NEEDS IN THE MANAGEMENT OF NATIVE FRESHWATER MUSSELS IN THE NATIONAL PARK SYSTEM

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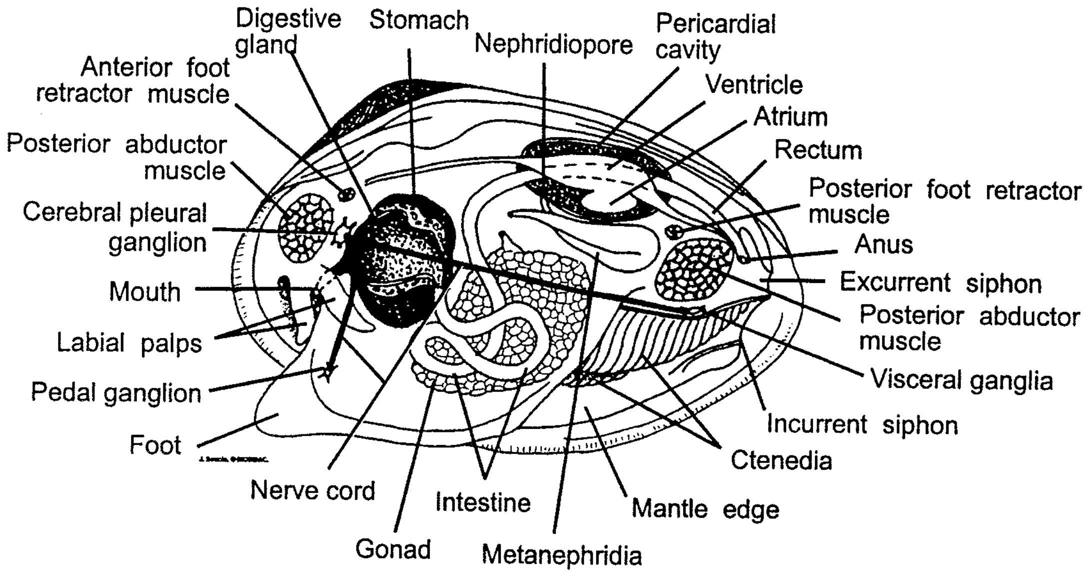

Internal Anatomy of the Clam

Diagram courtesy of BIODIDAC

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Executive Summary

Freshwater mussels (Phylum: Mollusk, Class: Bivalvia) have suffered a greater decline than any other wide-ranging faunal group in North America. Because of the decline of mussels throughout North America, many National Park System units are destined to become important refuges for this significantly endangered group of animals. Yet, data on the abundance, distribution, and health of mussel populations in National Park System units is lacking. A preliminary survey of 27 units with mussel resources indicated that 37% of the responding units did not make baseline mussel inventories. Of the parks with baseline data, 66% of the known mussel species were protected by federal or state laws. Five of the responding units provide a significant refuge for state and federally listed species: Big South Fork National River and Recreation Area, Buffalo National River, Mammoth Cave National Park, St. Croix National Scenic River, and the C&O Canal. These parks have exceptionally diverse assemblages of freshwater mussels that include state and federally listed species. The National Park Service has a critical role in the survival and recovery of freshwater mussel species.

Mussels have important functions in aquatic environments. They are a middle-link in the food chain and help to maintain water quality. Because they are long-lived and particularly sensitive to changes in water quality, mussels are important indicators of aquatic ecosystem health. The disappearance of mussels from a river or lake often signals that other aquatic species are at risk.

North American freshwater mussels have an extraordinary life history and reproductive adaptations. An important feature of their life history is the unique and complex larval need for a fish host to enable metamorphosis from the larval stage into an independent juvenile mussel. Freshwater mussels exhibit a variety of shapes from elongated or oval to subcircular, quadrate, or subtriangular. Shells also vary by species in size, thickness, color, shape, and texture. Although freshwater mussels are primarily sedentary, they use a highly muscular and flexible foot for movement, burrowing, or anchoring into the substrate or between rock crevices. Most freshwater mussels are suspension feeders, filtering unicellular algae, bacteria, and suspended detrital particles from the water.

Threats to the long-term survival of mussels include: degradation to mussel habitat (sediment loading, erosion, pollutants from improper agricultural, forestry, and coal mining practices); channelization, dredging and bridge construction; traffic (large vessels or domestic animal crossings); dams or other barriers to fish migration; over-harvest and illegal collecting; and competition from non-native species, including the zebra mussel. Given the preservation goals of the National Park Service and the importance of mussels to aquatic ecosystems, the protection of mussels and their habitats should become integrated in program planning, management, and education by park managers. Protection of water quality and habitats for mussel populations will protect other water dependent species in parks.

The protection and management of freshwater mussels in NPS units requires:

1 Acquisition of baseline data from inventory, monitoring, and research.
2. Protection and restoration of significant mussel habitats.
3. Prevention of aquatic nuisance species introductions, including the zebra mussel.

4. Restoration of stream banks with native vegetation and establishment of Best Management Practices for land use activities (forestry, mining, agriculture, and other developments) adjacent to rivers and streams.

5. Inclusion of host fish species management in fisheries management plans.

6. Evaluation of the influences of external activities and habitat alterations on aquatic resources (water quality, fisheries, mussels) and development of strategies for removing or mitigating them.

7. Development of watershed management plans with local communities, state agricultural agencies, the Natural Resource Conservation Service, and other agencies. Plans should include pesticide and soil best-management practices to reduce erosion, nutrient loading, and other forms of water pollution.

8. Education of park visitors, partners, and adjacent communities about freshwater mussels and protection needs.

Provided as appendixes in this report are a resource bibliography, references for education and outreach materials, and a glossary.

Key words: Mussels, unionids, mollusks, Bivalvia, management, protection, endangered species.

INTRODUCTION

Freshwater mussels (Phylum: Mollusca, Class: Bivalvia) of the family Unionidae are commonly known as pearly mussels, bivalves, mussels, niads, or unionids. About 1,000 species have been identified worldwide, and approximately 297 freshwater mussel species and subspecies occur in the United States (Biggins, et al. 1997). In fact, the richest mussel species aggregations in any watershed worldwide are in North America. Most freshwater mussels in the United States occur in the East (Dobson et al. 1997). A preliminary survey revealed that at least 70 species occur in National Park System units and that several units contain mussel assemblages that are of global significance.

Mussels are extremely important to freshwater communities. They are food for many mammals and birds, and they help maintain good water quality by filtering nutrients, contaminants, and sediments from the water. The decline of mussel abundance or the disappearance of mussels from a river or lake may be an indication of substantially deteriorating water and environmental qualities.

Recent surveys revealed that more than half of the mussel species in the United States are in need of protection (Fig. 1). The American Fisheries Society considers 72% of the species to be extinct, endangered, threatened, or of special concern (Biggins et al. 1997). As a group, native mussels, particularly the unionids (Superfamily: Unionacea), are the most rapidly declining animal group in the United States and constitute the largest group of federally listed endangered or threatened invertebrates (The Nature Conservancy 1996a). No other widespread group of animals in North America approaches this level of collapse. Nationwide, some mussel species have been reduced to so few and such small populations that the remaining populations are highly vulnerable to extirpation or extinction from random events such as natural disasters or chemical spills (Biggins et al. 1997). If the decline continues, freshwater mussels as a group will go extinct, representing the greatest rate of extinction witnessed in modern times (Williams and Neves 1995).

The decline of mussels is attributed to habitat loss and degradation; pollution, including agricultural run-off that contains nutrients and pesticides; siltation; streambank erosion and floodplain development; toxic spills, dam construction; dredge, fill, and other channel modifications; cattle and horse crossings through important mussel beds; population isolation; mining of minerals in the watershed; poaching; and most recently, the introduction of the exotic zebra mussel (*Dreissena polymorhpa*) that outcompetes native mussels for food and habitat.

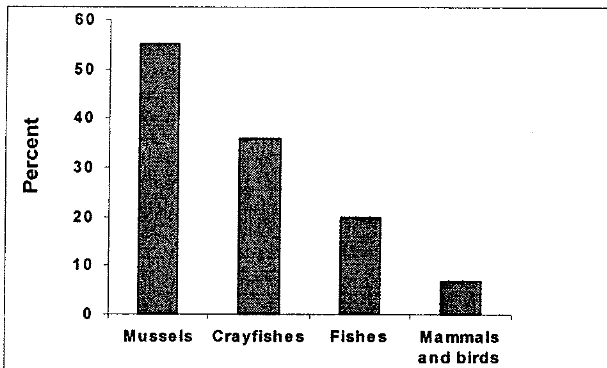

Figure 1. Imperiled proportions (%) of faunal groups in the United States. 1996 (from the files of The Nature Conservancy).

This report provides a summary of current information about the biology, ecology, and the causes of the decline of freshwater mussels for resource managers and interpretive staff of the National Park Service. Presented also are management options to protect mussels and their habitats, a resource bibliography, references to education and outreach materials, and freshwater mussel contacts (Appendixes A-D).

Background

The freshwater mussels of the Family Unionidae are included in the second largest phylum of the animal kingdom (Cummings and Mayer 1992), the Mollusca. Although the higher classification of these taxa has not been resolved, most malacologists tentatively recognize two families, three subfamilies, and about 49 nominal genera of unionids (Cummings and Mayer 1992). In this report, mussels denote members of the family Unionidae.

Worldwide, the greatest diversity of freshwater mussels occurs in the eastern United States. The Ohio River basin supports nearly 127 of the 297 North American species. More than 15 National Park System units in the eastern United States support or potentially support diverse mussel faunas. Diverse groups of mussels also occur in several Midwestern and southwestern states. In the Midwest, for example, the Upper Mississippi drainage, which includes the St. Croix National Scenic Riverway, is recognized as supporting a rich mussel community that has been described by biologists as a world-class assemblage.

Mussels are relatively stationary organisms that inhabit a variety of stable river and lake substrates, such as sand, gravel, cobble, boulders, or a combination of these materials. Different species of mussels require different types of substrate (Cummings and Mayer 1992). Mussels burrow in sand and gravel substrates of streams and lakes and usually leave small portions of their shells and siphons exposed above the substrate surface. They are filter feeders that depend on a stable substrate for burrowing and require good water quality and quantity (flow) for feeding, breathing, and reproducing. Typically, they inhabit unpolluted waters that are rich in oxygen, calcium, and suspended food particles. Unionids also require an intermediate host, usually a fish, to complete their life cycle.

Freshwater mussels provide significant ecological and economic benefits to the nation. Native Americans recognized the value of freshwater mussels as a food source, for the construction of tools, utensils, and pottery, for jewelry, as currency, and for trading. At the turn of the century, European settlers began harvesting freshwater mussels for pearl buttons. By 1912, nearly 200 factories manufactured buttons and developed into a multi-million dollar industry (Mueller 1993). In the 1940s however, the pearl-button industry was driven out of production by overharvest and the availability of inexpensive plastics. Nevertheless, interest in the consumptive uses of mussels persisted. By the 1960s, the Japanese cultured pearl industry had expanded. Today, thousands of mussels are legally harvested from North American rivers for this multi-million dollar enterprise. Illegal harvesting is on the rise in the United States and is contributing to the decline of certain species.

Mussels are extremely important to freshwater ecosystems because they form a critical middle link in the food chain. Mussels continuously siphon water from their surroundings, filtering from it phytoplankton and other microscopic organisms for food. In turn, mussels are eaten by muskrats (*Ondatra zibethicus*), raccoons (*Procyon lotor*), herons (Family Ardeidae), shorebirds (Order Charadriiformes), waterfowl (Order Anseriformes), and other aquatic and terrestrial animals.

Because they are sensitive to toxic chemicals, sedimentation, and other water quality perturbations, mussels serve as indicators of water quality (Biggins et al. 1997). Mussels are excellent biological indicators in part because of their key position in energy cycling. By filtering contaminants, sediments, and nutrients from the water column, mussels help maintain water quality.

Mollusks are ideal biomonitors because they are easily collected, sedentary, and long lived (30-80 years) and because they bioconcentrate contaminants (Muir et al. 1997). Additionally, their shells can be analyzed to determine whether and when toxic chemicals were accumulated. The presence and abundance (or absence) of mussels in a historical range are usually reflections of water and habitat quality in a watershed. As such, mussels are an important ecological component of the nation's lakes and rivers and represent the foundation of a healthy river or lake.

Unfortunately, mussels and other freshwater aquatic animals (crayfishes, fishes, and amphibians) are declining at an alarming rate (The Nature Conservancy 1996b). Information about unionids in national parks is limited. Regions of endemism and species richness are primarily in the southeastern United States, including the Ohio, Tennessee, Cumberland, and Mobile drainages and other rivers to the Gulf of Mexico and South Atlantic (Neves 1993). A preliminary survey of National Park System units in this region (Jennings 1997) revealed that data on the distribution, abundance, composition, and population trends are not available from 37% of the units with known mussels. Sixty-six percent of the known mussel species in parks with baseline data are protected species. In the implementation schedules of approved recovery plans, the National Park Service has been identified as having a lead role in the implementation of recovery of 13 federally listed species (Table 1). Protection is critical to the survival and recovery of 10 species of mussels in the Green River in Mammoth Cave National Park (R. Biggins, personal communication). The St. Croix National Scenic Riverway supports the only known world population of the winged mapleleaf (*Quadrula fragosa*) and one of a few reproducing populations of Higginsi pearly mussel (*Lampsilis higginsi*). Both species are federally listed as endangered, and their recovery plans identify the riverway as having a role in the recovery. The C&O Canal National Historic Site, Big South Fork National River and Recreation Area, Buffalo National River, and Niobrara and Ozarks national scenic riverways also have diverse and endangered mussel faunas. The Emory drainage, which includes the Obed National Scenic Riverway, has been seriously disturbed by activities outside of the park's boundary that caused a significant reduction in mussel diversity in the last

Table 1. Federally listed freshwater mussel species. When indicated in Column 4, the species occurs in National Park Service units or the National Park Service is responsible for the implementation of the recovery plan for the species. E=endangered, T=threatened

Common Name	Scientific Name	Status	Located in NPS units or cited in the Recovery Plan
Cumberland Elktoe	*Alasmidonta atropurpurea*	E[a]	X
Dwarf Wedge Mussel	*A. heterodon*	E	X
Appalachian Elktoe	*A. ravencliana*	E	
Birdwing Pearly Mussel	*Conradilla caelata*	E	
Fanshell Mussel	*Cyprogenia stergaria*	E	
Dromedary Pearly Mussel	*Dromus dromus*	E	
Tar River Spinymussel	*Elliptio steinstansana*	E	
Cumberland Combshell	*Epioblasma brevidens*	E	
Oyster Mussel	*E. capsaeformis*	E	
Curtis' Pearly Mussel	*E. florentina curtisi*	E	
Yellow Blossom Pearly Mussel	*E. florentina florentina*	E	X
Upland Combshell	*E. metastriata*	E	Potential
Purple Cat's Paw Pearly Mussel	*E. obliquata obliquata*	E	
White Cat's Paw Pearly Mussel	*E. obliquata perobliqua*	E	
Southern Acornshell	*E.othcaloogensis*	E	
Southern Combshell	*E. penita*	E	
Green-blossom Pearly Mussel	*E. torulosa gubernaculum*	E	
Northern Riffleshell	*E. torulosa rangiana*	E	X
Tubercled-blossom Pearly Mussel	*E. torulosa torulosa*	E	
Turgid-blossom Pearly Mussel	*E. turgidula*	E	
Tan Riffleshell Mussel	*E. walkeri*	E	
Shiny Pigtoe Pearly Mussel	*Fusconaia cor*	E	
Fine-Rayed Pigtoe Pearly Mussel	*F. cuneolus*	E	
Cracking Pearly Mussel	*Hemistena lata*	E	X
Pink Mucket Pearly Mussel	*Lampsilis abrupta*	E	X
Fine-Lined Pocketbook	*L.altilis*	T	Potential
Wavey rayed	*L. fascuola*	E	Potential
Higgins' Eye Pearly Mussel	*L. higginsi*	E	X
Orange-nacre Mucket	*L. perovalis*	T	
Arkansas Fatmucket	*L. powelli*	T	
Speckled Pocketbook	*L. steckeri*	E	
Alabama Lamp Pearly Mussel	*L. virescens*	E	
Carolina Heelsplitter	*Lasmigona decorata*	E	
Alabama Moccasinshell	*Medionidus acutissimus*	T	
Coosa Moccasinshell	*M. parvulus*	E	Potential
Rink Pink Mussel	*Obovaria retusa*	E	X
Rock Pocketbook	*Ouachita wheeleri*	E	
Little Wing Pearly Mussel	*Pegias Fabula*	E	X
White Wartyback Pearly Mussel	*Plethobasus cicatricosus*	E	
Orange-footed Pearly Mussel	*P. cooperianus*	E	
Clubshell	*Pleurobema clava*	E	X
James River Spinymussel	*P. collina*	E	
Black Clubshell	*P. curtum*	E	
Southern Clubshell	*P. decisum*	E	
Dark Pigtoe	*P. furvum*	E	
Southern Pigtoe	*P. georgianum*	E	
Cumberland Pigtoe	*P. gibberum*	E	
Flat Pigtoe	*P. marshalli*	E	
Ovate Clubshell	*P. perovatum*	E	

Table 1 cont'd

Rough Pigtoe	*P. plenum*	E	X
Heavy Pigtoe	*P. taitianum*	E	
Fat Pocketbook Pearly Mussel	*Potamilus capax*	E	
Inflated Heelsplitter	*P. inflatus*	T	
Rough Rabbitsfoot	*Quadrula cyclindrica strigillata*	*E	X
Winged Mapleleaf Mussel	*Q. fragosa*	E	X
Cumberland Monkeyfaced Pearly Mussel	*Q.intermedia*	E	
Appalachian Monkeyface Pearly Mussel	*Q. sparsa*	E	
Stirrupshell	*Q. stapes*	E	
Pale Lilliput Pearly Mussel	*Toxoplasma cylindrellus*	E	
Comberland Bean Pearly Mussel	*Villosa trabalis*	E	

70 years (Ahlsted and Rashleig 1996). Despite the protected status of mussels in many states and in National Park System units, The Nature Conservancy (1996b) reports that one in ten mussels may have already become extinct. In the absence of increased water quality conservation, extinction of the entire North American mussel fauna in the near future is a disinct possibility (Neves 1993).

Anatomy, Physiology, and Reproduction

A generalized description of shell features and organ system functions of freshwater mussels is provided in this report. For a more detailed discussion the reader is referred to the references in the *Resource Bibliography* (Appendix A).

Anatomy

A molluscan body has six fundamental parts: The shell, head, soft body, mantle, foot, and gill filaments (Fig. 3). The shell, which is made of calcium carbonate and protein, provides a protective outer skeleton for the soft-bodied animal, which is particularly important because the animal is relatively immobile and unable to swiftly escape predators. Inside the shell is the head, which is poorly defined (although well developed in other mollusks) and functions as a sensory organ with a mouth. The soft body is a thickened central mass and contains the heart and other essential organs of digestion, excretion, and reproduction (Fig. 3). It is attached to the top (dorsal) of the paired valves.

Exterior to the gills is a thin covering of tissue termed the mantle, which lines the inner surface of the shell and the body. The mantle tissue secretes the shell and prevents particles from getting between the mantle and shell. The space between the mantle and the viscera is the mantle cavity. Pearls are created by secretions of nacre when a foreign particle becomes trapped between the shell and the mantle. The mantle is sealed, but it forms low folds, which envelop the animal, and remains open anteriorly, ventrally, and posteriorly. The posterior portion of the mantle forms two tubes, the inhalant (incurrent) and exhalant (excurrent) siphons. The primary function of the mantle is to secrete the shell, yet blood vessels inside the organ allow a limited amount of gas exchange. The cilia on the epidermis of the mantle also aid in trapping food in mucus and passing a string of food to the labial palps (Miller and Nelson 1983). On either side of the shell are the gill filaments, which are feather-like projections, rich in blood vessels, that have a role in respiration, filtering and sorting food, and reproduction (Hornbach 1996). Cilia that cover the gills aid in the circulation of water. In females, the gills serve as a marsupium to hold developing eggs. Some

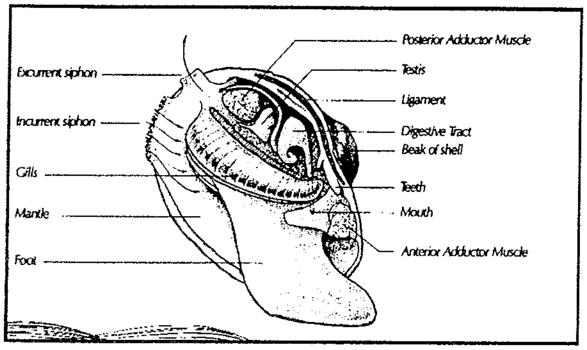

Figure 2. The molluscan body. Drawing courtesy of the James Ford Bell Museum, University of Minnesota, Minneapolis.

species contain a separate gill chamber that serves as a brood pouch. Finally, the forward bottom part of the body forms the foot that can extend outside of the shell and is the most noticeable anatomical feature. The contraction and expansion of this muscular organ enable the animal to move around, burrow, or secure itself in a river or lake bed. The six primary structures can be identified without a microscope.

Exterior Shell Characteristics

The external shell morphology of mussels has a variety of shapes from elongated or oval to subcircular, quadrate, or subtriangular. Shells also vary by species in size, thickness, color (exterior and interior), shape, and texture. Shell shape and exterior and internal surface features are significant diagnostic features. The shell consists of two valves (bivalves) that can open and close and are held together by a dorsal ligament. Major external features of the shell include the left and right valves, umbo (beak), hinge, and growth lines. External shell characteristics may include ridges, rays, pustules, and horns, although in some species the external shell is smooth. External colorations vary from light yellows, greens, browns, and reds to black. Dark green or black bands, rays, and chevrons add to the beauty of the external shell. The umbo (beak) is an external swelling on all shells, although it is modified in some species. It is where the valves are hinged together. This is where growth begins in the juvenile and represent the oldest part of the shell. Surrounding each umbo and extending to the margins of the valve are a series of concentric lines that form as the animal grows. These markings denote limits of annual growth and winter rest in many species and are often used to age the animal. However, accessory rings form in response to unfavorable environmental conditions (lack of food, low oxygen, or low water levels).

Shell construction of most bivalves includes three distinct portions: the outer periostracum, the prismatic layer, and the inner layer of nacre. The periostracum is relatively impermeable to water, which prevents the dissolution of calcium carbonate from the shell surface. This layer protects the underlying calcium carbonate from the erosive action of sand and gravel and the corrosive nature of low water pH (McMahon 1991). In older animals, particularly near the umbos, the outer protective periostracum is often eroded, pitted, or corroded, exposing the chalky white calcium carbonate layer beneath. The prismatic layer, which is relatively thin, consists of closely packed, prismlike blocks of calcium carbonate. The innermost and usually thickest layer of the shell is termed the nacre or mother-of-pearl and is composed of a series of thin calcium carbonate plates and varies from silvery white and salmon to dark purple. The accumulation of the nacreous layer over time contributes to the shell strength and rigidity (McMahon 1991).

Internal Shell Characteristics

Internal shell structures include the hinge and projecting hinge teeth that interlock to hold the valves together in juxtaposition and serve as a fulcrum, the pseudocardinal teeth, muscle scars, and the umbo cavity. Lateral and pseudocardinal teeth separated by a broad-to-narrow flat area (interdentium) are located on the upper (dorsal) point of the inside shell. The hinge, lateral, and pseudocardinal teeth help with holding the valves securely together and are significant taxonomic features in many species (Miller and Nelson 1983). In the Anodontinae family, they are rudimentary or non-existent. The umbonal cavity is a shallow or deep depression located ventral to the interdentium and pseudocardinal teeth. A variety of ligaments and muscles are attached to the shell, which assist in opening and closing the valves. The hinge ligament normally keeps the valves slightly open, however, the foot and siphons can be withdrawn, allowing the shell to close tightly if needed. The large posterior and anterior adductor muscles draw the shell together; the smaller anterior and posterior retractor muscles draw the foot into the shell. Ligaments and muscles leave diagnostic scars after the animal dies.

Generally, fast-growing species devote proportionately less energy to shell production than the slower growing species, which have thicker shells. Thin-shelled species thus allocate greater amount of energy toward growth and reproduction than thick-shelled species (McMahon 1991). Miller and Nelson (1983) observed that, because of their stronger teeth and muscles, the heavier, thick-shelled species can withstand drying conditions and other perturbations better than the thin-shelled species. Species in medium to large rivers or those living in swift currents in small streams develop thicker shells and a heavier type of hinge teeth and have deeper muscle scars (Parmalle 1967) than species typically found in ponds, lakes, or quiet waters.

Locomotion Organs

Primarily sedentary, North American freshwater bivalves use a highly muscular and flexible foot for movement, burrowing, or anchoring into the substrate or between rock crevices. Many juvenile bivalves crawl a considerable distance before they locate a suitable habitat and settle. The capacity for movement is reduced in adults, although it still occurs, particularly if water levels drop. Some species move several feet per hour, creating an elongated troughlike track or furrow, which is observable on sandy bottoms where wave action is minimal. Crawling is accomplished by extending the foot, anchoring its tip with mucus or with a muscular attachment, and then contracting foot muscles that pull the body forward, similar to the movement of an inch-worm. A similar series of contractions and expansions of muscles in and around the foot, combined with opening and closing the valves, enables the animal to burrow. As the valves open and close, they expel water. This burst of water loosens sediments and thereby assists with additional contractions of the muscle, which pulls the shell farther into the substratum. The burrowing cycle is then repeated. Mussels usually burrow into the substrate to a depth where the shell margin is just beneath the sediment, so that only the siphons are exposed above the sediment surface.

Feeding, Digestion, and Assimilation

Hornbach (1996) found that there is surprisingly little information about feeding habits in unionid bivalves. Tankersley and Dimock (1992, 1993a, 1993b) were cited as providing the most thorough overview of feeding mechanisms. Most freshwater mussels are suspension feeders, filtering unicellular algae, bacteria, and suspended detrital particles from the pallial water flow across the gill. In general, mussels use their branched gills as feeding organs to remove small suspended food particles from the water. Water is brought in by the inhalant siphon and expelled by the exhalent siphon. When water enters the mantle cavity by the inhalant siphon, it is brought to the gills by ciliary action. Water then moves through water tubes located in the gills where gas exchange takes place (oxygen is removed from the water in the gills). Microorganisms and organic particles suspended in the water are captured by the gills. Food is then carried on cillarly tracts from the gills to the palps, sorted, and moved to the mouth and finally to the stomach (Parmalee 1967). Food particles that are released into the stomach may either be passed on through or returned to the stomach for further breakdown. Mucus secreted by the gills traps the non-food particles that are then moved along with food particles by cilia to the palps. The palps sort inorganic debris and food particles. Inorganic materials and particles that are too large or harmful are carried by ciliary tracts back out toward the gills and ejected through the inhalant siphon (Hornbach 1996). Egested material is lined with a mucous coating (this prevents recirculation) and is expelled through the exhalent siphon as pseudofeces (McMahon 1991).

Temperature, food concentrations, food particle size, and body size greatly influence feeding rates (Hornbach 1996). Suspended silt in the water column can inhibit filtering and consumption rates in mussels, perhaps by overwhelming ciliary filtering and sorting mechanisms, which uses energy that would otherwise be available for normal biological functions. Thus, a high silt load can eliminate mussels from certain habitats (McMahon 1991). Hornbach (1996) cites various studies that revealed a reduced feeding rate in mussels exposed to intermittently high concentrations of suspended solids, which translates into reduced growth and vigor. Because suspended solids can greatly repress feeding rates, streambank stabilization upstream of mussel beds is an important conservation measure.

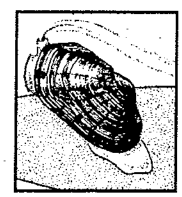

Figure 3. Male freshwater mussel releasing sperm into surrounding water. Drawing courtesy of the James Ford Bell Museum, University of Minnesota, Minneapolis.

Nervous System and Sense Organs

The head of bivalves is entirely enclosed inside the valves, has no direct contact with the external environment, and consists only of the mouth opening and attachment points of the labial palps. An assortment of nerve chords control movement of adductor muscles and coordinate foot and valve movements. Tissues that are most directly exposed to the external environment compensate for the enclosure and reduction of head sense organs by containing developed sensory organs. On the mantle edge and siphons are a variety of sense organs.

Photoreceptor cells (not eyes) detect changes in light intensity associated with shadows reflexes, diurnal rhythms, and animal movements. Other sense organs detect vibrations in the water or direct touch. On the siphon margins, these type of sense organs prevent large particles from being drawn into the mantle cavity. Stronger stimuli cause the valves to close rapidly, which forces water to be ejected from the siphons. Under intense stimulation of the mantle or siphons, the siphons are withdrawn and valves close tightly. This is a common predator defense in all freshwater bivalve species. Receptors on the foot assist with body orientation, positioning, and burrowing.

Reproduction and Life History

North American unionaceans have an extraordinary life history and reproductive adaptations. An important feature of their life history is the unique (and complex) larval need for a fish host to enable metamorphosis from the larval stage to the juvenile stage. All North American unionaceans have larvae (glochidia) that must attach and encyst, generally on the gills, of a species-specific host(s) to complete their life cycle. The reproductive cycle in unionids is fairly well documented. Once settled, the young begin to rapidly develop their shells, particularly in the first 4 years of growth.

The primary stimulus for reproduction seems to be temperature (McMahon 1991). When the ambient temperature rises above a critical level or falls in critical limits, gamete production and fertilization begin. Other environmental cues that may affect reproduction include density-dependent factors, diurnal rhythms, and parasites (McMahon 1991). In freshwater species, sperm is released by the males into surrounding water (Fig. 3), is carried by currents, and is taken in by the inhalant siphon of other individuals in the area.

During filtering, when the females take sperm in through the inhalant siphon, eggs are released into chambers in the gills. The sperm is carried to the unfertilized eggs that are retained in the gill marsupia. The eggs are fertilized and retained in either all four gills, in only the outer gills, or in only specialized parts of the gills that are used as brood chambers, depending on the species (Hornbach 1996). All North American freshwater bivalves brood embryos through the early development stages in the gill chambers (McMahon 1991). The size, location, and structure of the brood chamber vary in each family and in the genus and is a useful taxonomic tool. Unionids have been divided into two major groups based on how they brood their young. Species that are long-term brooders (bradytictic) retain their larvae overwinter (Hornbach 1996). Short-term brooders (tachytictic) release their glochidia shortly after fertilization and development; females are gravid during the summer. Glochidia in most species are present in the spring; some in mid to late summer (the zebra mussel, a non-native freshwater bivalve, releases both sperm and eggs into the water column, leading to external fertilization and development.).

Gravid female mussels release the bivalved glochidia either individually from their marsupial gills or as clusters (conglutinates) through the excurrent aperture (siphon). The glochidia of all unionids, except the salamander mussel (*Simpsonaias ambigua*), use fishes as hosts, but the intensity of the parasitization is typically low.

Released glochidia display snapping behavior, opening and shutting their valves, which seems to be stimulated by the presence of mucus, blood, gill tissue, or fins (McMahon 1991) and suggests the use of chemical cues. Glochidia initially attach to hosts by clasping fins, scales, or gill filaments of the fish with their valves. At this stage, the attachment of the glochidia does not seem to be host-specific; attachment is to any fish with which contact happens (McMahon 1991). However, if the glochidia attaches to an unsuitable host, the fish rejects the glochidia, sloughing them off after encystment (McMahon 1991). Once attached, glochidia encyst in host tissues in 2-36 hours of attachment and begin to grow. They remain attached for varying periods of time. Hornbach (1996) observed a range of 10-90 days in two species of *Villosa*, endemic to the southeastern United States. Whether the glochidia are true parasites on fishes has not been determined. In some species of mussels, the glochidia do not grow while encysted, although metamorphosis into a juvenile mussel does take place. Findings suggest that host suitability is more dependent on fish immunity mechanisms than on glochidial host recognition (McMahon 1991; Hornbach 1996). It is this host fish relation that makes the life cycle of mussels so unique, interesting, and perhaps fragile. Glochidia must attach to the correct host before metamorphosing into a juvenile. Without the proper fish host, the glochidia die.

Despite the tremendous fecundity of females, few glochidia come into contact with suitable hosts during this critical stage in the life cycle. The probability of contact between glochidia and host(s) is low, promoted by the respiratory and feeding behaviors of fish and the behavioral characteristics of some mussel species (McMahon 1991). To increase the probability of contact by glochidia with the proper fish host,

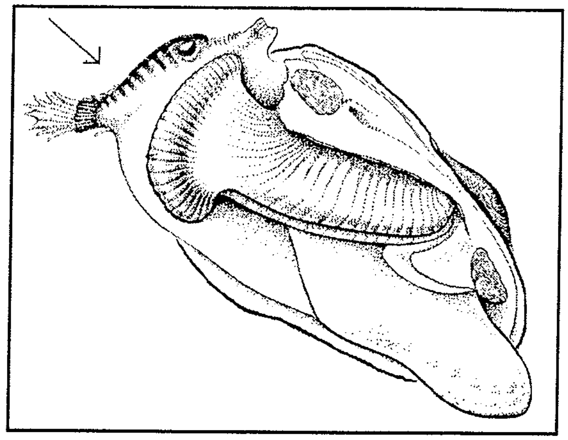

Figure 4. The mantle extrudes beyond the edge of the shell (upper left corner). When it flaps in the current, the extruding flap looks like a tiny fish and attracts host fishes. When a larger fish strikes this lure, the mussel closes its shell and squirts a stream of glochidia into the fish's mouth (James Ford Bell Museum of Natural History; drawing by Don Luce).

Table 2. Life history traits of freshwater bivalves (unionids), the Asiatic clam (Corbicula spp.),and the zebra mussel (Dreissenia polymorpha; McMahon 1991).

Trait	Unionids	*Corbicula* spp.	*Dreissena* spp.
Life Span	<6 >100 years species dependent	1-5 years	4-7 years
Age at maturity	6-12 years	0.25-0.75 years	1-2 years
Number of young per adult	200,000-17,000,000	3-136	30,000-40,000
Survivorship (juvenile)	low	high	low
Reproductive efforts per year	1	1-3	1

unionids display several adaptations. For example, although glochidial release occurs once a year, the duration of the release is species dependent. Tachytictic mussels (summer breeders) are short-term breeders, whose glochidial development and release take place between April and August, which corresponds with either migratory periods of anadromous fish hosts or the reproductive and nesting periods of host fish species. Bradytictic unionacean species (winter breeders) retain the developing glochidia in gill marsupia throughout the year and release them in the summer (McMahon 1991).

Some mussel species produce larvae that are hooked (e.g., members of the subfamily Anodontinae) that allow them to hook on or attach to the external surfaces of the fish host by the continuous snapping behavior. Hookless larvae (e.g., members of the Ambleminae and Lampsilinae families) tend to become encapsulated by tissue on the fish's gills (Hornbach 1996) when they are released by the feeding behavior of the fish. When the glochidia are shed from adult mussels, they are generally bound together by mucous into small packets, which either dissolve or are maintained intact as glochidial conglutinates of various species-specific colors and forms. Often, the threads of conglutinates are suspended in the water and resemble the food items of their fish hosts. The colorful movement, i.e., waving in the current, attracts a fish host. When the fish consumes the conglutinate, it releases the glochidia inside the fish where they can be carried directly onto attachment sites by respiratory currents. Lampsilid species have the most unusual form of host food mimicry. The females have colored extensions of their mantle edges (flaps), which resemble the fish prey of piscivorous fish hosts, including a darkened eyespot (Fig. 4). In this genus, gravid females periodically pulsate their mantle flaps to imitate swimming fishes. This deliberate action lures in the prey fish and, when the mantle flaps are snatched, glochidia are released into the fish's mouth, thereby ensuring glochidial contact with the fish host (McMahon 1991; Hornbach 1996). Conglutinates of other species are often found attached to macrophytes or rocks and are consumed by bottom feeding fish, which discharges the glochidia.

Species reach sexual maturity at various ages (between 3 and 9 years; Table 2). Headwater populations, which may have shorter lifespans than riverine populations, may sexually mature earlier (Hornbach 1996). Unionids are very prolific, producing from 200,000 to 17,000,000 glochidia/female/season (McMahon 1991), which serves to maximize the potential of correct host fish attachment. Early survivorship is low, which is not unusual for a species in a stable habitat. The primary advantage of the host fish relation is disbursement of the glochidia into favorable habitats and attainment of energy resources to complete the development from the glochidial stage to the settled juvenile. Adult mussel survivorship is high, and mussels tend to be long-lived.

In the early 1900s, many researchers attempted to determine the relation between mussels and fish hosts; many determinations were based on the examination of natural infections (Hornbach 1996). More recent findings indicated that field identifications are not reliable (identify potential hosts but not actual hosts), and thus these early determinations of host-mussel relations are questionable. A great deal of work is needed on the relation between fish host and unionid dispersal. More recent studies proved promising, particularly those involving molecular genetic techniques. Neves and Widlak (1988) intimated that mussel species from the subfamily Ambleminae are most often associated with fish of the family Cyprinidae (carps and minnows), whereas fishes from the families Cottidae (sculpins), Centrachidae (sunfishes), and Percidae (perches) more often serve as hosts for mussels from the subfamily Lampsilinae.

Host fish have been identified with various degrees of certainty for 33 genera and about 65 species of mussels (McMahon 1991). Host-specificity is particularly evident among the short-term brooders that release glochidia or conglutinates in summer. Fish host species are not known for about 16 of the 49 genera of mussels. Fuller (1974) and Watters (1994) produced lists based on literature searches of many host fish mussel species relations.

While encysted, larvae metamorphose and begin to resemble young adults. Juvenile mussels detach from the cysts and drop to the bottom of the stream or lake after metamorphosis is complete. Once settled, they begin their independent life. Successful settlement of juveniles seems to be particularly affected by human-induced disturbances. A disturbance-induced lack of juvenile recruitment can increase the composition of many North American mussel populations to that of a slowly declining group of adults destined for extirpation as pollution and other disturbances prevents juvenile recruitment (McMahon 1991).

Extended life spans, delayed maturity, low effective fecundities, reduced powers of dispersal, high habitat selectivity, poor juvenile survival, and very long turnover times render unionaceans highly susceptible to human disturbances. Mussels do not recover rapidly when decimated by pollution or other habitat disturbances, which contributes to their rapid declines (McMahon 1991) as habitat loss, pollution, and other environmental changes increase.

Environmental Physiology

Seasonal Cycles

Physiological responses associated with temperature and reproductive cycles have been observed in freshwater mussels (McMahon 1991). The metabolic rate in freshwater mussels is generally greatest in summer because of the effects of temperature (McMahon 1991), which has implications for the timing of mussel relocation and other activities that may stress the animal. Similarly, oxygen consumption rates are higher in the summer. Reproduction seems to require a massive use of energy stores. McMahon (1991) also reports that mussels contain minimum levels of biomass during the spring-summer glochidial release and build to higher levels during winter, which not only supports reproductive development during the following spring but prolongs survival during lengthy events of ice cover.

Diurnal Cycles

Activity in many species tends to be greatest during darkness. These activity rhythms may correlate with diurnal feeding and vertical migration cycles: individuals coming to the surface to feed at night and retreating below during the day to avoid predators (further research is needed; McMahon 1991). Chemical pollutants and suspended solids impair metabolic activity by interfering with respiratory, feeding, and reproduction.

Distribution and Habitat

The distribution of North American freshwater bivalves has been well described in McMahon (1991). Generally, North American unionacean species have a somewhat restricted distribution; few species range on both sides of the continental divide and many are limited to single drainage systems (McMahon 1991). Mussels are principally distributed throughout the Mississippi River drainage and river systems in eastern North America. Regions of endemism and species richness are primarily in the southeastern United States, including the Ohio, Tennessee, Cumberland, and Mobile drainages and other rivers to the Gulf of Mexico and South Atlantic (Neves 1993). Freshwater bivalve distribution is also related to stream size or order. The number of unionacean species in drainage systems is not, however, related to drainage area size—other environmental variables that may effect species richness include surface geology and soil porosity, water flow stability, high oxygen concentrations, and reduced silt loading. However, some species are well adapted to small, variable flow streams, where other species would be excluded (McMahon 1991). Unionaceans depend primarily on host fish transport of glochidium for dispersal, thus their ranges reflect those of their specific glochidial fish host(s). Although host fish transport increases the probability of dispersal of the glochidia into favorable habitats because host fish and adult unionacean habitat preferences generally closely coincide, it greatly limits the extent of dispersal, leading to development of highly endemic species (McManhon 1991). Therefore, barriers to fish dispersal are also barriers to unionid dispersal.

At the macrohabitat level, factors such as fish species diversity, geological formation, and hydrodynamic variability are important in predicting species richness and diversity (Hornbach 1996). Most species prefer shallow water habitats of generally less than 4-10 m in depth. Microhabitat factors that affect species richness (substrate, water velocity, water quantity, and quality) are discussed below.

Table 3. Water quality parameters that influence mussel distribution (from Hornbach 1996).

Parameter	Minimum or lethal levels	Concentration	Comments
Temperature			Temperature effects are mediated by humidity and low water levels.
Oxygen	Minimum level	3 mg/L	
Nitrogen	Lethal level	>0.6 mg NH3/L	Nitrogen as ammonia may be toxic; nitrate and nitrite effects are unknown.
Alkalinity	Minimum level	15 mg/L	Indirect influence on Ca availability.

Substrate and water velocity: Different species require different types of substrates, and substrate stability is essential for maintaining mussel populations (Hornbach 1996). Well-oxygenated, coarse sand and sand-gravel beds are optimal habitats for riverine species. Low or variable velocities allow silt accumulations that either make sediments too soft for maintenance of proper position or interfere with filter feeding and gas exchange. Conversely, periodic scouring of substrata exposed to high flow velocities can remove substrate and mussels and prevent successful resettlement (McMahon 1991). At smaller spatial scales (in mussel beds for instance), substrate differences are not useful predictors. Generally, fine substrates are inhabited by anodontines with thin shells, and others are associated with courser substrates or even in spaces between large boulders (e.g., the Spectacle Case [*Cumberlandia monodonta*]). Unionaceans are most successful where water velocities are low enough to allow sediment stability but high enough to prevent excessive siltation (McMahon 1991). Water level variation can affect distributions. Declining water levels during droughts or dry periods expose relatively immotile bivalves for weeks or months to the air. Some species are adapted to withstand prolonged emersion, wheras others are emersion-intolerant (McMahon 1991). Hornbach (1996) found that, in the St. Croix river, available habitat, substrate type, desiccation, and ice-scour were influenced by stream flow and currents.

Water quality: Most water quality parameters that may influence (limit) mussel distribution include dissolved oxygen, suspended solids, ammonia, calcium, and pH (Table 3). In addition, toxic compounds such as heavy metals, pesticides and herbicides, nitrogen, phosphorus, and trace metals can affect mussels. Unionaceans cannot maintain normal rates of oxygen uptake under severely hypoxic conditions. Thus, they are mostly restricted to shallow, well-oxygenated habitats (McMahon 1991). Fuller (1974) summarized the minimum level of required nutrients and the lethal limits of other chemicals for unionids.

Ambient pH does not greatly limit the distribution of mussels. Most species prefer alkaline waters with a pH above 7.0. Species diversity declines in more acidic habitats, although unionids can reproduce and grow over a pH range of 5.6-8.3. A pH of less than 4.7 is the absolute lower limit (McMahon 1991). Habitats of low pH generally also have low calcium concentrations. Low pH leads to shell dissolution and eventual mortality in older individuals if the shell is penetrated. Because many factors affect shell deposition and dissolution rates (e.g., temperature, pH, and calcium concentrations), the minimal calcium concentration or pH tolerated by a species may vary greatly between habitats, depending on interacting factors (McMahon 1991). Mussel species have specific upper and lower temperature limits for survival and reproduction.

Ecological Importance of Mussels

The continental United States has the world's most diverse mussel fauna, and in the last 100 years, this fauna has suffered a greater decline than any other wide-ranging faunal group. Because mussels have an important function in aquatic ecosystems, the ramifications are far-reaching. Bivalves, being filter feeders, act as water clarifiers and organic nutrient sinks. Because unionids filter suspended organic detritus and bacteria and consume interstitial bacteria and organic detritus in the sediments, they may also be significant aquatic decomposers (McMahon 1991). Unionids are more highly efficient at converting consumed and assimilated food energy into new tissue than most secondary trophic level aquatic animals because their sessile filtering feeding habits minimize energy for food acquisition, allowing for more efficient transfer of energy from primary production to bivalve predation. Therefore, bivalves can act as important conduits of energy fixed by photosynthesis in phytoplankton to higher trophic levels in the ecosystem. As previously noted, mussels are reliable indicators of water pollution and are a food source for many aquatic and terrestrial animals.

Threats

The abundance of freshwater mussels has been declining for 100 years, beginning in the late 1800s (Williams and Neves 1995), because of various habitat disturbances. Efforts to reverse the adverse effects with restoration, changed practices to avoid impacts, and education of communities in the value of healthy rivers and streams can help with the recovery of mussel species. Research, inventory and monitoring, and restoration also are crucial.

Aquatic Habitat Loss

Dams, dredging, channelization, and pollution (siltation and contaminates associated with construction, agriculture, mining, and forestry practices) have significantly modified or destroyed habitat. Silt impairs feeding and respiration. Excessive amounts of silt deposits, particularly associated with dams, smother mussels. Silt can reduce light penetration, which diminishes the abundance of an important food for mussels—algae. The evidence that impoundments are detrimental to mussels is overwhelming and indisputable (Muir et al. 1997). Silt, tailwater habitat alterations, fluctuating water levels, and barriers to fish movement are adverse effects of dams. Altered flow regimes from dams and reservoirs behind dams have caused the extirpation of 30%-60% of the native mussel species in selected rivers (Williams and Neves 1995). Reservoir construction and hydrologic changes in rivers such as the upper Mississippi, upper Ohio, Tennessee, and Cumberland rivers have been particularly disruptive to big-river mussel species (Neves 1993).

Increased water turbulence from large watercraft (tugs, paddleboats, barges) causes changes in habitat and may affect mussels in navigation channels (Muir et al. 1997) by stirring up bottom sediments and increasing the amount of suspended particles.

Organic enrichment, low dissolved oxygen levels, and other nutrients from municipal point sources or poor agricultural practices can also harm mussels and their habitats. Improper land-use practices (road and parking lot construction near streams with inadequate or un-maintained erosion control devices). Removal of riparian vegetation can destabilize stream bottoms and eliminate mussels and other benthic organisms. Contaminants such as heavy metals, pesticides, oil and gas drilling, and contaminated (acid) mine spoils can have serious implications for unionids

Research on the physical destruction of single mussels from crushing (machinery, boats, livestock crossings) is limited. Where livestock, such as cattle or horses have access to waterways, crushed mussels and deformed individuals are common. People who drag canoes across riffles and other shallow waters probably cause direct harm, although further investigations are needed for documentation (Muir et al. 1997).

Metal contaminants of principle concern in aquatic environments are zinc, copper, lead, mercury, cadium, nickel, arsenic, and chromium (Muir et. al. 1997). When present in concentrations that exceed biological need or storage capacity, several toxic responses are elicited. Unfortunately, water quality criteria established by the U. S. Environmental Protection Agency are based on toxicity data that involved virtually no information about unionid mussel sensitivity (Williams et. al. 1994). Industrial sewage, urban wastewater effluent (silts, sediments, sewage), and pesticides are other forms of water pollution that harm bivalves.

Excessive and Illegal Harvests

Shells were collected for the button industry until the 1950s, when plastics replaced the need for pearl. After a short lag, commercial harvesting began to accelerate again in the 1960s with the development of a mechanism that facilitates the punching of small beads from select shells by the cultured pearl industry. Shells have now become a valuable raw material for the cultured pearl industry. Shells collected in the United States are sorted and culled. Then beads are punched from desirable shells, transported overseas, and placed inside oysters to form a pearl. The nuclei of all cultured pearls in the world today are from these beads. Since the development and success of this technique, new markets are emerging today in Australia, China, Indonesia, and the United States. Many states regulate the harvest of mussels by limiting the species, size, and age of the mussels and the time of the harvest. Because the type of restrictions vary by state, it is advisable to contact the appropriate resource conservation agency before harvesting mussels.

Coinciding with the emergence of the new markets is an increase in poaching. With minimal effort over a few days of work, a poacher can net $30,000; some poachers have earned as much as $100,000 in as few as 9 months (Thomas Healy, U. S. Fish & Wildlife Service Special Agent, personal communication). Because commercial harvest laws vary by state, the apprehension of traffickers is

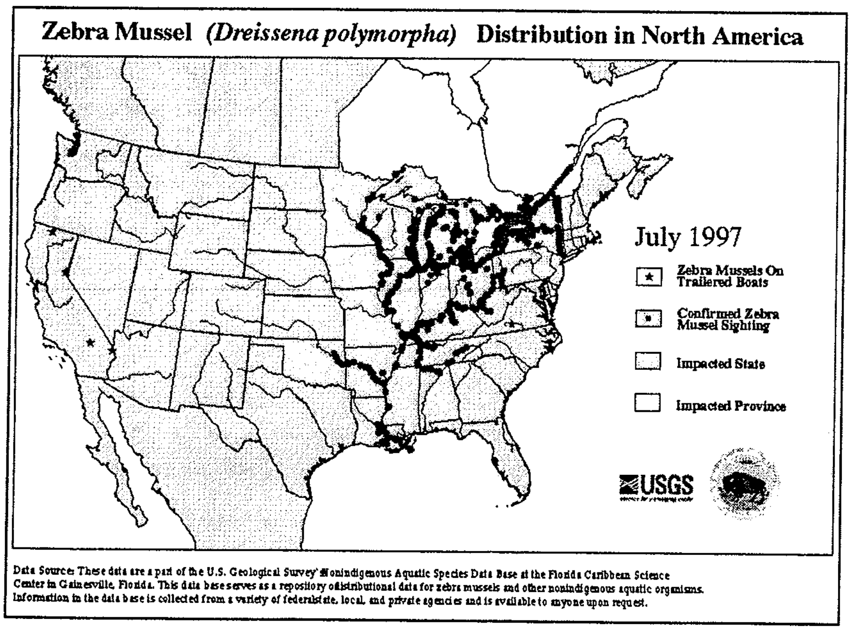

Figure 7. Distribution of the exotic zebra mussel in North America. Photograph courtesy of the U.S. Geological Survey.

often difficult. Poaching is seriously depleting native mussel beds in Alabama, Arkansas, Kentucky, Ohio, Tennessee, and elsewhere. Many endangered and threatened species are poached.

Mussel poachers have a history of arrests, including felonies, and should be considered dangerous. All observations should be reported to the proper law enforcement agency or staff.

Traits of Vulnerability

The decline, extirpation, or extinction of numerous taxa can be attributed to ecological and biological traits that are particularly vulnerable to anthropogenic effects (Neves 1993). As previously discussed, the life cycle of unionids contains a larval (glochiduim) stage that is an obligate parasite of fishes. As a consequence, mussels, particularly those with specific fish hosts, are susceptible to reproductive failure because of a lack of fish host availability. The sensitivity of glochidia and host fishes to polluted water, altered temperature regimes below impoundment's, and the chance encounter between glochidia and fish host can lead to a loss of recruitment in some years (Neves 1993). The fish faunas of many rivers have changed drastically as a result of dams (which block upstream and downstream migrations), introductions of exotics, management that favors certain species, channelization, snag removal, and permanent changes in the chemical and physical environment. Factors that reduce the survival of the glochidium or decrease the abundance and species composition of the fish fauna are probably harmful to the dependent mussel populations.

Exotic Species

The Asian clam *(Corbicula fluminea)*, which was introduced on the West Coast in the 1930s, has invaded nearly every watershed in the United States. Experimental evidence of effects by the Asiatic clam on native mussels is weak, although Williams and Neves (1995) reported adverse effects on some native bivalves. Introductions can be avoided by not taking water from one river to another (e.g., in bait buckets, by boats).

The zebra mussel (*Dreissenia polymorpha;* Appendix C) is an exotic mollusk that is threatening the environmental health of freshwater lakes and rivers in the United States. Adult zebra mussels are characterized by a semi-D shape, bivalved shell with light and dark brown or black banding (stripes) and a length of no more than 5 cm (2 inches). Adult zebra mussels reach reproductive maturity in 1 year (shell lengths at this stage are greater than 8 mm [0.3 inches]; Claudi and Mackie 1994) and begin spawning when the water temperature is 14-20°C (57-68°F).

The rapid dispersal of the zebra mussel is attributed in part to its high reproductive rate and its planktonic larval stage that, unlike that of native freshwater mollusks, does not require a host fish for development and maturation.

Because they do not need a host fish, zebra mussels adapt to new bodies of water, irrespective of local fish assemblages. Flowing waters carry the veligers downstream and thereby further the range expansion of the mussel.

Distribution of the species from infested to non-infested waters is accelerated by commercial and recreational vessels because the adult and juvenile mussels have the ability to attach themselves to hard surfaces, including boat hulls and boating equipment. This ability to attach to hard surfaces has exacted burdensome economic and ecological tolls.

Researchers predict that the invasion of zebra mussels will reduce the native mussel species in the Mississippi River basin by 50% in the decade. Because native mussels have an important role in nutrient cycling and sediment mixing, the accelerated decline of freshwater mussels could seriously affect the ecology of affected river systems.

Challenges: Tools for Recovery

Of the 297 North American species of native freshwater mussels, nearly one quarter occur in National Park System units. At least 15 park units in the eastern United States have been identified as providing habitat for diverse (20 or more species) or rare mussel assemblages.

The traditional methods of conservation (setting aside areas for protection) do not work on rivers. Neves (1993) found that of the 119 river reaches (15,000 km) designated as wild and scenic rivers, only a few (less than 1,600 km) are east of the Mississippi River where the hot-spots of mussel diversity are (Neves 1993; Dobson et al. 1997). Several protected waterways that are included in the National Park System are hot-spots for mussel diversity (e.g., the St. Croix, Namekagon, Green, and Big South Fork rivers and the C&O Canal).

The preservation of big-river habitats and their fauna is a great challenge. However, several initiatives and avenues are available to meet this challenge. Simply understanding the threats, knowing the resource, and developing partnerships can be powerful means to effect preservation. Establishing protective conditions for mussels in the permit review process (Section 404 of the Clean Water Act, 33 U.S.C. 1251-1376, ch. 758, Stat. 1155) can provide long-term protection. Conversely, errors in underestimating the harm from projects or effluents can be irreconcilable for rare mussel species (Neves 1993). The selection of appropriate management requires knowledge of species abundance, distribution, and status in the watershed. Similarly, known risks and threats should be identified.

Partnerships in compatible development can help in addressing nutrient management, pollution, and other concerns. Conservation tillage has been used to grow crops while reducing soil erosion by as much as 70% (The Nature Conservancy 1996b). Sedimentation from cattle operations can be mitigated by the construction of cattle stream crossings and streambank fences. Streambanks can be revegetated by working with Soil and Water Conservation districts, local botanical groups, and university extension services. Establishing and maintaining partnerships with local school groups, environmental groups, agricultural agencies, and water quality assessment programs can provide powerful (and rewarding) means for the long-term conservation of mussels in parks. In the Fish Creek watershed of northeastern Indiana and Ohio and in the Clinch River watershed of Tennessee and Virginia, projects are underway to protect endangered mussels through the cooperation of federal, state, and local agencies and local businesses and farmers. More than 31,000 tons of top soil/year have thus been kept out of the creeks and more than 1220 m (4,000 feet) of fence have been constructed to protect the vulnerable streambanks (The Nature Conservancy 1996b). Several opportunities for partnerships with federal, state, and local land management agencies are available.

Recommendations

Recommendations for the protection, conservation and restoration of mussel resources include:

- Inventories that include distribution, abundance, species richness, and habitat data on mussels and their host or potential host fishes.

- Inclusion of host fish species management in the development and implementation of fisheries management plans.

- Protection of important mussel habitats from direct and indirect impact.

- Evaluation of the influences of external activities and habitat alterations on aquatic resources (water quality, fisheries, and mussels) and development of impact assessments.

- Development of watershed management plans with local communities, state agricultural agencies, the Natural Resource Conservation Service, and other entities that include pesticide and best management practices (BMP's) to reduce soil erosion, nutrient loading, and other forms of water pollution.

- Implementation of integrated pest management to reduce or eliminate pesticide use.

- Restoration of unstable stream banks with native vegetation .

- Establishment of buffer zones for various land use practices adjacent to rivers and streams.

- Prevention of the spread of zebra mussels and other aquatic nuisance species by preventing the transfer of water or live baits between bodies of water; inspecting boat hulls, motors, and equipment at public landings where appropriate.

- Education of local communities about the value of freshwater mussels and their role in the ecosystem; involve the general public, conservation organizations, and private entities in conservation efforts.

Relocation and Restoration

Relocations of mussels from one site to another have been practiced as conservation and management by state and federal agencies for several decades. Mussels are relocated to replace populations eliminated by prior pollution; to remove mussels from road, bridge, dredge or other construction zones when the construction zone can not be moved; and to provide a refugia for populations of endangered or threatened species. Relocation has also been recently practiced to protect native unionid communities from the effects of zebra mussel infestations. However, the effectiveness of relocation has not been assessed or documented. Cope and Waller (1995) in their review of the literature found little guidance about relocation (handling methods, transport, tagging, time of year to relocate, aerial exposure, water temperature, and replacement). Protocols and other guidance for moving mussels are just now being developed. Furthermore, most projects were monitored for only 1-2 years after the relocation. Habitat requirements and the biological responses to removal, handling, transporting, and relocating must be further investigated and monitored on a long-term basis to measure the success of relocations (Cope and Waller, 1995). A 5-year monitoring cycle is recommended to document recruitment (Cope and Waller, 1995). Prior to any project that may affect streambanks or aquatic habitats, mussel surveys should be conducted if surveys have not been conducted. Relocating proposed project sites (instead of relocating mussels) should be pursued when possible. Placement of sediment barriers and relocation of mussels with provisions for long-term monitoring for survival and recruitment are recommended conditions for permits if the proposed project location cannot be changed.

The U.S. Fish & Wildlife Service operates several national fish hatcheries that are involved in mussel conservation and fisheries, including the development of captive breeding populations for the artificial propagation of mussels for temporary refugia. Mussel culture and rearing are also underway at some hatcheries, which may provide assistance to NPS units involved in restoration. However, as Neves (1993:8) eloquently stated, "the power of humans to degrade the natural world is awesome; the capability to reconstitute it later is mythical," and one must first seek to protect and preserve rather than rely on relocation and restoration as mitigation.

Necessary Research

Information about mussels in National Park System units is limited. Implementation of many management options recommended in this report requires information about populations (abundance, distribution, population structure, host fish availability, habitats, and threats). In some units, these data may be available from surveys by state resource management agencies, the National Water Quality Assessment Program, or the U.S. Fish & Wildlife Service. In other units, specific studies may be required to obtain this information. National research priorities, goals, and strategies for implementation of that research are outlined in the national strategy for the conservation of freshwater mussels (Biggins et al. 1997).

Interagency Coordination

Cooperation and collaboration with federal, state, and local governments is critical to the long-term sustainability and recovery of unionids in parks. This poses particular difficulties for parks with limited jurisdictional boundaries. Often, park waters are the bottom of watersheds and therefore bear the cumulative effects of upstream landuse. To carry out such broad recovery requires an unparalleled level of cooperation and coordination of private, state, and federal agencies.

Several implemented or drafted memoranda of understanding are intended to protect aquatic resources (e.g., memoranda of understanding between the seven departments for the protection of endangered species; draft memoranda of understanding by the Department of the Interior and the U.S. Department of Agriculture for mussel protection). Federal and non-profit funding initiatives that involve the protection and conservation of freshwater aquatic resources can provide valuable assistance with research, monitoring, restoration, and education on mussels (e.g., American Zoo and Aquarium Association, National Strategy for the Conservation of Freshwater Mussels, Species at Risk Initiative, Ohio River Valley Ecosystem Mollusk Subgroup, Upper Mississippi Resource Conservation Committee).

The Native Plant Initiative of the National Park Service continues to provide a useful vehicle for restoring eroded streambanks and lands in the watershed while promoting the use of native plant species for rehabilitation. The U. S. Environmental Protection Agency and The Nature Conservancy likewise have recently developed partnerships for water quality protection and habitat restoration that will also benefit mussels.

Public Education

Mussels are a relatively unknown natural resource. The development of educational outreach materials has been identified in the national strategy for the conservation of freshwater mussels. Interpretation and education in the National Park System are already considered to be important for resource preservation and management. Interpretive programs that emphasize the unique life history of mussels (host fish relation), their importance to water quality, and their ability to serve as an early warning system of degradation of water quality may help to improve public understanding of the need for conservation of these species. With names such as the *white cat's paw*, *purple wartyback*, *monkeyface*, *fat mucket*, and the *Carolina heelsplitter*, freshwater pearly mussels can easily elicit interest.

Interpretive programs about mussel conservation must extend beyond the traditional park boundaries. Park-sponsored events such as *River's Are Alive* field trips, National Fishing Week, and similar conservation programs must recognize mussel protection, water quality, and watershed management as important interpretive themes. A variety of educational outreach resources are now available (traveling trunks, videos, educational posters, and school curricula) through the Freshwater Mollusk Conservation Society.

Increased public support will be essential for the conservation of riverine ecosystems. Failure could result in a "a waterfall of extirpations and extinctions of invertebrates" (Neves 1993: 2) including the nation's rich mussel heritage. Such a loss would be a marked environmental tragedy for the twenty-first century .

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Appendix D. Glossary

The glossary includes terms not mentioned in the guide. Such terms are provided to assist readers with text in reference materials.

Acephalous Headless Poorly defined in mussels.

Adductor muscles Large muscles attached to each valve at the anterior and posterior end of a bivalve shell. Their contractions bring the two valves together and close the shell.

Adductor muscle scar Largest of the nacreous impressions on the interior portion of the shell, forming the attachment of the muscles that close the valve.

Ala (Alate) Thin, flat, wing-like extensions (dorsal) of the shell above the hinge line. Usually an extension of the posterior slope but can occur anteriorly.

Amblemine mussels Mussels in the Amblemine Family. Tend to be short-term breeders. Most reproductive activity is restricted to summer and glochidia are releases shortly after fertilization and development. Tend also to exhibit a great deal of host fish specificity, predominately on cyprinid fishes.

Annular Made of rings.

Anterior end The shorter end of the shell as measured from the umbo (beak); also considered the front end.

Arcuate Arched, bowed.

Beak Shell knob on hinged end of valve. The raised part of the dorsal margin of the shell, also called the umbo. Oldest part of the valve.

Beak cavity A depression or cavity on the inside of each valve that extends into the beak, usually under the pseudocardinal teeth.

Beak sculpture The raised loops, ridges, or bumps on the beak or umbo. Surface relief on the disc.

Bivalve Having two shells (or valves) that are bound together by a ligament, which allows them to gape open. Of the Class Bivalvia, in the Phylum Mollusca, in which freshwater bivalve molluscs are included.

Bradytictic Winter breeders; having eggs, embryos, or maturing glochidia carried through winter into spring.

Branchial The lower or ventral siphon. Used to take in food particles and oxygen and to release fertilized eggs. [See inhalent siphon].

Brood chambers The water tubes of the gill(s) where the fertilized eggs develop in the female. Depending on the species, either all four gills, only the outer gills, or specialized parts of the gills are used for this purpose.

Byssiferous Attached by a byssus as in some Unios.

Byssal thread or byssus (plural Byssuses or byssi) Tuft of fibers secreted from a gland in juvenile mussels. Allows attachment to the substrate, thereby anchoring the mussel and preventing it from being swept off by currents. In *Dreissends*, the adults maintain their byssal threads, which allows them to attach to hard substrates (rocks, shells, boats, docks, etc.). Produced by byssal glands.

Calcareous Composed of carbonate of lime.

Cardinal teeth Elevations on the hinge plate of one valve that interlocks with corresponding elevations or depressions on the opposing valve; NOT found in unionids, which have pseudocardinal teeth.

Carinate Keeled. Having a sharp projection at the periphery.

Caruncle Specialized structure on the mantle margin.

Cheveron A "V" shaped marking.

Cilium (plural Cilia) A hairlike extension from the cell surface and capable of rhythmic movement. Used to designate the hairs on the mantle, gills, etc.

Clam A type of mollusk; includes freshwater and marine animals. Have equal shells closed by adducter muscles of equal size.

Clavate Club-shaped.

Conglutinates Gelatinous material enclosing packets of glochidia. Vary in size, shape, and color. May appear as elongated, muscleangeous strands. Conglutinates are often attached to macrophytes of rocks and are consumed by bottom-feeding fishes.

Corbiculidae Non-native bivalve family of asciatic clams.

Cyprinid Fish family of minnows and carp.

Diaphragm The partition between the branchial and anal openings, i.e., between the inhalent and exhalent siphons.

Dioecious Having separate sexes (male and female) for sexual reproduction.

Disc The part of the valve bordered by the beak, posterior ridge, anterior ridge, and ventral margins.

Distal Away from the center of origin, the farthest part from an object.

Dorsal Referring to the top part of the shell where the hinge is located. The back; in niads the edge with the ligament or hinge. Opposite of the siphons.

Dreissenidae A group of mussels belonging to the family *Dreissenidae*, which includes zebra mussels and quagga mussels. Adults have byssus threads. Not native to the United States. Found in fresh, brackish, and marine waters.

Encystment Fish tissue which surrounds the attached glochidia. *Excystment* occurs when the juvenile glochidia drop off the host fish. (See *glochidial cysts*).

Exhalent siphon Located ventral to the inhalant siphon; a fleshy fold of the mantle used to expel water and other waste particles. Also called excurrent siphon or anal opening.

Fecundity Number of produced eggs; reproductive capability.

Filibranchiate Branched (filaments) gills with cilia. Mussels are filibranchiates.

Fluted Where the posterior margin is corrugated, the corrugations open onto the margin of the shell.

Fluviatile Living in running streams.

Foot A large flexable, muscular organ. The contraction and expansion of the organ is used in burrowing, locomotion, and for anchoring the mussel into substrate.

Gelatinous Like jelly. As in glochidia.

Glochidium (plural Glochidea) Microscopic larval stage of the mussels life cycle, brooded in gill marsupia of freshwater unionid mussels. Released en-mass by the female mussel into the water. Develop as an external parasite on a fish (or sometimes an amphibian) after the female mussel releases it into the water. The larval form of a before metamorphosis into a juvinile mussel. Shaped like the adults with two valves, however, the internal structure is different from that of an adult mussel. Two primary types: Hookless glochidia attach to the gill filaments of fishes, and hooked glochidia attach to the fins or scales. The third type is the axe-headed glochidia that have a flaired valve margin.

Glochidial cysts Formed by tissue of the host fish and surrounds the glochidium after attachement to the fish. Glochidia encyst in host tissues in 2-36 hours of attachment and may or may not grow during encystment, depending on the species. [See encystment]

Gills Large sheet-like organs which play a dual role in respiration and feeding. The gills have a mucous lining and are covered by cilia. The cillia help to circulate water and capture food particles. Cillary tracts move the food to the palps, which surround the mouth. Fertilized eggs are also retained in the gills fo the female while they develop into glochidia.

Gravid Pregnant. Mussel marsupium containing eggs/glochidea.

Growth lines Darkened lines on the surface of the shell indicating periods of rest. Used to age mussels, much like tree growth rings.

Haemolymph Molluscan blood.

Hinge The elastic part of the shell that unites the valves along the top of the shell. (Also hinge ligament; see Ligament).

Hinge plate The dorsal portion of the shell bearing the lateral and pseudocardinal teeth.

Hypostracum The layer of the shell that touches the animal; next to the muscular mantle layer.

Inhalant siphon A fleshy fold of the mantle at the posterior end, used to take in water that provides oxygen and food particles to the animal. Mature glochidia are released via this siphon as well. Also serves as reproductive function when sperm from the male is taken in with the water. Also called the *incurrent* or *brachial siphon.*

Inflated Swollen or expanded shell morphology.

Inner laminae The inner gill.

Interdentum Flattened area between the pseudocardinal and lateral teeth.

Juveniles Settled stage. Glochidia that metamorphosed. During this stage, they drop off of their fish host (excystment) and settle when suitable habitat is presented. The time from juvenile metamorhposis and excystment is species-dependent, ranging from 6 to160 days.

Lateral teeth The elongated teeth along the hinge of the shell, posterior articulating surfaces (see Teeth).

Lampsiline mussels Mussels in the Lampsiline family. This family tends to consist of long-term breeders that reproduce year round.

Larvae Any prejuvenile stage.

Left valve Left valve of the shell when the dorsal edge or hinge is facing up and the anterior end is directed forward (away).

Ligament Tissue that joins the right and left valves.

Malacology The study of mollusks (clams and snails) based on soft anatomy.

Mantle A sheet of soft tissue that surrounds the mussel's body and lines the inner surface of the shell. Secretes the materials that form the inner surface of a mussel shell. Outermost part of the animal; secretes the hypostracum and the shell at the edges and produces the periostracum.

Mantle flap Large, often colorful, fish-like structure on the postbasal mantle margin of species in the genus Lampsilis.

Margaritiferidae One of the freshwater mussel families of the Superfamily Unionacea.

Marsupium An expanded section of the gill that forms a brood pouch (chamber), containing glochidia. Structured to protect mussel eggs and to incubate glochidia. Not all species have this.

Metamorphosis A change in form exhibited by some animals in their development; in a mussel, the change from glochidium to the adult niad.

Mollusks A group of invertebrates that have shells (excluding land slugs). Includes bivalves (two shells) and snails (have single, coiled shell). Mussels, clams, oysters, cuttlefish, octopi, snails, and slugs of the phylum: Mollusca. Two native freshwater bivalves families: Sphaeriidae (fingernail clams) and Unionidae (pearly mussels). In freshwater, includes bivalves and snails.

Mussel Any bivalve mollusk that produces a byssus (e.g., *Mytelidae* and *Dreissenidae* families), but also includes all large freshwater bivalves of the family *Unionidae* that do not produce a byssus in adult life, although the glochidia of many species in the Unionidae family do produce byssal threads.

Nacre The interior layer of the shell, usually white, pink, salmon, or purple and iridescent.

Nacreous Pearly or iridescent nacre as the interior of some Unios.

Naiad The common name used for freshwater mussels of the Superfamily Unionacea. A freshwater bivalve or Unionid. Often called a *mussel.* Adult unionids lack proteinaceous threads used to attach to substrates (excluding zebra mussels, which are native to the Black Sea area). Origin: In Greek mythology, nymphs were lesser divinities or spirits of nature, dwelling in groves and fountains, forests, meadows, streams, and the sea. Nymphs were distinguished according to the part of nature they personified. The naiads were nymphs of brooks, springs, and fountains. They were gifted in music and also thought to have healing and prophetic powers (Microsoft 1997).

Palps (plural palpi) Ciliated structures that surround the mouth. Food is sorted here and moved toward the mouth. Suitable particles that have been received from the gills are taken into the mouth and digested. Non-suitable food is rejected, falls on the mantle tissue, and is transported from the inhalent siphon.

Papilla (plural Papillae) Tentacle-like structure on the mantle margin; small finger-like projections around the incurrent and excurrent siphons. Often branched like a feather or a tree.

Pearly mussel Any freshwater mussel or clam that produces mother-of-pearl or a nacre. Use is restricted to unionids and byssate bivalves in freshwater.

Periostracum The outside layer or covering of the shell.

Pinnate Branched like a feather as the gills of some mollusks.

Postbasal Area where the ventral (basal) and posterior margins of a mussel meet.

Posterior end The longer end of the shell as measured from the umbo; the back end; the end with the siphons, usually sticks above the substrate.

Posterior ridge The ridge on the back half of the valve running from the umbo to the posterior ventral ridge. A ridge emanating from the beak area and extending posteriorly.

Posterior slope Area of a valve bordered by the posterior ridge and dorsal and posterior margins.

Pseudocardinal teeth Triangular, often serrated teeth on the anterior-dorsal part of the shell. False cardinal teeth.

Pseudofeces Non injested particles that are too large or noxious to injest and are ejected from the inhalent siphon.

Pustules A bump or raised knob on the outside surface of the shell. Any pimple-like or blister-like swelling or elevation.

Ray A liniar mark typical on the periostracum of some unionids; may be continuous or interrupted.

Right valve Right half of the shell when the dorsal edge or hinge is facing up and the anterior end is directed forward (away).

Sculpture The natural markings on the surface of many freshwater mussels; includes knobs, pustules, undulations, etc.

Shell Hard outer covering of the mussel, composed of proteinaceous and crystalline calcium carbonate elements. During winter, growth slows or stops and rings of darkened lines or ridges form on the outside of the shell that can be counted to estimate the age of the mussel.

Shell Dimensions Length: Greatest horizontal dimension; Height: Greatest vertical dimension measured at a right angle to the length exclusive of the umbo and alae. Width: Greatest lateral dimension measured when both valves are closed.

Simple Unmodified: e.g., a simple postbasal mantle margin has no specialized structures (papillae, caruncle, mantle flap).

Sulcus Shallow depression, furrow, or channel on the disc.

Tachytictic Summer breeders; includes species whose females are gravid during summer.

Teeth The elevations or depressions on the hinge line of one valve that interlock with the corresponding structures on the opposite valve; in the Unionacea, the anterior articulating surfaces are the pseudocardinal teeth and the posterior surfaces are the lateral teeth.

Tubercle A pointed, rounded, or shelf-like projection from the outer shell surface. Rounded knob.

Umbo Inflated dorsal part of the shell, beak.

Unionacea The superfamily of bivalve mollusks to that most freshwater mussels belong. Common name: Niad. With one exception, all American unionaceans have glochidia that parasitize fishes.

Unionid Common name of a freshwater bivalve in the Family Unionidae. Also called freshwater pearly mussel, niad, or unio.

Unionidae One of the freshwater mussel families of the genus *Unionacea.* Unios. Found in freshwater lakes, streams, and ponds.

Valve One of two opposing parts of the hard shell. Mussels and clams are bivalved.

Veliger Larval stage of bivalves with a ciliated swimming structure (velum). Pre-settled stage. Used most often to describe zebra mussel larvae.

Ventral On niads, the bottom edge of the shell.

Volvocoid bodies Packets of sperm released by male species of mussels.

Wing A thin, flat projection extending dorsally from the posterior slope of some freshwater mussels [see Alate].