R
Fragile papershell *Leptodea fragilis*						
Pink papershell *Potamilus ohiensis*						
Pink heelsplitter *Potamilus alatus*						
Fat pocketbook *Potamilus capax*		E	E		X	E
Lilliput *Toxolasma parvus*						
Black sandshell *Ligumia recta*				SC	SC	
Rayed bean *Villosa fabalis*	C2		E			
Slough sandshell *Lampsilis teres teres*			E		E	E
Yellow sandshell *Lampsilis teres anodontioides*			E	E		E
Fat mucket *Lampsilis siliquoidea*						
Higgins eye *Lampsilis higginsi*	E	E	E	E	E	E
Plain pocketbook *Lampsilis cardium*						
Snuffbox *Epioblasma triquetra*	C2	E		T	R	E

Abbreviations: E = endangered, T = threatened, R = rare, X = extirpated, SC = special concern, WL = watch list, C2 = formerly considered for Federal listing, IL = Illinois, IA = Iowa, MN = Minnesota, MO = Missouri, WI = Wisconsin

Mussel beds often are dominated by one to five primary species, but surveys indicate that up to 26 species may be found at a single site (Perry 1979). Sites with higher numbers of species indicate high-quality habitat, while degraded sites may support only a few hardy species. Selective harvest, siltation, and pollution can have different effects on individual species; thus, a stressor may have an impact only on a portion of the community.

In addition to depleting population densities, the result of most stressors is loss of species richness (numbers of species), a common measure of ecosystem health. This is important because changes in mussel community diversity in the UMRS are due only in part to loss of species richness. Other species (Table 11-1) have become rare although they still are present at reduced population levels. The result is loss of species evenness and communities dominated by one or a few species (Starrett 1971; Hornbach et al. 1992; Miller et al. 1993). When Hornbach et al. (1992) compared surveys from 1930 and 1977 to those they conducted, they found three fewer species than the 36 previously reported. However, they found a significant increase in abundance of the threeridge mussel with a concomitant decrease in abundance of other species (Hornbach et al. 1992).

Button Industry

Human use of freshwater mussels dates back to the archeological record but early human impacts would be impossible to determine. We therefore start our investigation of the change in mussel populations with the first well-documented event, the advent of the shell button industry (Figure 11-4).

The first large commercial use of mussels began in 1889 when the German button maker John Boepple pioneered the use of freshwater mussel shells in America (Thiel and Fritz 1993). The industry grew rapidly. By 1898, 49 button-making plants in 13 cities along the Mississippi River employed thousands of people (Duyvejonck 1996).

The industry devastated mussel resources. Shellers found they could strip a bed of useable shells quickly and move on to the next bed. For example, one bed, 2-miles (3.2-km) long and a quarter-mile (0.4-km) wide, produced 500 tons (454 metric tons) of mussels in 1896. Another bed near New Boston, Illinois, produced 10,000 tons (9,072 metric tons) of mussels (100 million individuals) over a 3-year period (Duyvejonck 1996). The industry first centered around Muscatine, Iowa, then spread upstream to Prairie du Chein and La Crosse, Wisconsin, and Lake Pepin, Minnesota, as beds were depleted downstream. The Illinois River was another mussel “hot spot” that in the early 1900s was considered the most productive mussel stream per mile in America (Danglade 1914).

The impact of commercial harvest was first noted in 1899 when Smith (1899) reported on mussel decline and recommended that harvest restrictions be implemented. As pressure on the resource increased, the harvest declined (Coker 1919). Harvest in Lake Pepin dropped from more

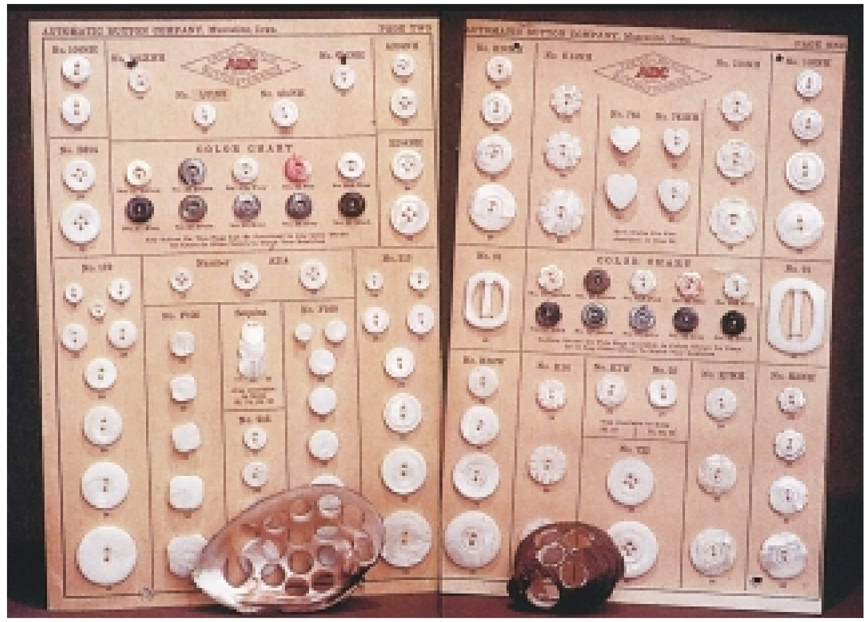

Figure 11-4.
Freshwater mussel shells were used to make buttons and other ornamentation when the shell button industry flourished in river communities from the 1890s to the 1930s. The industry at one time employed as many as 20,000 people. Declining mussel populations and development of new materials, however, signaled the industry’s demise (Source: Richard Sparks, Illinois Natural History Survey, Havana, Illinois).

than 3,000 tons (2,721 metric tons) to just 150 tons (136 metric tons) between 1914 and 1929. In Iowa, harvest dropped from more than 2,000 tons (1814 metric tons) to less than 200 tons (181 metric tons) in the 1930s (Thiel and Fritz 1993). The shell button industry declined rapidly after 1930 in response to the dwindling supply of shells and implementation of harvest restrictions. The advent of plastics and other button-making material also contributed to its decline.

Widespread mussel mortality thought to be caused by ammonia toxicity was first noted in the Upper Illinois River in 1912.

Chicago Sanitary and Ship Canal Municipal and Industrial Pollution

In 1900, the Chicago Sanitary and Ship Canal was opened to transport sewage and industrial waste from Chicago. It was an effective engineering feat and the impact of massive inputs of raw sewage soon were felt downstream. While some fish may have migrated out of the polluted part of the river, mussels were forced to sustain or succomb to the disturbance in place. Widespread mussel mortality thought to be caused by ammonia toxicity (Starrett 1971) was first noted in the Upper Illinois River in 1906–1909 (Table 11-2). But 55 years later, mussel diversity had declined throughout the river (Table 11-2). More recent unpublished survey data indicate some recovery in the Upper Illinois where 11 species were found between 1993 and 1995 (Scott Whitney, Illinois Natural History Survey, Havana, Illinois, personal communication).

Similar levels of pollution also were transported downstream from Minneapolis-St. Paul during the early 1900s and mussel populations declined to near zero between Minneapolis and Lake Pepin. Mussel populations there remained stressed until 1984, when waste treatment discharge to the river began to meet new guidelines (Mike Davis, Minnesota Department of Natural Resources, Lake City, Minnesota, personal communication).

The environmental movement, which grew considerably in the 1960s, helped pass sweeping legislation to clean and protect the nation's waterways. To date, the 1972 Clean Water Act may be one of the most significant events in the conservation of freshwater mussels. Municipal waste treatment and control of industrial waste significantly improved water quality in river reaches downstream from large urban areas (see Chapter 7). Contaminated sediments are being buried under cleaner sediments but still may be harmful to species that burrow deep in the sediment.

Table 11-2. **Numbers of species of mussels present in the navigation pools of the Illinois River at different points in time (Source: Scott Whitney, Illinois Natural History Survey, Long Term Resource Monitoring Program, La Grange Field Station, Havana, Illinois).**

	Number of Species			
Navigation pool	**1870–1900**	**1906–1909**	**1966–1969**	**1993–1995**
Marseilles	38	0	0	11
Starved Rock	36	0	0	8
Peoria	41	35	16	15
La Grange	43	35	18	15
Alton	41	36	20	17

Navigation Projects

Navigation-related impacts on mussels started with dredging and wing dam construction. In earlier days, dredging was conducted without the involvement of conservation agencies and many mussels were dredged along with gravel and sand. Once the problem was recognized, the agencies began to coordinate the location of dredging and material placement.

The effect of expansive wing dam construction in the last 100 years has been equally dramatic. These dams act to slow flow and modify hydraulic patterns of flow in channel border habitats important to mussels. Siltation rates between wing dams are high as a result of the modified hydraulics and many channel border mussel beds likely were destroyed.

Lock and Dam 19 was the first UMRS navigation dam. It differs from the other dams in that it has a hydroelectric power plant and creates a near-permanent obstruction for fish migrations. The blocked migration of skipjack herring, the only known host of the ebony shell mussel, has been implicated in the near eradication of this mussel species above Lock and Dam 19 (Fuller 1974, 1980). The movements of other fish species have been restricted by dam construction (Joseph H. Wlosinski and Scott Maracek, USGS Environmental Management Technical Center, Onalaska, Wisconsin, unpublished data), possibly affecting distribution and survival of juvenile mussels in the UMRS as has occurred elsewhere (Williams et al. 1992; Neves 1993).

Another dam-related impact is the alteration of the river's natural hydrology. Dams impound water and slow current velocity in the lower one-half to two-thirds of each navigation pool. The modified hydrology and reduced current velocity reduce habitat quality and may have a negative effect on delivery of food and oxygen to the mussel communities in the lower reaches of the navigation pools. Tucker et al. (1996) suggest that closing off backwaters can reduce unionid diversity in backwaters and near their connection with the river by interfering with energy transfer from the river to the backwater. In backwaters connected to the river, species diversity fell with increasing distance from the backwater–river interface because of the reduced influence of the river. Completely isolating backwaters from the river would cause substantial changes in backwater mussel fauna as well as disrupt energy transfer from the backwater to the river (Tucker et al. 1996).

The final and perhaps most significant dam-related impact is the sediment-trapping effect inherent in construction of dams. Because dams slow current velocity, sediments in suspension drop out of the water column and accumulate in low-current velocity areas. Mussel beds located in the lower reaches of navigation pools are therefore likely to have been smothered by sediment.

Effects of Row Crop Agriculture (1950s)

After World War II, agriculture experienced a dramatic shift toward row crop agriculture (corn and soybeans) that emphasized mechanized farming and a heavy reliance on agrichemicals. Land-use practices for much of the period between the 1950s and the present have focused on getting the maximum possible acreage into production. Wetlands were drained, fields were tiled to drain water rapidly, and streams were channelized to speed tributary flow to larger rivers. Deep plowing, which leads to high soil erosion rates, also was a common practice.

The combination of intensive land use and stream channelization resulted in high rates of soil loss. The soil washed into streams and larger rivers as fine silts and clay that filled interstitial spaces in gravel beds. In many areas siltation occurred at such high rates that backwaters and side channels were filled with fine sediment (see Chapter 4).

Mussels are affected by a variety of factors related to sedimentation. The first impact is direct burial. Mussel beds located near tributary inflows and slow flowing areas where silt settles can be covered deep enough to suffocate the population. Ellis (1936) experimentally showed that as little as one-quarter of an inch (6.35 mm) of silt covering the substrate caused death in about 90 percent of the species he examined. Siltation also is detrimental to young mussels and reduces their survival (Scruggs 1960).

A second longer-lasting impact is habitat alteration. Where sedimentation occurs on

The blocked migration of skipjack herring, the only known host of the ebony shell mussel, has been implicated in the near eradication of this mussel species above Lock and Dam 19.

gravel beds, the silt fills the interstitial spaces that mussels inhabit. Flow through the gravel is inhibited and algal and microbial communities change. Some species are able to survive in the modified habitat, but many less-tolerant species drop out of the community (Waters 1995). Juvenile survival in silt-impacted mussel beds (even hardy species) may be reduced, which can limit recruitment in the entire bed.

The third major agricultural impact is in the form of chemical contamination and nutrient enrichment (see Chapter 7). Pesticides were detected in the flesh of Illinois River mussels in 1971 but concentrations were not high (Starrett 1971). Chemical contaminants are a concern because they bind with suspended and settled sediment. Mussels are nonselective filterers and therefore contaminants have the capacity to bioaccumulate in the long-lived mussels. Nutrients promote plant and noxious algal growth that can disrupt flow over mussel beds and inhibit feeding.

Figure 11-5. **These boats display the brail bars used by commercial shellers to collect mussels in the days when the animals were plentiful. The bars, lined with chains and hooks, were dragged along the river bottom where mussels clamped unto the hooks (Source: Richard Sparks, Illinois Natural History Survey, Havana, Illinois).**

Cultured Pearls

Commercial shelling had a resurgence in the 1950s (Figure 11-5) after the Japanese cultured pearl industry developed on a large scale. Kokichi Mikimoto experimented with a variety of materials to serve as the nucleus (or “seed”) of cultured pearls and determined that the nacre of freshwater mussel shells from the United States was the best material. Mussel shells are sliced, cubed, and then rounded before being implanted in a salt-water oyster, which lays its own nacre over the nucleus. Much of the shell harvest is lost during the processing because a ton of shell produces about 40 to 60 pounds of pellets (Lopinot 1967). As with natural pearls that occur in many freshwater and salt-water mollusks, cultured pearls are created by the mollusk to reduce irritation from coarse foreign material (sand, gravel) trapped in the shell.

Initially the pearl industry wanted shell from live mussels; large washboard and threeridge mussels were the preferred species. As stocks dwindled after a die-off in the early 1980s (see *1980s Die-Off* below) and demand for pearls increased, dead shells were incorporated into the harvest and collection methods shifted from reliance on brail bars to surface air supply diving. Recently, the percentage of dead shell in the harvest has ranged from 32 to 71 percent (Thiel and Fritz 1993). Demand for live mussels remains high, however, because live shell brings a higher price. In the mid-1980s, low supplies of shells drove prices up and pressure on the resource increased. In Iowa, 131 tons (118 metric tons) of shell were harvested by 129 shellers in 1984; the following year, 583 tons (528 metric tons) were harvested by 220 shellers (Thiel and Fritz 1993).

The impact of commercial harvesting is apparent in many river reaches. The catch of live washboards has declined in Illinois and Iowa. In Pool 15, Whitney et al. (1996) documented significant declines in the density of live washboard and threeridge mussels between 1983 and 1995. They also determined that the rate of recruitment of young washboards into the population was low, possibly because there were few individuals of reproductive age and those present had infrequent reproductive success. Washboards at the study sites may reproduce successfully only once in 10 years (Whitney et al. 1996). Threeridges had more consistent reproductive success.

All commercially harvested species

showed truncated size distributions that correspond with a minimum harvestable size limit. (Whitney et al. 1996). Threeridge mussels at sites in Minnesota showed a similar decline in densities and size truncation at the commercial size limit between 1990 and 1996 (Mike Davis, Minnesota Department of Natural Resources, Lake City, Minnesota, personal communication). In Wisconsin waters, washboard mussels are of concern because of declining densities and lack of recruitment (Kurt Welke, Wisconsin Department of Natural Resources, Prairie du Chien, Wisconsin, personal communication). The five UMRS states currently are coordinating a system-wide closure of washboard harvest.

1980s Die-Off

Conservation agencies on the Upper Mississippi River heightened their concern for freshwater mussels in the 1970s and initiated surveys to determine the status of the mussel stocks (Thiel and Fritz 1993). The surveys were initiated to document a massive 1983 to 1985 mussel die-off detected by the presense of large numbers of dead and dying mussels between La Crosse, Wisconsin (Pool 8), and Hannibal, Missouri (Pool 25). Blodgett and Sparks (1987) found high mussel mortality in Pools 14 and 15. They showed that two important commercial species experienced some of the highest mortality, 35 percent for washboards and 41 percent for threeridges. Several State and Federal agencies investigated the cause of the die-off but no contaminant, disease, or parasite was identified (Thiel and Fritz 1993). The unexplained die-off spurred further agency cooperation and mussel research that continues today.

Zebra Mussels

Many changes in mussel density, faunal composition, and diversity resulting from human alteration of habitats in the UMRS are documented. Introduction of the exotic zebra mussel, however, significantly complicates conservation of unionid faunas in the UMRS (Tucker et al. 1993; Tucker 1994; Tucker and Atwood 1995). This exotic species was transported in the ballast of transatlantic ships navigating the Great Lakes. They entered the UMRS by passive transport in currents from Lake Michigan into the Illinois Waterway and on the hulls of boats.

Zebra mussels attach to hard surfaces with byssal threads that secrete a strong glue-like substance. They also have high reproductive potential (fecundity) and can produce several broods in a single summer. As a result they can form dense aggregations on unionid mussels (Figure 11-6), which may be the only hard substrate in some areas. Attached zebra mussels on native mussels compete for food, make movement difficult, and can force shells open (Haag et al. 1993). These aggregations lead to decreased unionid density (Gillis and Mackie 1994; Nalepa 1994) and have even been blamed for complete extirpation of unionid faunas in some portions of the Great Lakes (Schloesser and Nalepa 1994) .

Zebra mussels were first documented in the Illinois River in 1991 when a commercial sheller brought a single specimen

Figure 11-6. **Introduced into the Upper Mississippi River System in currents and on the hulls of ships, the zebra mussel poses a severe threat to native freshwater mussels. The exotic species attaches itself to hard surfaces, including native mussels, as above, forming dense aggregations that interfere with the movement and feeding of their hosts. Small zebra mussels also can grow between valves (shells), sometimes forcing them open (Source: Scott Whitney, Illinois Natural History Survey, Havana, Illinois).**

The prolific zebra mussel has been transported throughout the inland waterway system on the hulls of barges and by river currents that carry their larval stage.

attached to a native mussel to biologists at the Illinois Natural History Survey. Since then, the prolific zebra mussel has been transported throughout the inland waterway system on the hulls of barges and by river currents that carry their larval stage. Zebra mussels do not require a fish host; they develop as planktonic organisms drifting in the current.

Because of their potential to affect native mussels, the aquatic environment, and municipal and industrial infrastructure (e.g., water supply and industrial cooling), monitoring the distribution of zebra mussels became a priority of resource managers. The Illinois Natural History Survey tracked zebra mussel and native mussel populations along the entire Illinois River from 1992 to 1995. Their monitoring of the invasive species detected density changes that started from the initial specimen and peaked in 1993 with maximum densities that approached 83,612 per square yard (100,000 per square meter) at one site near the confluence with the Mississippi River. That huge population crashed and was largely gone by 1994, but zebra mussels in upstream reaches persisted. The last survey in 1995 showed that zebra mussel densities had dropped to insignificant levels at sites sampled throughout the lower two-thirds of the River. Scott Whitney speculated that low dissolved oxygen, warm water temperatures, and high concentrations of suspended sediment may be factors that contribute to the decline in zebra mussels (Scott Whitney, Illinois Natural History Survey, La Grange Station, Havana, Illinois, personal communication).

In the Mississippi River, the LTRMP and the U.S. Army Corps of Engineers cooperated on studies to monitor the spread of zebra mussels in the five LTRMP study reaches, at locks and dams, and at industrial water intakes. The zebra mussels' spread throughout the system was extremely rapid resulting in distributions of low density throughout the system by 1993. As far as can be determined from unpublished results, the population growth was rapid—high densities of more than 25,000 per square yard (>30,000 per square meter) were reported in Pools 9 and 10 in 1997 (Kurt Welke, Wisconsin Department of Natural Resources, Prairie du Chien, Wisconsin, personal communication). Apparently, population densities in pooled reaches of the Mississippi continue to increase and the native mussel fauna are being colonized at a high rate.

One effect of the zebra mussel in the UMRS may be a further reduction in the diversity of native communities. Initial unpublished surveys suggest that the absolute number of mussels will decrease where zebra mussels become and remain abundant (Ricciardi et al. 1995). Furthermore, species diversity may decrease because some species apparently are more adversely affected by zebra mussel colonization than others (Tucker 1994). Figure 11-7 illustrates the impact of zebra mussels on native species diversity over a 3-year period in one location in Pool 26. In 1993, 18 species of native mussels with three codominant species were found at a density of 15.5 mussels per square yard (18.6 per square meter; Tucker 1994). One year later, another survey at the site heavily colonized by zebra mussels found ten native species; density was reduced to 5.5 mussels per square yard (6 per square meter) and the fauna was dominated by a single species. In 1995, only four native species were collected, density was 1.7 mussels per square yard (2 per square meter), and threeridge mussels constituted nearly all specimens. If the decline in abundance and diversity of unionids is characteristic of regions with high concentrations of zebra mussels, this trend will accelerate. Illinois River surveys showed similar changes in native mussel

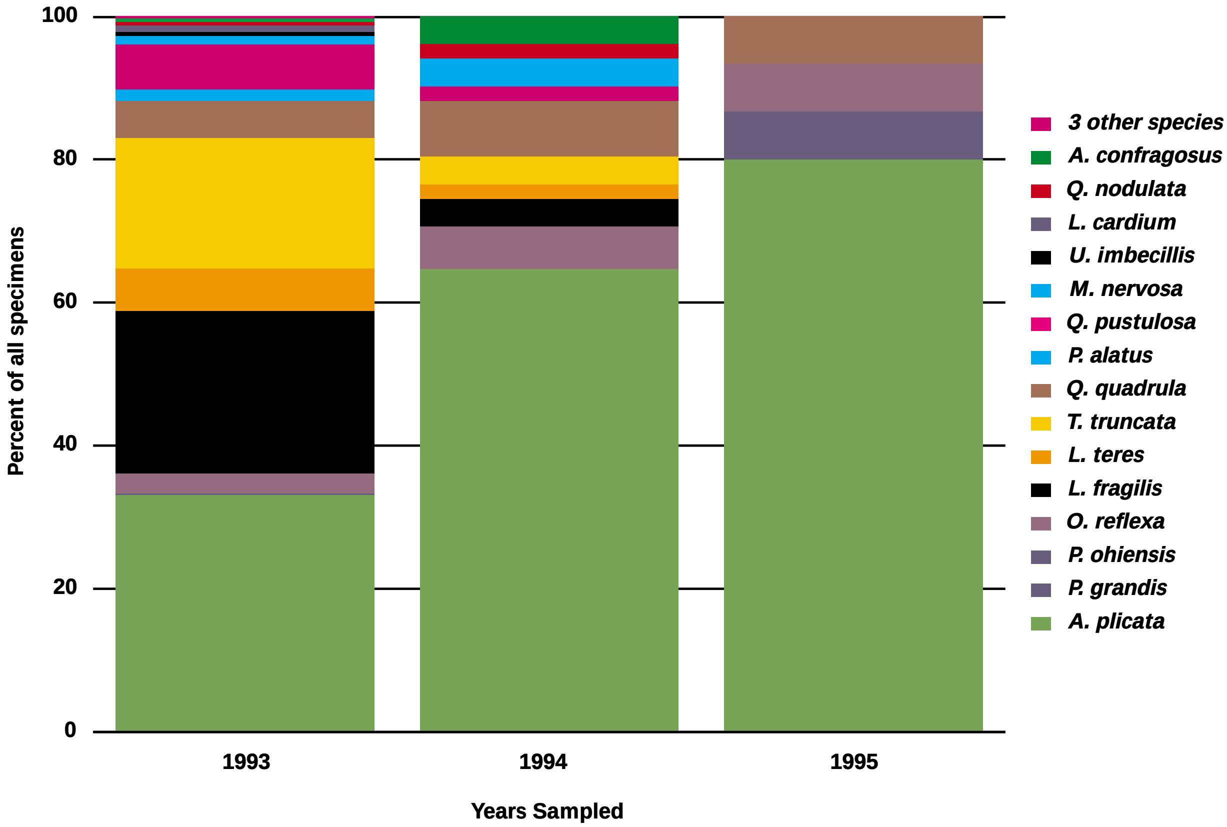

Figure 11-7. **Results of surveys of unionids at the confluence of the Mississippi and Illinois Rivers at Grafton, Illinois, over a 3-year period show the response of native mussels to zebra mussel colonization. Sampling showed significant changes in both total numbers and species composition. In all, 18 species of native mussels were collected in 1993, 10 in 1994, and 4 in 1995.**

populations and detected species-level impacts that may be related to burrowing behavior (Scott Whitney, Illinois Natural History Survey, Havana, Illinois, personal communication).

Discussion

Mussel conservation became an important issue on the UMRS before the turn of the century (Smith 1899) and has remained important because of the many disturbances discussed here. Generally the impact from each disturbance was investigated, documented, and in some cases responded to with measures to protect mussels.

Control of the shelling industry among early clammers amounted to stripping a bed and moving on to more productive ground. As the industry grew and harvest pressure increased, size regulations and closed areas were implemented to maintain spawning stock. Artificial propagation was attempted (Coker et al. 1921). The shell button era ended when the depleted resource became uneconomical for commercial use and new materials came on the market.

Today harvest for the cultured pearl trade is regulated by season, species, and size in all the UMRS states. Although state regulations and reporting have been dissimilar in the past, states are moving toward standardization throughout the system. The five states also are cooperating to close commercial harvest of washboard mussels to help recovery of larger, older individuals in the population. The Upper Mississipppi River Conservation Committee has maintained a harvest database since 1987 to help monitor the resource.

Reduced municipal and industrial pollution may be one of the biggest accomplishments in the conservation of all freshwater fauna and particularly for UMRS mussels. Nonpoint pollution, on the other hand, has not been controlled effectively. Sedimen-

Sedimentation, nutrient enrichment, and chemical contamination are particularly harmful to bottom fauna, such as the sessile freshwater mussels.

tation, nutrient enrichment, and chemical contamination are particularly harmful to bottom fauna, such as the sessile freshwater mussels. Further reducing upland erosion and flushing sediments would improve mussel habitat in the UMRS.

Damage from zebra mussels is impossible to prevent at this point, and many other exotic species have the potential to invade the inland waterways. However, newly enacted legislation to control ballast-water release should help minimize future invasions. Some measures, such as electric barriers, have been proposed to block exotic species at the mouth of waterways that link Lake Michigan to the Illinois River. One effort to retain a stock of uninfested mussels in isolated hatchery ponds met with limited success.

Similar threats to mussels exist nationwide. That is why a national strategy for the conservation of native freshwater mussels was developed to address the points discussed above (Neves 1997). This national strategy also addresses the following issues:

- Insufficient information on basic mussel biology
- Insufficient information on current and historic mussel populations
- Lack of public understanding of the plight of the mussel
- Insufficient mussel propagation technology
- Poor captive holding and reintroduction technology
- Insufficient funds committed to mussel conservation and recovery

Many UMRS mussel biologists participated in development of the national strategy and the issues listed above are of equal importance on a regional scale.

John Tucker is an associate research scientist at the Illinois Natural History Survey, Great Rivers Field Station, Alton, Illinois. Charles Theiling is an aquatic ecologist at the USGS Environmental Management Technical Center, Onalaska, Wisconsin.

Contributors

Doug Blodgett
Illinois Natural History Survey
Havana, Illinois

Richard Sparks
Illinois Natural History Survey
Havana, Illinois

Scott Whitney
Illinois Natural History Survey
Havana, Illinois

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