Native Freshwater Mussels

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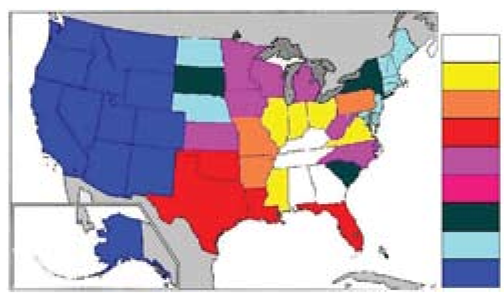
Introduction

Freshwater mussels belong to the phylum Mollusca, the second most diverse group of animals in the world in terms of number of described species. The phylum consists of approximately 100,000 freshwater, marine, and terrestrial species and includes mussels, snails, octopi, squid, as well as several other less familiar groups. Although freshwater mussels are distributed throughout the world, they reach their greatest diversity in North America, east of the Mississippi River. United States mussel populations have been in decline since the late 1800s for a number of reasons. Currently, nearly three-quarters of North America's native freshwater mussel species are considered endangered, threatened, or species of special concern, and some researchers believe that as many as 35 species (12%) are already extinct.

The objective of this leaflet is to raise awareness about the decline of freshwater mussels in North America, their life history requirements, and the important ecological role they play in aquatic habitats. In addition, this leaflet provides a number of practical habitat management considerations to help protect freshwater mussel populations. Freshwater mussels can also be referred to as freshwater clams or bivalves. However, for the sake of consistency, they are referred to as freshwater mussels throughout this leaflet.

Virginia Department of Game and Inland Fisheries

Although freshwater mussels are found throughout much of the world, they reach their greatest diversity in North America.



Adapted from presentation of Kevis S. Cummings, http://clade.acnatsci.org/mussels/graphics/presentations/granum_salis_lg.jpg

Freshwater mussels are found in 49 of the 50 United States.

Values of freshwater mussels

Cultural and economic importance

Freshwater mussels were once an important natural resource for Native Americans, particularly the mound-building tribes of the Midwest. While it seems that they were gathered primarily for use as a food source, their shells were also valued and used for tempering pottery and making tools, utensils, and jewelry. It was not until the late 1800s, however, that the commercial value of freshwater mussels was recognized by the newly born American button industry.

This, coupled with loss and degradation of freshwater habitats associated with the America's rapid industrialization, contributed to the first major declines in freshwater mussel populations in the United States. By 1912, nearly 200 button factories were operating in towns all over the country; pearly shells of harvested mussels were used for buttons and their soft tissues for livestock feed. The button industry declined with the advent of plastics in the 1950s.

By the 1950s, however, the Japanese had found a new market for freshwater mussels as a source material for cultured pearls. Mussels harvested for this purpose are sorted and steamed or cooked to remove the soft parts. The shells are then cut and finished into beads for insertion into oysters to serve as nuclei for cultured pearls. Thousands of tons of mussel shells are processed and exported to Japan each year to supply the cultured pearl industry. Additional commercial and medical uses for freshwater mussels are under consideration. For example, recent research suggests that some mussels may be resistant to certain types of cancer and that the extraction of cancer-curing drugs from mussels may be feasible in the future.

Ecological role

Freshwater mussels are an important part of the food web in aquatic ecosystems. Adults are filter-feeders and consume phytoplankton, diatoms, and other microorganisms in the water column, as well as detritus and bacteria. As juveniles, mussels are deposit feeders and use their ciliated foot to obtain nutrients. Mussels are, in turn, consumed by muskrats, otters, and raccoons, and young mussels are often eaten by ducks, herons, and fishes, as well as other invertebrates.

As natural filter feeders, freshwater mussels strain out suspended particles and pollutants from the water column and help improve water quality. Some mussels can filter up to 10 gallons of water per day, which helps to improve water quality for other animals, including humans.

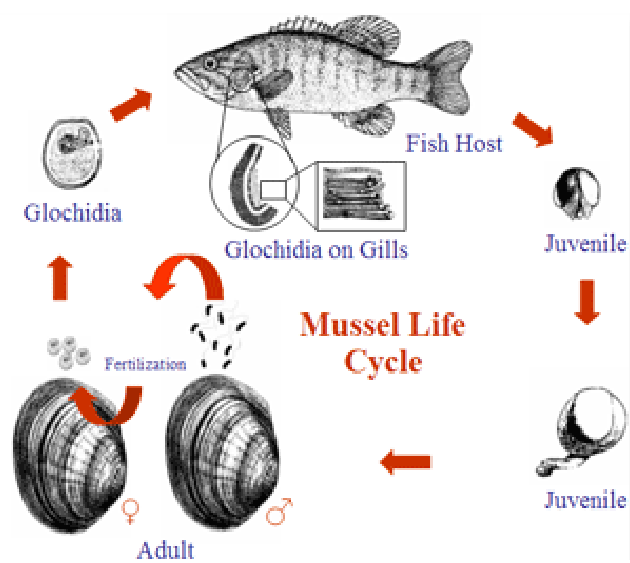
Mussels are commonly used as indicators or biological monitors of past and present water quality conditions in rivers and lakes. A sudden increase in mortality of freshwater mussels is a reliable indicator of toxic contamination. The disappearance of freshwater mussels usually indicates chronic water pollution problems. Moreover, biologists can measure the amount of pollutants found in mussel shells and tissue to determine the type, extent, and even timing of water pollution events in streams and lakes.

Life history

Freshwater mussels are easily recognized by their hinged shell; however, shape, size, thickness, and color of shells vary greatly among species. Shell surfaces vary in color from yellow or green to brown or black; they also may contain distinctive ridges, rays, bumps, and textures. Many species have colored rays or chevron marks on their shells. The interior of the shell is composed of pearly nacre that varies in color from pure white to shades of pink, salmon, gray, and purple. Males and females of some species can be distinguished by their shell size and shape.

Due to their sedentary lifestyle, mussels rely on a unique reproductive strategy to colonize new areas. Freshwater mussels have three basic life stages: larval (or parasitic), juvenile, and adult. When water temperatures and other environmental variables reach ideal conditions, male mussels release sperm into the water column. The female mussels draw the sperm into their shell cavities as they filter water. After fertilization, females brood the young from the egg to larval stage in their gills. The larvae, called glochidia, may mature and be released the same year or may be retained in the gills over winter and released the following spring. Species that release glochidia in the same year are called short-term brooders, whereas species that retain their glochidia over winter are called long-term brooders.

Once released, glochidia must attach to the gills or fins of an appropriate fish host to complete their metamorphosis to the juvenile stage. For many species of mussel, the host is limited to a single species of fish, and their survival is wholly dependent on the presence of that species in the ecosystem. Subject to the availability of fish hosts, only a small percentage of the 75,000 to 3,000,000 glochidia released from a female may survive to the juvenile stage. Several species of freshwater mussels have fascinating adaptations that serve to increase the chance that their



Virginia Department of Game and Inland Fisheries

Freshwater mussels have three basic life stages: larval (or parasitic), juvenile, and adult.

glochidia will come into contact with the appropriate fish host. For example, female plain pocketbook mussels (*Lampsilis cardium*) wiggle a modified soft tissue part resembling a small minnow to lure the host fish, a smallmouth bass. When the smallmouth bass attempts to bite the minnow, the female releases her glochidia. The oyster mussel (*Epioblasma capsaeformis*) opens its shell wide and flashes a brilliant blue mantle. The fish is lured towards the mussel, and the mussel slams its shell shut on the fish's head and holds on tight while the glochidia are released and attach to the captured fish.

Glochidia generally remain attached to host fish for 2 weeks to 7 months, depending on the species. The mobile nature of fish allows glochidia to be transported to other waterbodies and far stream reaches. Following metamorphosis, juveniles drop from the fish and take up life as sedentary filter feeders.

As adults, mussels have very limited mobility. Mussels have a muscular foot that protrudes out between the shells, wedges into the substrate, and contracts to pull the animal a short distance. Mussels can use this method to move either sideways or vertically. Some are fairly active, while other species may remain in the same location for the duration of their lifespan.

It is estimated that only about 1 in 1,000,000 glochidia develop into juveniles. The juvenile stage, or period of sexual immaturity, ranges from 2 to 12 years, depending on the species. Adults can be very long-lived with most species living for decades and some for over a century.

National Park Service

The juvenile stage is the last life stage before the mussel begins producing offspring.

Habitat requirements

Most species of freshwater mussels are adapted to life in streams and rivers, although they can also be found in artificial flow areas (ditches) and wetlands with persistent standing water (lakes). Most species of freshwater mussels prefer medium to large bodies of water in areas with depths less than 3 feet. The majority are found along the shallow edges of waterbodies where warmer temperatures and additional light generally provide them with more food.

Currently, little is known about environmental factors that have the most significant effects on mussel communities. However, available information suggests that mussels prefer well-oxygenated water flowing over a stable substrate, usually comprised of sand and gravel with some silt. The base water flow sustained by ground water discharge or surface runoff must be adequate to moderate seasonal changes in streamflow and water temperature, dilute contaminants in surface water runoff, and withstand periods of drought. Waterborne contaminants, such as sediments and pollutants, must be minimal, and host species of fish must be available for glochidia to develop. Preferred sources of food for adults and juveniles include many forms of algae, zooplankton, bacteria, and detritus.

Habitat loss and degradation

Although the overharvest of vulnerable mussel beds (locations with large numbers of mussels) has played a major role in the decline of freshwater mussel numbers in the United States, the destruction and degradation of suitable habitat has been equally as detrimental. Major contributors to losses and degradation of mussel habit are water flow alterations associated with channel modification (damming, dredging, and channelization) and wetland loss and hydrologic changes in the watershed; water pollution and sedimentation; and invasive species. Unfortunately, declines in mussel populations went virtually unnoticed until the 1970s.

Freshwater mussels possess a suite of traits that make them especially vulnerable to habitat disturbances. Delayed reproductive maturity limits the number of breeding individuals entering the population each year. Additional constraints on the ability of mussels to respond to environmental changes include limited dispersal abilities, poor juvenile survival, high toxin accumulation rates, limited refugia, and host specificity. For threatened and endangered species listings, visit the U.S. Fish & Wildlife Service Threatened and Endangered Species System at *http://ecos.fws.gov/tess_public/StartTESS.do*.

Water flow alterations

Natural water flow patterns are altered by dams, diversions for irrigation, channelization, ground water pumping, and catchment conversion through urbanization, deforestation, and agriculture. Altered flow regimes and reservoirs caused by damming have resulted in the local extirpation of 30 to 60 percent of the native freshwater mussel species in many United States rivers.

When a body of water is dammed, the stream channel is transformed from a free-flowing, well-oxygenated environment to one that is more stagnant and prone to heavy silt deposition. This is an intolerable condition for many mussel species adapted to riverine conditions.

The suitability of downstream habitats for mussels is also influenced by the operation of dams. The discharge of accumulated flood waters from reservoirs may be maintained at half- to full-channel capacity for extended periods, confining the energy of a flood to the downstream channel rather than allowing it to be distributed over the flood plain. Releases from impoundments can cause high water velocities that can displace settling juveniles before they can burrow or attach to the substrate. Conversely, extended periods of low flow below impoundments may strand mussels; thus killing them or impairing reproduction. Mussels farther downstream likely suffer physical stress through changes in habitat, food, and availability of fish hosts.

Water flow alterations contributing to the loss of host fish, increased turbidity, and accelerated sedimentation, also adversely affect freshwater mussel populations.

Loss of host fish

Damming, channelization, and other water modifications have the potential to interfere with glochidia locating suitable fish hosts. Changes in water temperature, velocity, and depth as a result of these modifications can change fish faunal composition, potentially extirpating species that glochidia depend on for survival. Additionally, dams are barriers to movements by both host fish and freshwater mussels, preventing upstream and downstream colonization.

Suspended sediments

Channelization and agitation from watercraft activities increase suspended sediments that potentially erode mussels' shells, rendering them more susceptible to shell-dissolving pollutants. Wakes generated by watercraft may escalate shoreline erosion and introduce additional suspended solids into the water. Suspended sediments interfere with mussel respiration and feeding, resulting in diminished health. Moreover, elevated levels of suspended sediments can interfere with specialized reproductive adaptations (reduced visibility of mussel lures mentioned previously), gas exchange, and the brooding of glochidia. Suspended sediments can affect mussels indirectly by

U.S. Environmental Protection Agency

A visible cloudiness in rivers, lakes, and streams is caused by suspended sediments. These sediments can have significant negative affects on freshwater mussels.

South Carolina Department of Natural Resources

Wake from boats and other watercraft can cause significant erosion damage bringing an excess of sediments into the waterbody.

reducing light availability for photosynthesis and productivity of food items. Sediment deposition may limit burrowing activity and can reduce the abundance, diversity, and reproduction of fish hosts upon which glochidia rely.

According to the U.S. Environmental Protection Agency (EPA), sediments impair more than 40 percent of the rivers in the United States. Sediment covering the substrate decreases substrate permeability, an important factor in determining the dissolved oxygen availability to juvenile mussels. Decreased current velocity as a result of dams allows suspended sediments to drop out of the water column and settle on the river bed, which can bury the mussels. Juveniles are generally restricted to interstitial habitats, and the smothering effect of sediment is potentially a major factor in preventing successful recruitment for sensitive species. This effect is also linked to mortality in adult mussels. As little as a quarter inch of sediment covering the substrate can cause up to 90 percent mortality to mussel populations.

Pollution and sedimentation

The deterioration of water quality is a widespread problem for freshwater mussel assemblages. The persistent influx of organic nutrients from point and nonpoint source pollution, particularly agricultural sources, is a significant threat to mussel populations. Nonpoint source pollution remains the leading cause of the deterioration of water quality across the United States. For more information regarding point and nonpoint source pollution, visit the EPA's Web site at *http://www.epa.gov/nps*.

Increased pollution can negatively affect the survival rates, reproductive success, growth, and behavior of aquatic organisms. Logging, mining, construction, farming, livestock operations, and a host of other land uses often adversely affect mussel populations by releasing runoff containing pollutants into freshwater systems. Eutrophication (a process whereby bodies of water receive excess nutrients that stimulate excessive plant growth) may disrupt water flow over mussel beds, inhibiting feeding and reducing oxygen supplies. Resulting deficits in dissolved oxygen, especially in interstitial habitats, may reduce survival of juvenile mussels. Excessive amounts of fine sediment washing into streams can become lodged between coarser grains of the substrate to form a hardpan layer, thereby reducing interstitial flow rates.

Land uses in the watershed may affect riverine sediments. Careless logging can alter channel structure and reduce the ability of riparian buffers to filter surface runoff containing sediments. Approximately 40 percent of sediment and nutrient loads are attributed to farming and ranching activities. Urbanization changes sediment regimes though the creation of impervious surfaces and installation of drainage systems. These modifications reduce infiltration rates which increase both the amount of surface runoff and the magnitude and frequency of flooding. Highway construction sites, surface-mined areas, dams, reservoirs, and channelization can all increase sedimentation rates. Damming and impoundments, channelization, and other freshwater modifications increase water flow and alter the distribution of sediment through scour, flushing, and deposition of newly eroded materials from the banks. Erosion caused by increased flows results in deposition of this material further down stream. Thus, increased flows cause habitat loss through both sediment deposit and increased bed mobility.

Invasive mussel species

The introduction of nonnative species can present serious problems for ecosystems, often displacing native species. Many nonnative aquatic species have been introduced to the United States by ship ballast water and the movement of recreational watercraft between rivers, lakes, and ponds. There are several invasive mussels but, perhaps, the two most widely spread are the zebra and quagga mussels.

Zebra (*Dreissena polymorpha*) and Quagga (*Dreissena bugensis*) mussels

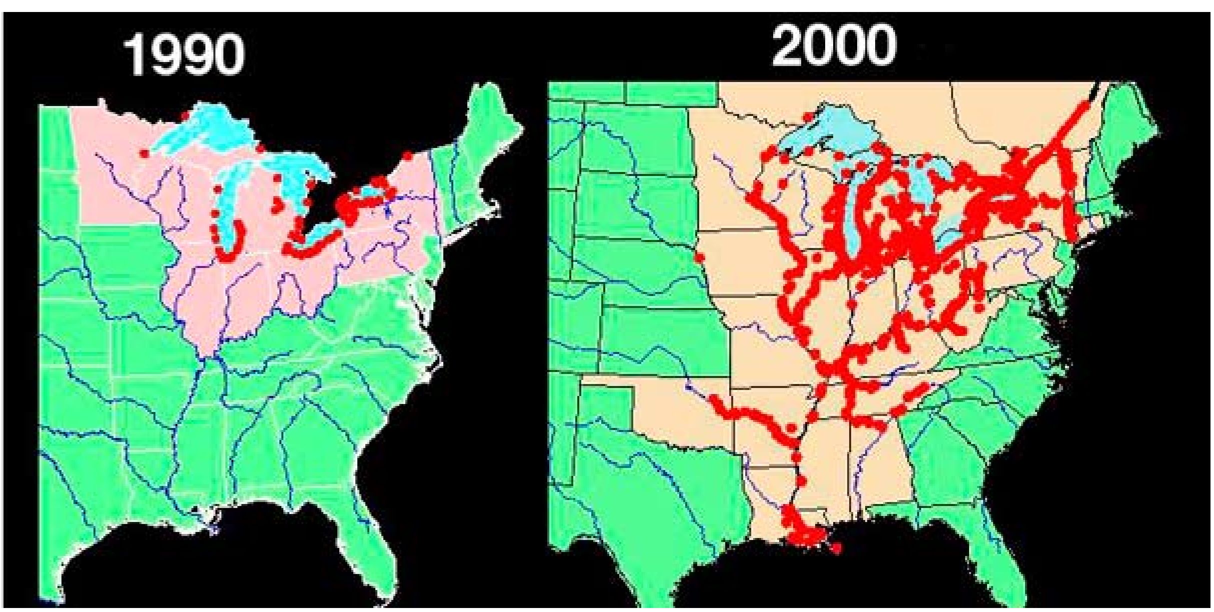
Originating in Poland and the former Soviet Union and brought to North America in the ballast water of ships, zebra mussels (*Dreissena polymorpha*) were first discovered in North America in 1988 at Lake St. Clair in Canada. By 1990, they were found throughout the Great Lakes, then the Illinois and Hudson rivers, leading eventually to the Mississippi River in 1991. Populations expanded incredibly, sometimes reaching densities of 60,000 individuals per square yard. The movement and relocation of zebra mussels is due, in part, to private boats that move from lake to lake. They have been very successful in colonizing North American waters due to their short reproductive cycle and readiness to attach to tow boats, barges, and recreational watercraft, allowing for easy transport. Zebra mussels interfere with feeding, growth, locomotion, respiration, and reproduction of native mussels. Research has shown that zebra mussels prefer to attach to live mussels and rocks. Since their establishment in North America, zebra mussels have eliminated 90 percent of native mussels in Lake Erie. Zebra mussels filter water, removing substantial amounts of phytoplankton and suspended particulates from the water. By removing the phytoplankton, these nonnatives decrease the availability of food for zooplankton, thereby altering the food web and increasing competition for food between themselves and the native mollusks.

Like the zebra mussel, the quagga mussel (*Dreissena bugensis*) is believed to have been transported from Europe in ballast water and was established in the Great Lakes by the 1980s. Quagga mussels are very similar to zebra mussels; however, they can survive in deeper water and reproduce at lower temperatures.

Zebra and quagga mussels not only affect native mussels, but also their ability to rapidly colonize hard surfaces causes serious economic problems. These organisms can clog water intake structures, such as pipes and screens, thereby reducing pumping capabilities for power and water treatment plants, costing industries, companies, and communities. Recreation-based industries and activities have also been impacted; docks, breakwalls, buoys, boats, and beaches have all been heavily colonized.

U.S. Environmental Protection Agency

Both the zebra mussel (top) and quagga mussel (bottom) are a significant threat to North America's native freshwater bivalves.



U.S. Geological Survey Nonindigenous Aquatic Species Program

The range of the zebra mussel in North American waters has expanded incredibly since 1990.

Maintenance of pipes clogged with zebra mussels costs the power industry up to $60 million per year, and temporary shutdowns due to insufficient water flow can cost over $5,000 per hour. The total cost to the United States of the zebra mussel invasion is estimated at $3.1 billion over the next 10 years. For more information, visit the U.S. Department of State at *http://www.state.gov/g/oes/ocns/inv/cs/2304.htm*.

Harvest

The use of freshwater mussels for making pearl buttons dates back to at least 1800, but a thriving industry did not develop until the late 1800s. Since then, harvest has been regulated by individual states. Mussels occur in most rivers and lakes, but not all states presently allow commercial harvest. In 1997, only 14 states allowed commercial harvest. Shell harvests are controlled through permit and harvest reports required of both musselers and shell buyers. State regulations specify the species that can be harvested, the minimum shell size, open areas, season and time of day, method of capture, and other limitations to prevent over harvest. Close regulation of harvest is made difficult by imprecise survey methods, nonspecific harvest methods, and lack of state financial resources and staff. In some areas, overexploitation has contributed to the decline of mussel fisheries.

Conservation and management

Biologists from the U.S. Fish & Wildlife Service and the U.S. Geological Survey, along with other Federal, State, and private agencies, are working together to find solutions to problems facing North American freshwater mussels. These partners have developed a National Strategy for the Conservation of Freshwater Mussels (*http://ellipse.inhs.uiuc.edu/FMCS/Meetings/NatStrategyConsev.pdf*), which will serve as a blueprint for native mussel restoration. Specifically, the goals of this initiative are to identify the research, management, and conservation actions necessary for the maintenance and recovery of healthy mussel populations, increase government and public awareness of the plight of freshwater mussels and their essential ecosystems, and foster creative partnerships among Federal, State, tribal, and local governments and the private sector to restore the mussel fauna and environmental quality to our rivers. Additionally, partners formed the Freshwater Mollusk Conservation Society (*http://ellipse.inhs.uiuc.edu/FMCS/*) that will help guide research, restoration, and recovery efforts for freshwater mussels.

Efforts to recolonize areas where populations have declined have met with limited success. Consequently, researchers are seeking to develop methods that will improve survival, growth, and recruitment of relocated individuals.

U.S. Geological Survey

Zebra mussels can become an economical problem when they begin to colonize on pipes, boats, screens, buoys, and docks.

U.S. Geological Survey

This composite view of ideal surface and subsurface characteristics shows environmental factors favorable for native freshwater mussels including a riparian buffer and gravel streambed with a moderate silt covering.

Habitat assessment

For landowners who wish to participate in conservation efforts, the first step is to identify limiting factors for freshwater mussels and opportunities to address these factors. For adequate restoration or enhancement projects, site conditions must be understood in relation to the watershed in which they occur.

A watershed is a complex and valuable ecosystem that includes the land, plants, and animals, and a network of streams within it. Streams and rivers, along with their tributaries, transform land features by transporting and depositing soil from one place to another. The health of a stream ecosystem depends on the complex interaction of physical, chemical, and biological processes that often times can be difficult to evaluate. Because more than 90 percent of a river's flow may be derived from upstream sources, efforts to maintain or restore natural flow regimes should focus most intensely in upstream reaches.

To evaluate existing conditions, a quick visual assessment will often yield clues about the general health of a stream reach. The Stream Visual Assessment Protocol (SVAP), developed by the NRCS, is a simple tool that requires little specialized equipment or experience. Table 1 summarizes some of the components and characteristics of streams evaluated by the SVAP. Using SVAP, the landowner can evaluate and score each stream habitat component separately and then average all the scores together to determine an overall rating of stream condition. If the landowner is unqualified to make this assessment, assistance may be provided by the local NRCS biologist. Individuals interested in obtaining a copy of the SVAP can visit *http://www.nrcs.usda.gov/technical/ECS/aquatic/svapfnl.pdf*.

Severely eroding streambanks are often the first sign that a stream and its habitat are in poor condition. Landowners wishing to stop erosion of streambanks should seek technical assistance in evaluating the

Table 1 SVAP components of stream health

	High score	Above average score	Below average score	Low score
Channel condition	Natural channel; no evidence of erosion	Evidence of past channel alteration	Altered channel	Channel is actively downcutting or widening
Hydrologic alteration	Flooding every 1.5–2 years	Flooding every 3–5 years	Flooding every 6–10 years	No flooding
Riparian zone	Natural vegetation extends >2 active channel widths on each side	Natural vegetation extends 1 active channel width on each side	Natural vegetation extends 1/3 of active channel width on each side	Natural vegetation extends <1/3 the active channel width on each side
Bank stability	Stable	Moderately stable	Moderately unstable	Unstable
Water appearance	Very clear or clear but tea-colored	Occasionally cloudy	Considerable cloudiness	Very turbid or muddy
Nutrient enrichment	Clear water	Slightly greenish water	Greenish water	Pea green, gray, or brown water
Barriers to fish movement	No barriers	Water withdrawals limit fish movement	Drop structures <1 foot	Drop structures >1 foot
Instream fish cover	More than 7 cover types available	Five to seven cover types available	Two to three cover types available	Zero to one cover type available
Pools	Deep and shallow pools abundant	Pools present but not abundant	Pools present but shallow	Pools absent
Riffle embeddedness	Gravel or cobble particles are <20% covered with fine sediment	Gravel or cobble particles are 20–40% covered with fine sediment	Gravel or cobble particles are >40% covered with fine sediment	Riffle is completely covered with fine sediment

cause of the severe erosion and selecting corrective measures that are compatible with conservation of fish and wildlife habitat. Bioengineering approaches to streambank stabilization that use natural materials such as logs, boulders, and live trees and/or cuttings to temporarily arrest erosion until riparian vegetation can be re-established are especially well suited for small streams. Streambank restoration has proven most successful in slowing bank erosion when the flow regime is relatively unaltered or controlled to mimic natural conditions. For additional information and guidelines for implementation, visit *http://plant-materials.nrcs.usda.gov/technical/publications/riparian.html.*

Restoration/enhancement options

The involvement of concerned local people is critical to protecting rivers and streams with freshwater mussels. State and Federal regulations help, but pollution control agencies often lack resources needed to adequately monitor water quality. It is up to the public to keep watch on their local streams, identify problems, and report suspected water pollution to the authorities. There are many options landowners have to improve or restore habitat for freshwater mussels including reducing runoff, removing dams, and managing for invasives.

U.S. Environmental Protection Agency

Contour farming and stripcropping are the practice of planting along the slope instead of up-and-down slopes, and planting strips of grass between row crops. Farming practices such as these can significantly reduce soil erosion.

Management considerations for reducing harmful runoff

To reduce erosion and nonpoint source pollution, vegetative buffer strips can be planted surrounding waterbodies. Buffers are small areas or strips of land in permanent vegetation designed to intercept pollutants and sediments. Strategically placed buffer strips can effectively impede the movement of sediment, nutrients, and pesticides into freshwater systems. When coupled with appropriate upland treatments, including crop residue management, nutrient management, integrated pest management, winter cover crops, and similar management practices and technologies, buffer strips can effectively protect water quality. Buffer strips can also enhance wildlife habitat and protect biodiversity. For more information on buffer strips, visit the NRCS vegetative buffer Web site at: *http://www.nrcs.usda.gov/feature/buffers/* and *http://www.riparianbuffers.umd.edu/fact.html.*

To reduce soil losses, farm management activities, such as crop rotations, contour farming, terracing, and strip cropping of cultivated areas, can be implemented. These practices can reduce soil losses by as much as 70 percent. Reduced soil tillage or no tillage methods reduce soil exposure and erosion of soil particles that often contain absorbed nutrients and biocides. Other methods to reduce nonpoint source pollution include:

- managing animal waste to minimize contamination of surface water and ground water
- protecting drinking water by minimizing the use of pesticides and fertilizers
- using planned grazing systems on pasture and rangeland
- disposing of pesticides, containers, and tank waste in an approved manner

Street litter, fertilizers, pesticides, herbicides, pet and yard waste, motor oil, anti-freeze, paint, and household hazardous wastes are just a few of the pollutants that find their way into storm drains from urban and residential areas. This water travels from storm drains into local streams, rivers, ponds, and lakes. Reductions of urban nonpoint source pollution can be made by:

- keeping litter, pet wastes, leaves, and debris out of street gutters and storm drains (these outlets drain directly to lakes, streams, rivers, and wetlands)
- applying lawn and garden pesticides and fertilizers sparingly and according to directions

- disposing of used oil, antifreeze, paints, and other household chemicals properly, and not into storm sewers or drains
- cleaning up spilled brake fluid, oil, grease, and antifreeze, as opposed to hosing them into the street where they can eventually reach local streams and lakes
- controlling soil erosion by planting ground cover and stabilizing erosion-prone areas
- encouraging local government officials to develop construction erosion/sediment control ordinances
- having septic systems inspected and pumped, at a minimum, every 3 to 5 years so that they operate properly
- not using septic system additives
- purchasing household detergents and cleaners that are low in phosphorous to reduce the amount of nutrients discharged into waterbodies

For more information on reducing point and nonpoint source pollution, funding opportunities, and publications, visit the EPA's polluted waters Web site at *http://www.epa.gov/owow/nps/*.

National Oceanic and Atmospheric Administration

Power spraying can effectively remove zebra and quagga mussels that have attached to hulls, rudders, and other locations on watercraft.

Dam removal

If damming and impoundments are important contributors to declines in mussels, dam removal or changes in dam operation may be required to restore freshwater mussel communities. Widespread mussel mortality in both upstream and downstream reaches may occur following the removal of dams. Rapid dewatering of reservoirs may result in increased mortality of freshwater mussels due to stranding, desiccation, and predation. Thus, although dam removal may be needed to restore fish migration and continuous streamflow, the short-term cost to mussels can be substantial. Because of their delayed reproductive maturity, low mobility, and complete dependence on fish hosts for reproduction and dispersal, recovery of mussel populations following a disturbance may be slow. Nonetheless, the removal of dams contributing to restoration of a healthy stream will eventually lead to increases in local mussel populations. Trade-offs between ecological costs and benefits are a fundamental part of restoration projects. Consideration of restoration options should ensure that the short-term consequences are not so great that long-term goals cannot be realized.

The potential for species losses should be assessed before dam removal. The dam removal assessment should include a careful survey of the reservoir and downstream aquatic communities to determine if any threatened or endangered species are present. The survey will provide the basis for potential mitigation efforts to minimize adverse effects associated with dam removal and provide a baseline for follow-up monitoring studies. Mitigation options include relocating mussels in downstream reaches unlikely to incur excessive sedimentation, a slow (months to years) drawdown of the reservoir allowing mussels to move with the decreasing water levels, and stabilization of reservoir sediments.

Invasive Species Management

Once zebra and quagga mussels become established in a waterbody, they are virtually impossible to eradicate with the technology currently available. However, there are a wide variety of methods used to control zebra and quagga mussels. Removal from surfaces is accomplished with mechanical scrapers, hot water, air, chemicals, and sound. Additional methods proposed to eliminate zebra mussels include chemical molluscicide, thermal methods (steam injection), manual removal, dewatering, and use of electrical currents. A shortcoming of many of these techniques is the unavoidable destruction of nontarget populations. New methods for targeted removal and control of mussels are under investigation. At present, there is no single, ideal solution for all affected facilities or sites.

Boat operators can assist in slowing the spread of invasive mussels by removing attached vegetation from boats, washing boats and trailers, flushing engine cooling systems, disposing of unused bait, and inspecting hulls of boats prior to relocation.

Case study: Propagation and juvenile mussel releases in Virginia and Tennessee

The Freshwater Mollusk Conservation Center (FMCC) at Virginia Tech has been conducting research on propagation and reintroduction of endangered mussel species since 1997. The facility has successfully propagated 39 species of mussels including 25 federally listed species. Of the 1.28 million juveniles that have been produced to date, almost a half million have been released into various tributaries in the Upper Tennessee River system.

The three sites chosen for releases have different environmental parameters. Indian Creek has received juveniles of the tan riffleshell (*Epioblasma florentina walkeri)* and purple bean (*Villosa perpurpurea*) for several years. The results of this release are still under investigation. The releases of oyster mussel (*Epioblasma capsaeformis*) juveniles at Horton Ford, Clinch River, were successful in augmenting and reestablishing the species at that site. Releases of several endangered species at McDowell and Bales Fords on the Powell River thus far have been unsuccessful.

One critical factor in survival of released juveniles may be their age and physiological condition the time of at release. Early reintroduction efforts involved the release of young juvenile mussels (1 to 2 weeks old). However, at Horton Ford, juvenile survivorship was highest in older, robust juveniles 8 weeks of age.

A suite of environmental factors, continued anthropogenic impacts, and characteristics of the release site also influenced the success of the releases. Water and substrate conditions unsuitable for survival of juvenile mussels were attributed to chronic and episodic disruptions in Indian Creek and the Powell River.

National Park Service

Mussels should be relocated into substrate that is appropriate for the species.

Assistance programs

Financial and technical assistance for restoration and enhancement of freshwater habitats is available from an array of government agencies and public and private organizations (table 2). Grant programs are available from the National Fish and Wildlife Foundation for projects ranging from restoring native species to their historic range to protecting, restoring, or enhancing habitat for fish and wildlife. To access more information on grant qualifications and applications, visit *http://www.nfwf.org/grant_apply.cfm*.

Conclusion

In spite of increased awareness of population declines in freshwater mussels, these important aquatic organisms and their habitats continue to be threatened. Conservation efforts should focus on restoration and pollution management at the watershed scale. Stream restoration, dam removal, and control of invasives and pollution are some of the options under consideration to protect native freshwater mussels. To effectively carry out such a broad scale recovery effort will require an unparalleled level of cooperation and coordination between State and Federal agencies. Perhaps even more critical to the success of ecosystem and watershed conservation is the involvement of the general public, land users, conservation organizations, and private corporations.

Table 2 Assistance programs

Program	Land eligibility	Type of assistance	Freshwater restoration or enhancement opportunities	Contact
Conservation Reserve Program	Riparian pastureland and highly erodible land	50% cost-share for establishing permanent cover, annual rental payments in return for establishing long-term, resource-conserving covers, additional financial incentives are available for some practices	Plant long-term, resource-conserving covers in freshwater and upland areas to improve water quality, control erosion, and enhance wildlife habitat	NRCS or FSA State or local office
Partners for Fish and Wildlife Program	Most degraded fish and/or wildlife habitat	Up to 100% financial and technical assistance to restore wildlife habitat under minimum 10-year cooperative agreements	Restore freshwater hydrology; plant native trees, shrubs, grasses, and other vegetation; install fencing and off-stream livestock watering facilities to allow for restoration of stream and riparian areas; remove exotic plants and animals	U.S. Fish & Wildlife Service local office
Waterways for Wildlife	Private riparian or aquatic land	Technical and program development assistance to coalesce habitat efforts of corporations and private landowners to meet common watershed level goals	Enhance freshwater and adjacent upland habitats by planting buffers, creating habitat structures, and other activities	Wildlife Habitat Council
Wetlands Reserve Program	Previously degraded wetland and adjacent upland buffer, with limited amount of natural wetland and existing or restorable riparian areas	75% cost-share for wetland restoration under 10-year contracts and 30-year easements, and 100% cost-share on restoration under permanent easements. Payments for purchase of 30-year or permanent conservation easements	Restore and protect freshwater and limited adjacent upland area; improve wetland wildlife habitat	NRCS State or local office
Wildlife at Work	Corporate riparian or aquatic land	Technical assistance on developing habitat projects into a program that will allow companies to involve employees and the community	Enhance freshwater and adjacent upland habitats by planting buffers, creating habitat structures, and other activities	Wildlife Habitat Council
Wildlife Habitat Incentives Program (WHIP)	High-priority aquatic fish and wildlife habitats	Up to 75% cost-share for conservation practices under 5- to 10-year contracts	Establish and improve fish and wildlife habitat, including freshwater and adjacent upland habitats, particularly those for wildlife species experiencing declining or significantly reduced populations	NRCS State or local office
Special Grant Programs	Freshwater habitat	Varies from technical to financial assistance	Varies. Several programs are location specific	National Fish and Wildlife Foundation

Table 2 Assistance programs—Continued

Program	Land eligibility	Type of assistance	Freshwater restoration or enhancement opportunities	Contact
Environmental Quality Incentives Program (EQIP)	Cropland, rangeland, pasture, forestland, and other farm or ranch lands. Priority areas are defined as watersheds, regions, or areas of special environmental sensitivity or having significant soil, water, or related natural resource concerns	5- to 10-year contracts that provide incentive payments and cost sharing for conservation practices called for in the site-specific plan. Cost-share up to 75% of the costs of certain conservation practices. Additional technical, educational, and financial assistance may be provided for other conservation practices	Establish and improve fish and wildlife habitat, including freshwater and adjacent upland habitats, by planting riparian buffers, creating habitat structures, and other activities	NRCS State or local office

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