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An Introduction to Freshwater Mussels as Biological Indicators

Including Accounts of Interior Basin, Cumberlandian, and Atlantic Slope Species




EPA-260-R-08-015
November 2008

An Introduction to Freshwater Mussels as Biological Indicators

Including Accounts of Interior Basin, Cumberlandian, and Atlantic Slope Species

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Printed on chlorine free 100% recycled paper with
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Funding was provided by the U.S. Environmental Protection Agency under Contract # 68-C-04-006, Work Assignment #4-79 with the Great Lakes Environmental Center, Inc.

The appropriate citation for this report is:
Grabarkiewicz, J. and W. Davis. 2008. An introduction to freshwater mussels as biological indicators. EPA-260-R-08-015. U.S. Environmental Protection Agency, Office of Environmental Information, Washington, DC.

The entire document can be downloaded from:
http://www.epa.gov/bioindicators/html/publications.html

Acknowledgements

We would like to thank the many individuals who provided manuscripts and papers for our review and reference. Thanks also to the University of Michigan Museum of Zoology and the Ohio State Museum of Biological Diversity for providing access to their collections. Last, but certainly not least, thank you to the reviewers who took the time to look over this document, including Dr. Tom Augspurger, Dr. Chris Barnhart, Dr. Arthur Bogan, Dr. Hans Gottgens, Edward Hammer, Tina Hendon, Dr. Teresa Newton, Dr. Brenda Rashleigh, Brett Rodstrom, and John Tetzloff.

Contents

Contents (con't)

*Taxonomic Note: To simplify the taxonomy of this guide, all names follow Turgeon et al. (1998). However, we recognize that this may not represent the most current taxonomic scheme.

FIGURES

Photographs

Photographs (con't)

All photographs by Jeff Grabarkiewicz and Todd Crail

Introduction

While marine environments harbor the delicate beauty of the seahorse, coral reef, and anemone, North American freshwater streams and lakes support a splendor all their own. Freshwater mussels, also called pearly mussels, naiads, or clams, are a diverse group of creatures that are both unassuming and inconspicuous. Most will not confound passersby with oddities or evoke awe-inspired gasps from onlookers. In fact, many spend a good deal of their life partially or wholly buried in stream sediments, detectable to only the most astute observer. Yet, despite their mild manner and cryptic nature, evolution has bestowed a great variety of these creatures on the North American continent. And we should consider ourselves fortunate! Not only do these mussels possess a unique elegance and beauty, but they also exhibit a dizzying array of adaptations and life history strategies.

As a group, freshwater mussels are differentiated from other bivalves by their unique life cycle. This life cycle includes a parasitic larval stage that requires, in most cases, a fish host to complete. Adult mussels can measure up to ten inches in length and, under certain conditions, live more than 100 years (Bauer 1987; Cummings and Mayer 1992).

From an economic perspective, mussels have been valued for their beauty, shell material, and natural pearls for centuries. Unfortunately, this has also led to the overharvesting of mussel resources. For example, during the mid-1800s, freshwater mussels were commonly collected by people seeking fortune in the form of freshwater pearls. Following a valuable discovery, successive collecting often led to the wholesale destruction of entire mussel beds (Anthony and Downing 2001). The pearl button industry, founded during the late 1800s, provides another example of overharvesting leading to resource depletion. This industry created buttons from the durable shells of freshwater mussels. Thousands of tons of shells were harvested in Eastern North America from the late 1800s to the mid 1900s to fuel the button industry. Coker et al. (1921) eloquently observed “equal as they were to the vicissitudes of natural conditions, they were unable to withstand the unchecked ravages of commercial fishery”. Freshwater mussels continue to be an important economic and ecological resource (Anthony and Downing 2001, Pritchard 2001).

The primary purpose of this guide is to encourage the use of freshwater mussels for water quality assessment and to briefly review their use as biological indicators and biomonitors. This document is not intended as a “how to” manual or methods document, but as an educational tool. It was designed and written with a wide audience in mind, including academic institutions, natural resource managers, park naturalists, conservationists, monitoring groups, environmental managers, and interested citizens. Several topics will be examined in detail, including ecology, reproduction, indicator use, sensitivity to toxic contaminants, survey methodologies. In addition, species records are included with pictures to assist in identification and indicator usage.

Distribution and Conservation Status

Freshwater mussels (Bivalvia: Unionoida) are distributed nearly worldwide, inhabiting every continent on Earth except Antarctica. Approximately 780 species belonging to 140 genera have been identified, with species diversity maximized in the creeks, rivers, and lakes of North America (Graf and Cummings 2007). Globally, six families of freshwater mussels are known, although only two occur in North America - the Unionidae and Margaritiferidae. The Unionidae makeup the vast majority of the North American fauna. Overall, approximately 300 species of mussels are found in the U.S., with the highest species richness found in the Southeast (Fig. 1) (Neves et al. 1997).

Various unionoid faunal zones have been identified by malacologists during the past century (e.g. Simpson 1900; van der Schalie and van der Schalie 1950; Parmalee and Bogan 1998; Abell et al. 2000). This guide borrows from the interpretation introduced by Parmalee and Bogan (1998) (Fig. 2). Faunal regions are useful when attempting to describe the distribution patterns and evolutionary characteristics of freshwater mussels. For example, some faunal provinces represent areas of considerable endemism, such as the Ozarkian, Cumberlandian, and Mobile Basin. Within these regions, faunal "hotspots" occur that support unionoid species found nowhere else on Earth.

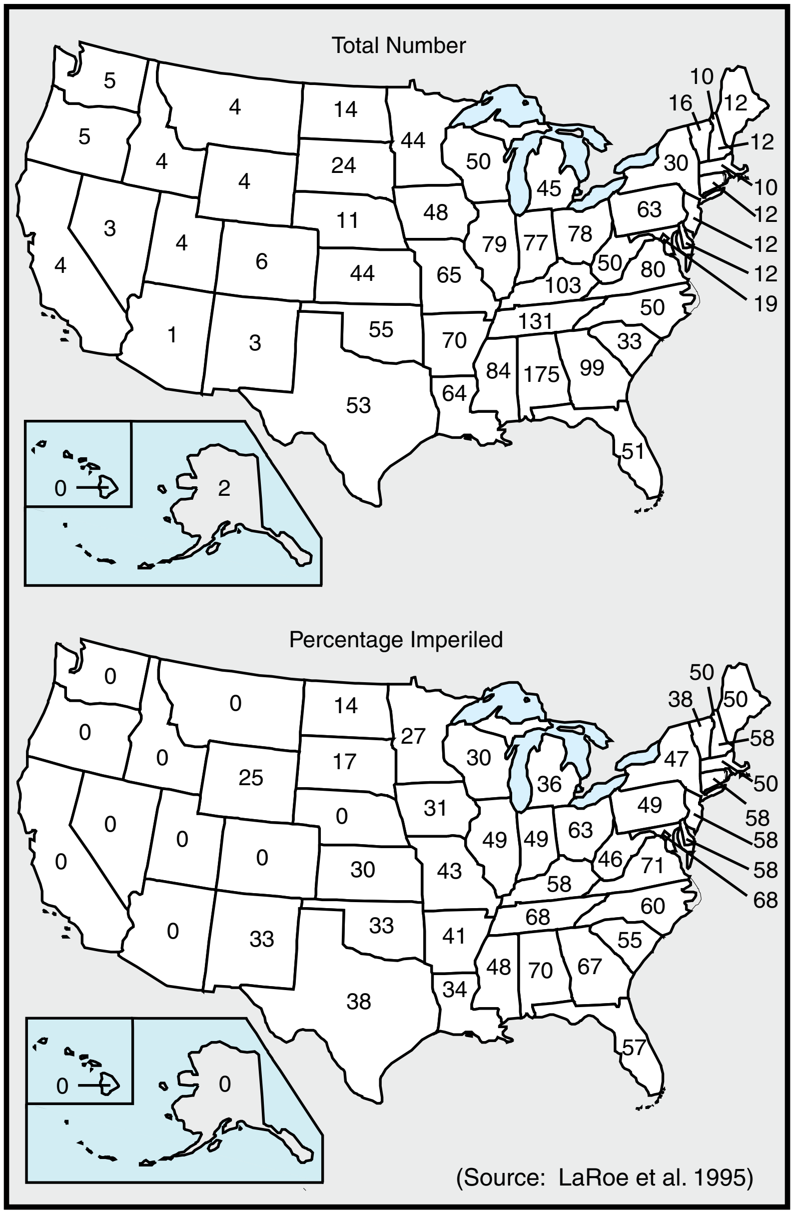


Figure 1: (Top) Total number of freshwater mussel species by state. (Bottom) Percentage of imperiled freshwater mussel species by state.

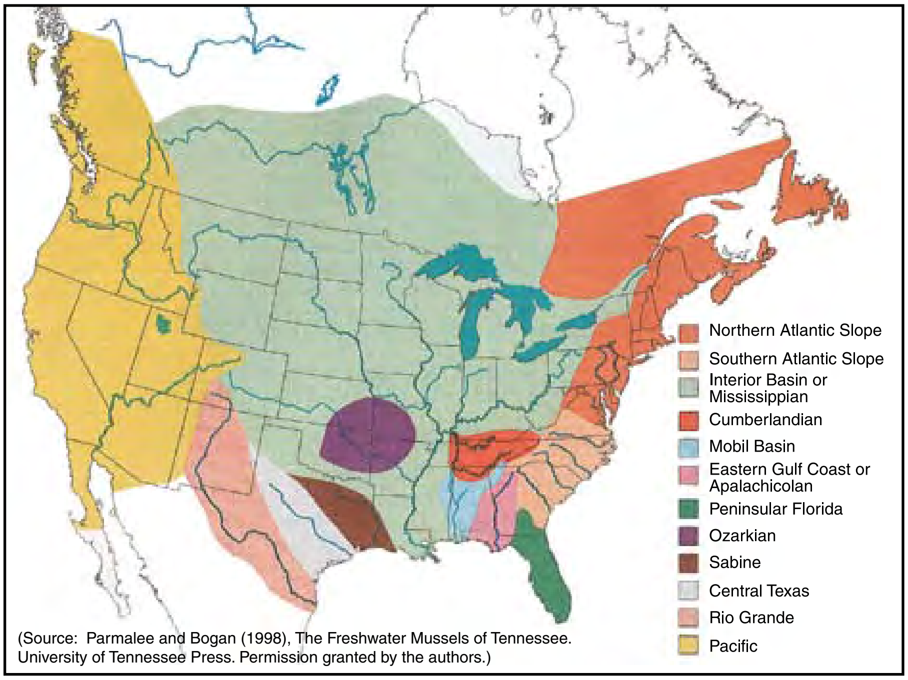


Figure 2: Freshwater mussel faunal provinces.

While historically highly diverse and abundant throughout a good portion of the U.S., unionoids are now one of the most imperiled groups nationwide (Fig. 3). Approximately 70% of the North American fauna is in various states of decline (Williams et al. 1993; Master et al. 2000; NatureServe 2008). Sadly, 37 species are now presumed extinct (Master et al. 2000). This decline is often attributed to habitat destruction, water quality degradation, damming, exotic species, and hydrologic changes (Williams et al. 1993; Strayer et al. 2004).

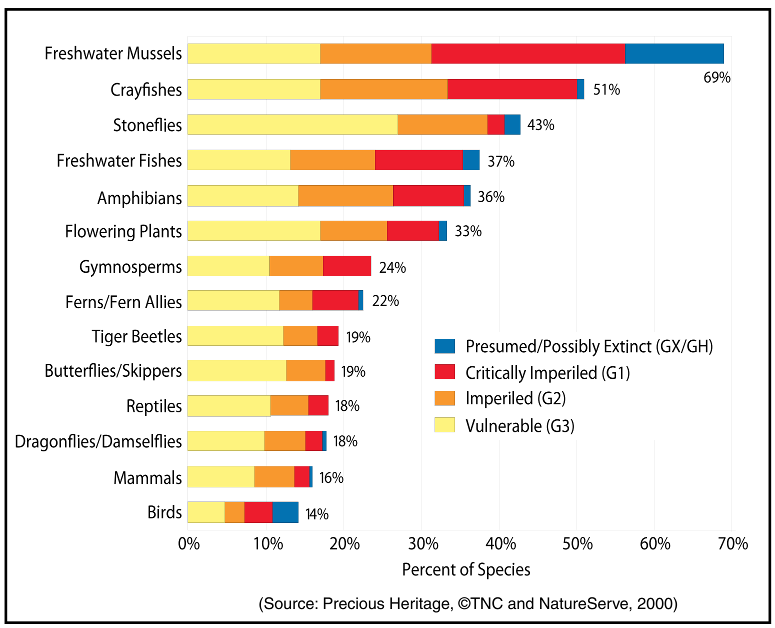


Figure 3: Proportion of species at risk by plant and animal group.

Freshwater Mussel Ecology

Freshwater mussels play a number of important roles in aquatic ecosystems. As sedentary suspension feeders, unionoids remove a variety of materials from the water column, including sediment, organic matter, bacteria, and phytoplankton. Siphoned material is either transferred to the mouth for digestion or sloughs off the gills and exits via the ventral margin of the shell (pseudofeces). Digested material is either used as fuel for various life processes or excreted as feces. The amount and rate of particulate matter removed from the water column and subsequent deposition of waste is largely dependent on temperature, particle concentration, flow regime, mussel size, and species (Vaughn and Hakenkamp 2001). While the siphoning activities of mussels are often overlooked, they provide an integral resource link between pelagic and benthic habitats (Nelepa et al. 1991; Howard and Cuffey 2006).

Mussels also interact with stream sediments. The burrowing behavior of unionids mixes sediment pore water, releasing nutrients and oxygenating substrates (Photo 1) (Vaughn and Hakenkamp 2001). Particularly dense assemblages of mussels may influence substrate stability and provide nutrients and microrefugia for benthic life (Vaughn and Hakenkamp 2001; Zimmerman and de Szalay 2007).

Juvenile mussels have demonstrated the ability to pedal feed by sweeping their foot to collect food particles from sediments. Studies conducted by Gatenby et al. (1996) documented the importance of sediments to the growth of juvenile Rainbow (*Villosa iris*). Researchers reported increased shell growth and survival rates when algal diets were supplemented with a fine sediment substratum.

Photo 1: A Kidneyshell (*Ptychobranchus fasciolaris*) repositioning in the substrate.

Freshwater mussels also provide food for a number of terrestrial and aquatic species. Raccoons, muskrats, otters, fishes, turtles, and birds all feed on mussels. The cracked valves and weathered remains of unionids often litter gravel bars and floodplains, a testament to the efficiency of terrestrial predators. The spent valves of freshwater mussels play a role in aquatic ecosystems as well. Shells provide habitat for a variety of life, including fish (Photo 2), periphyton (Photo 3), crustaceans, molluscs, and macroinvertebrates (Photo 4). Additionally, the weathering and eventual erosion of shell material recycles calcium carbonate back to aquatic ecosystems.

Photo 2: Small fishes, such as this Brindled Madtom (*Noturus miurus*), often take shelter in the spent shells of freshwater mussels (Photo: Threeridge shell).

Photo 3: The Spike (*Elliptio dilatata*) blanketed in periphyton.

Photo 4: Water pennies (*Psephenidae* sp.) grazing on a White Heelsplitter shell (*Lasmigona complanata complanata*).

Freshwater Mussel Reproduction

The reproductive characteristics and processes found among the Unionoidea are diverse, complex, and more than a little intriguing. As a group, they exhibit extraordinary variations in fecundity, brooding tendencies, host specificity, and "luring" techniques (Photo 5) (Watters 1995; Haag and Warren 1999; Haag and Staton 2003; Haag and Warren 2003).

While sexes are separate in most freshwater mussels, hermaphroditic species have been reported (van der Schalie 1970). The reproductive process is initiated when an upstream male releases sperm into the water column and a downstream female collects it via the incurrent aperture. Fertilization occurs internally, with embryo development ensuing within the marsupia (gill pouches) (Photo 6). The resulting larvae, termed "glochidia," are brooded by the female for a period of time ranging from a few weeks to several months. While some species use all four gills to brood (e.g. *Quadrula*), others use only the outer gills or specialized portions of the outer gills (e.g. *Lampsilis*). Once released, glochidia are, for the most part, obligate parasites that must find a suitable host or perish.

With few exceptions, freshwater mussels utilize freshwater and anadromous fishes as hosts. While some mussel species have proven capable of parasitizing a wide range of fish hosts, others are seemingly more specific. For example, laboratory host studies

Photos 5 and 6: (Top) The mantle flap lure of the Plain Pocketbook (*Lampsilis cardium*). (Bottom) The charged gills of the Plain Pocketbook (*Lampsilis cardium*).

suggest that the Giant Floater (*Pyganodon grandis*) may be capable of successfully transforming on nearly 40 species (Watters 1994; Watters 1995). Conversely, Layzer et al. (2003) exposed 18 species of fish (from six families) to the glochidia of the Cumberland Pigtoe (*Pleurobema gibberum*) and reported just two species as suitable hosts. Glochidia that successfully locate a host species attach to the fins, skin, or gills. Once attached, glochidia feed on host tissue and develop anatomical structures. After a period of time, the glochidia excyst and drop off into the substrate or attach to objects with byssal threads (Photo 7).

Photo 7: A 12 mm Rayed Bean (*Villosa fabalis*) attached to a small piece of gravel via byssal threads.

Freshwater mussels utilize a variety of structures and techniques to attract potential host species. For example, several members of the genus *Lampsilis* display a mantle flap lure (Photos 5 and 6) to entice various piscivorous hosts, including species such the Largemouth Bass, Rock Bass, and Black Crappie. When the mantle lure is struck by an unsuspecting fish, the female responds by expelling glochidia out of the excurrent siphon and infecting the potential host. The *Fusconaia* utilize a markedly different strategy, packaging glochidia in capsule-like cases termed “conglutinates.” After being ejected into the water column, the conglutinates are fed on by fishes, initiating glochidial attachment to the gills of potential host fishes. A few species have the ability to produce “superconglutinates,” gelatinous masses that are attached to the female mussel via a mucus cord. The minnow-like masses “swim” back and forth in the current, and are presumably preyed upon by species such as the Smallmouth Bass (Haag and Warren 1997).

Shell Morphology

In order to accurately identify freshwater mussels, some basic knowledge of shell morphology is required. While some species have distinctive features that allow for instant identification, others are much more cryptic. In addition, young mussels often vary significantly in shape, thickness, length, color, and inflation when compared to older individuals. To further complicate matters, the same species may vary in appearance from watershed to watershed, or even within the same watershed. Perhaps the easiest (and most efficient) way to become proficient with the identification of mussels is to visit an established collection. Many major universities maintain collections of mollusks that are open to researchers and interested naturalists by appointment. Additionally, numerous regional and state guides are now available at reasonable prices (e.g. Oesch 1984; Cummings and Mayer 1992; Parmalee and Bogan 1998; WDNR 2003).

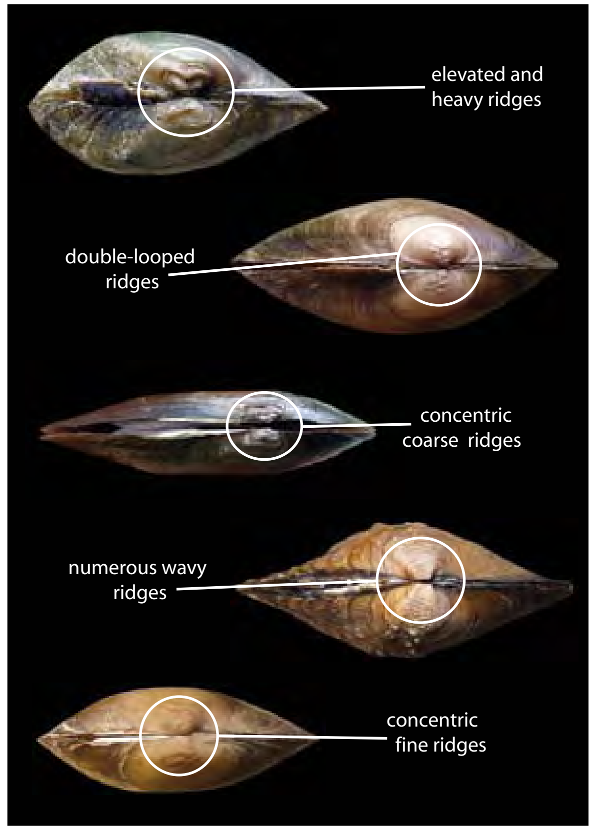


Figure 4: Various beak sculptures.

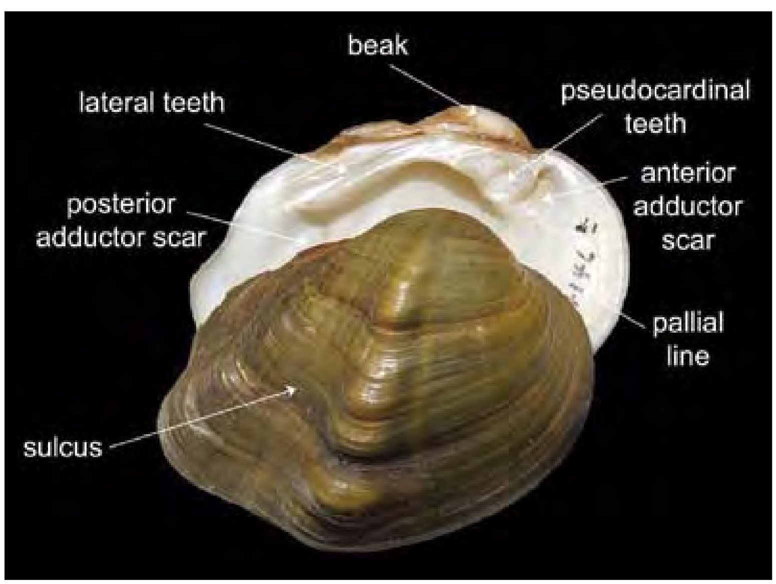


Figure 5: Basic shell anatomy.

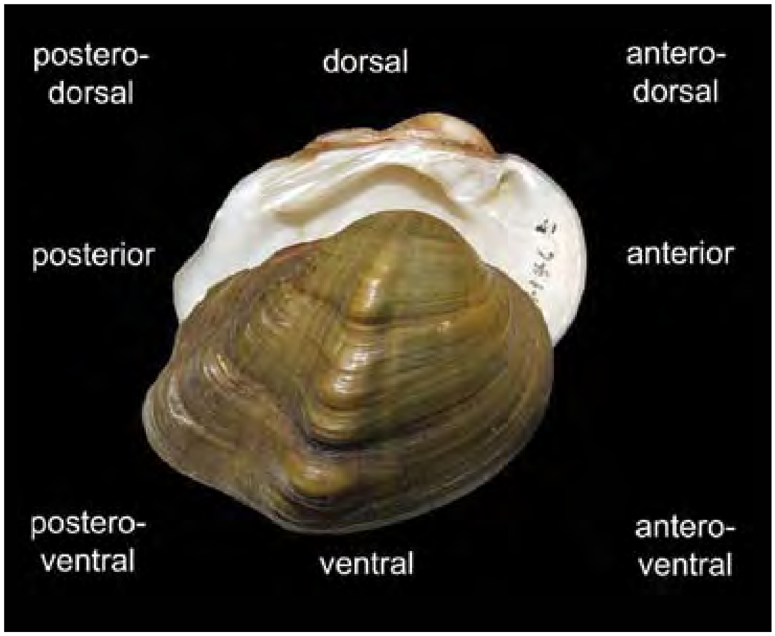


Figure 6: Basic shell orientation.

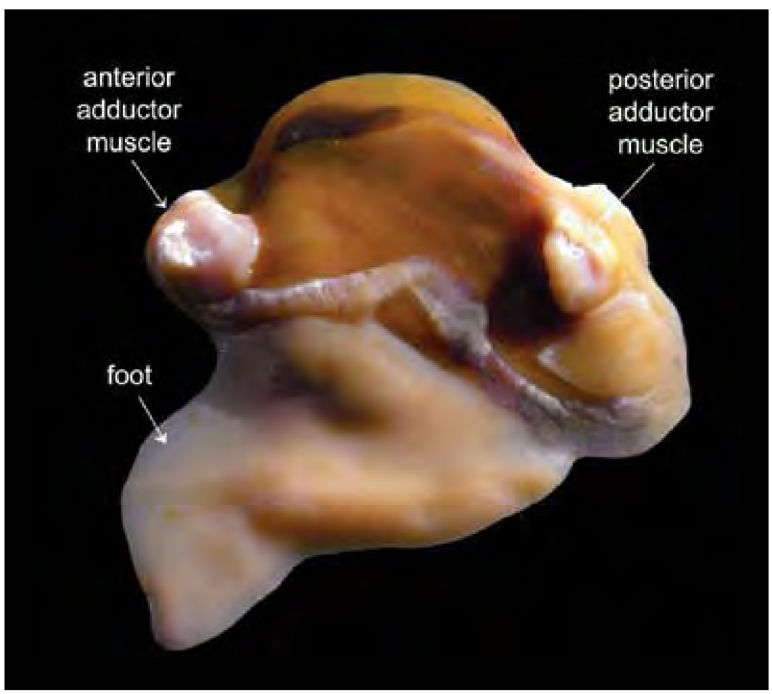


Figure 7: Inner soft tissue.

Photo 8: Clinch River, TN.

Sampling Freshwater Mussels

General Overview

Freshwater mussel sampling designs and techniques are largely dependent on the resources available, sampling conditions, survey objectives, and prior knowledge of the target population(s) (Strayer and Smith 2003). Surveys range from informal or qualitative timed searches to intensive, quantitative designs aimed at providing precise population estimates.

Photo 9: Sampling a small creek with a view-bucket and snorkeling gear.

Survey area size and water depth play an important role in determining sampling techniques. For example, small, shallow streams can often be effectively sampled with little more than a view-bucket or mask and snorkel (Photos 9 and 11). However, large streams, rivers, and lakes usually require SCUBA gear (Photo 10) or surface-supplied air (SSA) systems. Biologists and commercial divers utilize a widerange of SSA systems, some of which are intended for recreational purposes while others are designed for deepwater diving. Hookah compressors (recreational) are popular when surveying small streams where the water is clean and relatively shallow. Conversely, navigational channels often require the use of SCUBA gear or commercial SSA dive stations. Commercial dive stations usually permit divers to communicate with a topside dive supervisor as well as each other; thereby adding an extra degree of comfort and safety to dive operations. Commercial systems may also utilize a "hardhat," a helmet that completely encapsulates the head, protecting the ears and oral-

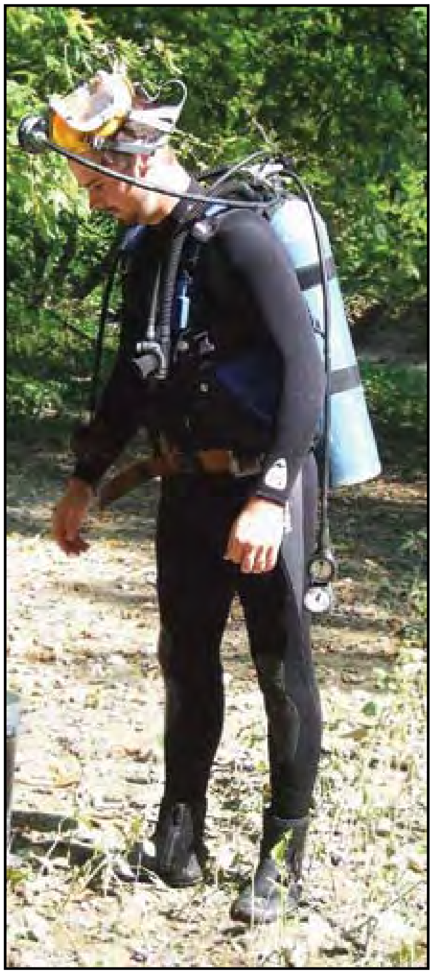


Photo 10: Typical diving gear used by biologists searching for mussels.

nasal passages from contact with the water column. This may be especially important when surveying in contaminated environments.

Photo 11: Mussel researcher utilizing an underwater viewer.

Sampling conditions and the habits of freshwater mussels can make them difficult to detect. Detection is usually related to substrate type, species, mussel length, instream vegetation, and observer proficiency (Smith et al. 2001a). Mussel investigators often use their hands to gently feel or disturb the substrate, a technique informally termed “noodling.” Noodling is effective when searching for young mussels or species that burrow deep into the substrate.

Photo 12: Researcher sorting mussels for identification and measurement.

Qualitative Searches

Qualitative searches are generally performed in a bounded area (such as 30m x 20m cell) for a finite amount of time. Time is often expressed in person-minutes or person-hours when multiple investigators survey the same area. Qualitative timed searches usually are designed to optimize species detection without expending the effort required to derive population estimates, calculate relative abundances, or detect statistically significant changes in mussel populations over time. As such, qualitative searches are generally more efficient for species detection than quadrat-based surveys where sediments are excavated (Obermeyer 1998; Smith et al. 2001a; 2001b; Smith 2006).

Example. Figure 8 provides a plan view example of a typical qualitative survey. In this study, a small area near a bridge is being surveyed qualitatively by two malacologists. The survey design partitions the study area into 15m x 20m sampling units, which are delineated onsite using a variety of markers. The investigators then survey each cell using snorkeling gear for 40 person-minutes, searching for mussels visually and tactually. Assuming a search efficiency of 1 m^2 /minute, an "effective sampling fraction" of 0.13 can be calculated (see Smith et al. 2001a). Essentially, the effective sampling fraction is defined as the percentage of the cell that is thoroughly searched for mussels, which is 13% in this example. To increase the amount of coverage in the study area, the cell dimensions could be altered or the survey time per cell increased.

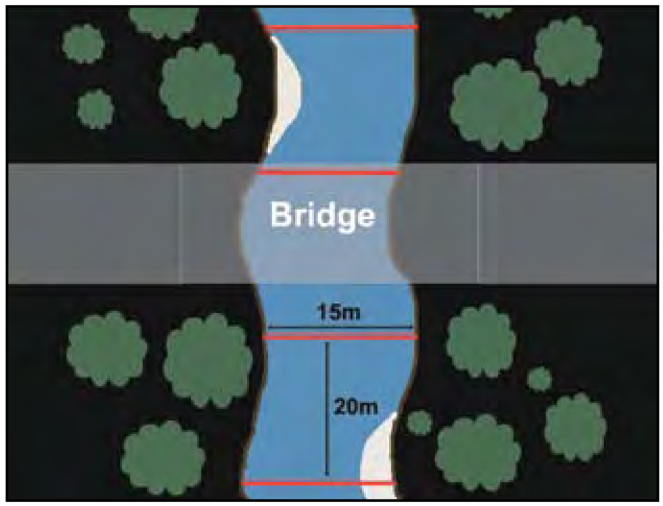


Figure 8: Hypothetical qualitative bridge survey.

Photo 13: Unionids collected during a qualitative survey.

Quantitative Studies

Quantitative studies are performed when population estimates are desired for a particular area or target population. Unlike qualitative sampling, a “comprehensive” sampling effort requiring excavation of each sampling unit (typically a 0.25 m^2 quadrat) is needed to ensure mussel detection. Such sampling efforts are usually time intensive and expensive due to the number of samples required and the need to excavate sediments. Smith (2006) found that excavation required 3 to 12x more time than surface counts. However, guidelines have been developed by Smith et al. (2001a; 2001b) to limit the amount of excavation required based on the traits of the target population.

A number of sampling strategies can be utilized independently or in combination to assess a study area, including random sampling, systematic sampling, double sampling, and adaptive cluster sampling. For a detailed explanation of probability-based sampling strategies, refer to Strayer and Smith (2003). Essentially, the goal of the survey designer is to take enough samples to achieve the desired amount of precision. Where the target population is abundant, less effort is generally required. Unfortunately, due to the patchy nature of unionoid populations (even within the limits of a mussel bed) and the low densities at which imperiled species often occur, a large number of samples is usually needed.

Example. The objective of a survey may be to estimate the population size of federal candidate Sheepnose (*Plethobasus cyphyus*) near a bridge site. From prior knowledge of the site, the designer anticipates finding Sheepnose at densities of 0.5/m^2. With these data and a few additional site attributes (e.g. survey area), the designer uses quantitative, systematic sampling techniques (Photos 14 and 15; Fig. 9) to collect an unbiased sample of the survey area. The number of quadrats required to achieve the desired amount of precision can be calculated using the methods presented in Smith et al. (2001a) or Strayer and Smith (2003).

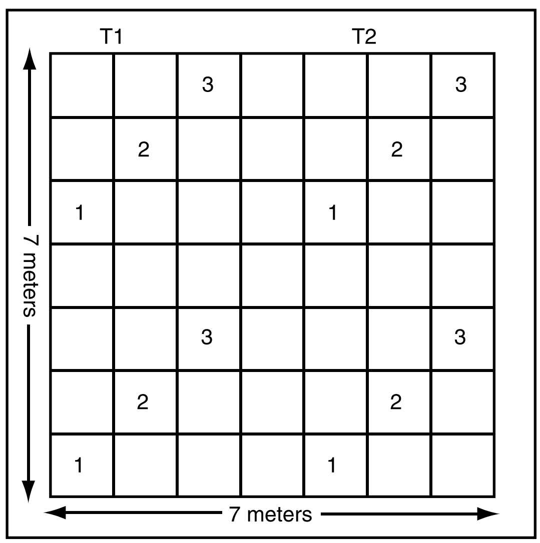


Figure 9: A systematic sampling design along 2 transects with 3 random starts (see Strayer and Smith 2003). Generally, 0.25 m^2 quadrats are used for quantitative work; 1 m^2 sampling units are used here for simplicity.

Photo 14 (left) and 15 (right): Excavating sediments within a 0.25 m^2 quadrat during a quantitative survey.

Big River Surveys - ORVET Protocol

Protocols have been developed by the Ohio River Valley Ecosystem Team (ORVET - Mollusk Subgroup) with the intent of providing a consistent and reliable approach to mussel survey activities in the Ohio River (ORVET 2004). This methodology has also been applied to large rivers throughout the Midwest and eastern United States. It is a simple, adaptable, qualitative method that that does not require quadrat-based sampling or sediment excavation. The following is a summary of ORVET (2004):

> *The protocol calls for 100 meter transects laid perpendicular to flow, spaced 100 meters apart. Buffer areas are added to the total survey area based on the type of planned disturbance or presence of federal species. Transects are divided into (10) 10 meter segments or "samples." A diver searches a 1 meter wide path over each sample (10 meter segment) for a minimum search time of 5 minutes. Mussels are bagged at the end of each 10 meter segment. This protocol assumes that the diver detects only 50% of the actual mussels present, therefore densities of 0.5/m^2 may actually equal 1.0/m^2.*

Example. Figure 10 provides a plan view example of a typical large river survey using the ORVET protocol. In this example, transects are laid according to protocol along the left bank of the river. Divers would then proceed to search each 10 meter segment for a minimum of 5 minutes. Mussels are usually identified on a boat by a qualified malacologist.

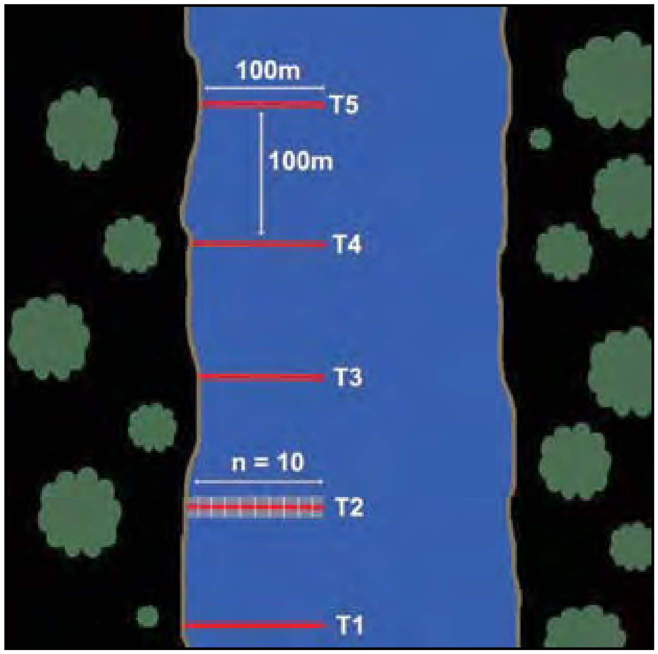


Figure 10: Hypothetical survey layout using the ORVET protocol.

Freshwater Mussels as Biological Indicators

Freshwater mussels possess several characteristics that make them suitable indicator organisms (Ortmann 1909; Wurtz 1956; Bedford et al. 1968; Simmons and Reed 1973; Imlay 1982; Neves 1993; Naimo 1995). These attributes allow individuals or assemblages to function as "environmental logbooks," effectively recording changes in water and habitat quality over time. North American unionoids have, in fact, been sounding the alarm for over the past century. What follows is a short list of qualities that support the use of mussels as bioindicators:

Unionoidean Attributes

1. Long-lived: some species may reach 70+ years.
2. Sedentary: juvenile and adult mussels move little during their entire lifetime.
3. Burrowers: some species and juveniles burrow deep into the streambed.
4. Filter feeders: mussels obtain food and oxygen from the water column and via interstitial flow.
5. Fairly large: mussels contain ample soft tissue for chemical analysis.
6. Spent valves: dead mussels leave a historical record.

Photo 16: The Green River, KY, home to 71 mussel species and 151 fish species.

Sensitivity to Environmental Perturbations

1. Unionoids demonstrate a gradient of tolerances to both chemical contaminants and physical alterations.
2. Exhibit sensitivity to habitat or watershed changes that alter flow regimes, reduce substrate stability, or cause siltation.
3. Vulnerable to periods of low dissolved oxygen.
4. Sensitive to exotic species invasions, such as the zebra mussel (*Dreissena polymorpha*).

Sampling and Monitoring

1. Unionoids are widespread throughout the United States, and are particularly speciose in the eastern United States.
2. Protocols have been developed to survey mussels, although sampling techniques have not been standardized.
3. Freshwater mussels are relatively easy to tag and monitor.

Biological Indicator
A numerical value(s) derived from actual measurements, has known statistical properties, and conveys useful information for environmental decision making. It can be a measure, an index of measures, or a model that characterizes an ecosystem or one of its critical components (USEPA 2007).

Biological Integrity
The capability of supporting and maintaining a balanced, integrated, adapted community of organisms having a species composition, diversity, and functional organization comparable to the natural habitats of the region (Karr and Dudley 1981).

Biomonitor
An organism that is sensitive to, or is capable of detecting, changes in the surrounding environment.

Indicator Organism
An organism whose characteristics are used to point out the presence or absence of environmental conditions which cannot be feasibly measured from other taxa or the environment as a whole (slightly modified from Landres et al. 1988).

Photo 17: The Shelbyville dam, Duck River, TN.

Tolerance to Habitat Alterations

From the sinking mud of turbid embayments to the sand and gravel of morainal streams, the Unionidae and Margaritiferidae can be found in a wide range of habitats throughout North America. Yet, despite the seemingly ubiquitous distribution of some species, the vast majority of freshwater mussels thrive in clear, oxygenated streams and rivers where the bed is comprised of sand, gravel, and cobble substrates.

Of the habitat alterations initiated by humans, the systematic damming of creeks and rivers has likely had the most profound effect on freshwater mussels (USFWS 1985a; Bogan 1993; Neves 1993; Yeager 1993). The alteration of shallow, flowing habitats to long, linear pools has drastically altered the physical, chemical, and biological characteristics of numerous North American rivers (Ellis 1942; Bates 1962; Coon et al. 1977; Yeager 1993; Hughes and Parmalee 1999). Impoundment not only reworks the depth and hydraulics of a river reach, but also prevents the migration of host fishes and may severely alter downstream water quality (Watters 1996c; Vaughn and Taylor 1999; Watters 2000). As a result, mussel species adapted to shallow, flowing rivers are now some of the most imperiled animals in the United States. The destruction of the *Epioblasma* (riffleshells), for example, has been largely attributed to the impoundment of small and large rivers (USFWS 1983b; USFWS 1985a; USFWS 2004). Nonetheless, diverse unionid assemblages have persisted under impounded conditions. For example, Haag and Warren (2006) recently documented a fairly diverse, recruiting unionid community in an impounded portion of the Little Tallahatchie River (MS) below Sardis Dam. However, it should be noted that the assemblage consisted of many species known to tolerate impoundment or lentic conditions.

Sedimentation is another process that may have harmful impacts on freshwater mussel communities. With the exception of some anodontines, the majority of North American unionoid mussels occur in coarse substrates and flowing water. Soft, cohesive substrates and suspended fine sediments are deleterious for most species and may affect respiration, feeding, and growth (Marking and Bills 1979).

Waterway modifications such as channelization and dredging homogenize habitat, alter flow regimes, and may increase streambed and bank shear stresses. The physical straightening and deepening of streams has been associated with the decimation of mussel communities and changes in faunal composition (Stansbery and Stein 1971; Watters 1988). In addition, stream "maintenance" is often a reoccurring event, as unstable streams "silt in" or develop various obstructions. Continuous channel maintenance may destabilize streams, resulting in shifting, unstable substrates, excessive erosion, and soft mid-channel bars.

While not frequently named as a primary contributor to the decline of mussels in North America, landscape alterations such as urbanization have been documented to reduce stream quality and alter macroinvertebrate communities (Stepenuck et al. 2002; Deacon et al. 2005). Watershed modifications that increase the volume and change the timing of stormwater runoff may initiate substrate instability, increase bank erosion, and promote the siltation of downstream habitats. Strayer (1999) found mussels to be correlated closely with areas of hydraulic stability, moreso than other habitat features such as depth and substrate size. While American cities and suburbs continue to expand, stable habitat will likely become increasingly rare to the detriment of freshwater mussel communities.

Indicators of Biological Integrity

Freshwater mussels are commonly labeled as "good" indicators of biological integrity and water quality by scientists. Despite this, there remains little guidance available for monitoring groups or agencies as to how to utilize unionoids in this capacity. A review of published literature, technical reports, and research does provide some information, however. For example, Kearns and Karr (1994) used mussels from the genus *Epioblasma* and three snail genera as an intolerant metric when developing a B-IBI (Benthic Index of Biotic Integrity) for the Tennessee Valley. Pip (2006) analyzed water quality and mollusk communities in southern Lake Winnipeg, Manitoba, Canada. Freshwater mussel species richness was positively correlated with total dissolved solids and negatively correlated with lead. She also found a significant reduction in mussel species diversity and suggested the change was possibly due to oxygen depletion, algal toxins, sewage and agricultural spills and runoff, application of copper sulphate, and habitat changes. Hoggarth and Goodman (2007) utilized a multimetric Mussel Index of Biotic Integrity developed by Goodman (2007) to evaluate changes in the mussel fauna of the Little Miami River, OH. The Index included metrics that assessed distribution and abundance, reproductive potential, and community structure.

While freshwater mussels do present unique challenges to monitoring (e.g. patchy distributions, sampling conditions, etc.), the information gained from their study can provide unique insights regarding biological integrity and water quality. Although developing complex multimetric mussel indices is beyond the scope of this guide, below are a few basic recommendations on monitoring techniques that may provide valuable information when assessing local waterways.

Community Demographics

Characterizing community demographics over time may yield important data on species viability, conditions conducive to reproductive success, water quality, and ecosystem stability.

When monitoring community demographics, multiple stations with known mussel populations should be setup within the desired study area. If possible, monitoring should be done quantitatively to limit sample bias.

To evaluate community age class structure, a malacologist typically uses a metric caliper and measures live individuals in one (anterior to posterior) or three dimensions. Basic summary statistics can be generated to analyze shell length diversity, age class heterogeneity, and recent recruitment. This may be especially interesting when the collected data is contrasted with “ideal” study sites that maintain a “healthy” cross section of age class diversity. For example, Grabarkiewicz and Crail (2008) used simple summary statistics to compare age class diversity in three different waterways. This method might be further developed as a metric in a full multimetric index.

Mark and Recapture

Mark and recapture is a method often used when translocating mussels from one area to another. With this technique, mussels are first marked or given a unique tag and moved to a defined area up or downstream. Mark and recapture may also prove useful in water quality assessment. For example, with a unique tag the health and growth of multiple individuals may be monitored over time by measuring shell dimensions, weight, or biological markers. This type of monitoring may assist when assessing lethal or sublethal impacts of nearby industrial or sewage outfalls.

Photo 18: A researcher measures a mussel with a caliper to collect demographic data.

Long Term Quantitative Monitoring

Quantitative sampling generally involves the excavation of quadrats and the sieving of sediments. Long-term quantitative monitoring is useful when assessing trends of community diversity, abundance, and overall system integrity. For example, Ahlstedt and Tuberville (1997) reported trends in species composition, abundance, and recruitment between 1979 and 1994 in the Clinch and Powell River (TN, VA). The researchers reported that a severe drought had a strong impact on mussel populations during the mid-1980s and that mussel distribution and abundance patterns were "influenced by proximity of mined land." They also noted that declines in tributary streams were generally more severe for freshwater mussels than fish, suggesting that mussels are more sensitive to environmental perturbations.

Sensitivity to Toxic Contaminants

Toxic contaminants have long been implicated in the reduction or extirpation of mussel populations throughout the country (Lewis 1868; Ortmann 1909; Clark and Wilson 1912; Baker 1928). Early 20th century accounts of industrial stream pollution tell of dyestuff discharges from knitting mills "causing widespread destruction" (Clark and Wilson 1912) and rivers "acting as the sole receptacle of sewage and manufacturing waste" (Howe 1900). More recently, regional and continent-wide assessments of unionoid populations have cited toxic contaminants as a contributor to widespread faunal declines (Havlik and Marking 1987; Bogan 1993; Neves et al. 1997).

Toxic contaminants are defined here as inorganic or organic contaminants that have the potential to be lethal or elicit sublethal responses from a chosen study population. The concentration and exposure required to elicit a response from a particular species may vary greatly from pollutant to pollutant. Additionally, the toxicity of a particular pollutant may be influenced by a number of variables, including concentration and exposure route, frequency, and duration.

Freshwater mussels exhibit a variety of sensitivities to toxic contaminants based on species, life stage (glochidium, juvenile, or adult), and environmental conditions. For example, Wang et al. (2007a) reported that glochidial Oyster Mussel (*Epioblasma capsaeformis*) and Scaleshell (*Leptodea leptodon*) were far more sensitive to copper than glochidial Dwarf Wedgemussel (*Alasmidonta heterodon*). Interestingly, all three species are listed as federally endangered by the U.S. Fish and Wildlife Service. Interspecific disparities like these can be helpful to bioassessment programs in compiling and diagnosing sources and causes of impairment.

Heavy Metals

The American Society for Testing and Materials (ASTM 2006) issued new guidelines for freshwater mussel toxicity testing. The studies included in this document meet the requirements of the ASTM guidance. Heavy metals are a concern to freshwater mussels due to their ability to cause mortality, disrupt enzyme efficiency, alter filtration rate, reduce growth, and change behavior (Naimo 1995). Because freshwater mussels exhibit suspension and deposit feeding behaviors (Gatenby et al. 1996; Raikow and Hamilton 2001), heavy metals may be available to unionoids through both the water column (dissolved or attached to suspended particles) and streambed sediments (Naimo 1995). However, the overall bioavailability of metals is complicated and influenced by a suite of factors, including metal concentration and speciation, water column chemistry, redox potential, particulate matter, and flow regime characteristics (Luoma 1989).

While it is well-known that freshwater mussels readily bioaccumulate metals, the rate and location(s) of accrual may vary greatly by unionoid species, unionoid size, and heavy metal species (Adams et al. 1981; Naimo et al. 1992b; Pip 1995). For example, studies have suggested that metals such as zinc accumulate most readily in the gills (Adams et al. 1981), while others such as cadmium become concentrated in the heart (Pip 1995). In addition to the heart and gills, metal accumulation may occur in the kidney, digestive gland, foot, and mantle.

Before discussing heavy metals in greater detail, some perspective on the background levels at which they occur may be helpful. The following was modified from the excellent review done by Naimo (1995):

Metal	Locality	Condition/Area	Total*	Dissolved*
Cd	Rhone River, France[1]	Industrial	20-117	17-80
	Mississippi River, USA[2]	At mouth	-	8-16
	Lake Vanda, Antartica[3]	Pristine	10-70	-
Cu	Rhone River, France[1]	Industrial	405-1340	119-1240
	Mississippi River, USA[2]	At mouth	-	1810-1960
	Lake Vanda, Antartica[3]	Pristine	400-600	400-600
Hg	Silver Lake, CA[5]	Pristine	0.6	0.4
	Clear Lake, CA[5]	Polluted	3.6-104	1.1-1.5
	Onondaga Lake, NY[6]	Polluted	7-19	2-10
Zn	Ohio River, USA[7]	Industrial	-	288-3203
	Lake Erie, USA[8]	-	-	26-55
	Yangtze River, China[7]	At mouth	-	39-78

*in units of ng/L

References: [1]Huynh-Ngoe et al. 1988a [2]Trefry et al. 1986 [3]Green et al. 1986 [4]Huynh-Ngoe et al. 1988b [5]Gill and Bruland 1990 [6]Bloom and Effler 1990 [7]Shiller and Boyle 1985 [8]Coale and Flegal 1989

Cadmium. Cadmium is a common pollutant found in mine drainage, industrial discharges, insecticides, fungicides, and urban runoff. Generally considered highly toxic to aquatic life (Eisler 1985), the effects of cadmium have been evaluated by mussel toxicologists under both laboratory and "semi-field" conditions (Jenner et al. 1991; Lassee 1991; Hansten et al. 1996). Jenner et al. (1991) described the accumulation patterns in adult Painter's Mussel (Unio pictorum) as follows:

> *"....the process of concentration (accumulation) to high levels is rapid without direct toxic (lethal) effects. Detoxification by metal-binding proteins will require energy and resources which are drawn from the energy and nitrogen (protein) pool of the animal. A delayed effect will occur in which the population size diminishes due to the constant drain of energy and protein, causing energy exhaustion."*

AWQC *Ambient Water Quality Criteria*
Quantitative concentrations or qualitative assessments of the levels of pollutants in water which, if not exceeded, will generally ensure adequate water quality for a specified water use (U.S. EPA 2000).

GMAV *Genus Mean Acute Value*
The geometric mean of the SMAVs for the genus.

SMAV *Species Mean Acute Value*
The geometric mean of the results of all acceptable flow-through acute toxicity tests with the most sensitive tested life stage of the species.

LC50 *Lethal Concentration (50%)*
The concentration of a toxicant within a medium that causes the death of 50% of a population.

EC50 *Effective Concentration (50%)*
The dose at which a defined non-lethal response occurs in at least 50% of the study population.

Lasee (1991) and Naimo et al. (1992) also investigated the chronic effects of cadmium exposure. Lasee (1991) documented the dissolution of the crystalline style, an anatomical structure that assists in food digestion, when mussels were exposed to mercury, cadmium, and copper. Naimo et al. (1992a) studied the physiological responses of adult Plain Pocketbook (*Lampsilis cardium*) to cadmium concentrations ranging from 22-305 ug Cd/L. While most physiological responses were widely variable, respiration rates significantly decreased with increased cadmium exposure.

Copper. Elevated levels of copper in the aquatic environment may come from a variety of sources, including mine drainage, coal ash effluent, industrial discharges, and urban runoff. Recent studies and data compilations suggest that freshwater mussels are among the most sensitive aquatic taxa to copper (Figs. 11 and 12). It should also be noted that a significant amount of variability has been observed among the individual responses unionids exhibit to copper (Milam et al. 2005).

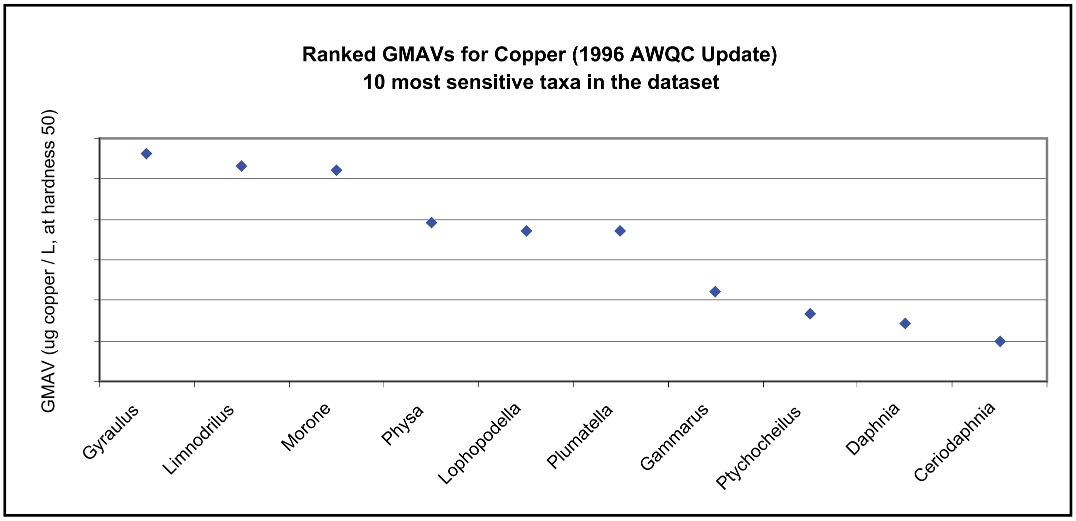


Figure 11: A listing of the most sensitive aquatic genera to copper excluding freshwater mussels (Augspurger et al. 2006). Used with permission.

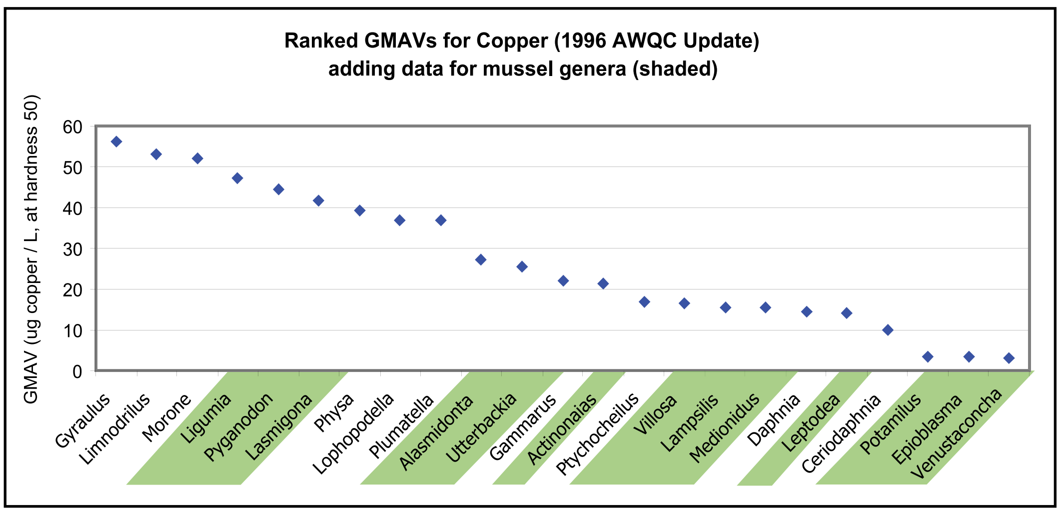


Figure 12: A listing of the most sensitive aquatic genera to copper including freshwater mussel taxa (Augspurger et al. 2006). Used with permission.

The toxicity of copper to freshwater mussels has been investigated by several researchers (e.g. Jacobson et al. 1993; 1997; Cherry et al. 2002; Milam et al. 2005; Wang et al. 2007a; Wang et al. 2007b).

During 24-hour exposures, Jacobson et al. (1993) calculated EC50s (valve closure) as low as 33 ug Cu/L and 27 ug Cu/L for juvenile Giant Floater (*Pyganodon grandis*) and Rainbow (*Villosa iris*), respectively. Reported LC50s ranged from 44 ug Cu/L (hardness = 70 mg/L) to 83 ug Cu/L (hardness = 190 mg/L) for Giant Floater (*P. grandis*) and Rainbow (*V. iris*), respectively.

Jacobson et al. (1997) further investigated the toxicity of copper to the early life stages of freshwater mussels by assessing exposures to brooded, released, and encapsulated glochidia. Brooded and encapsulated glochidia exhibited little sensitivity to copper exposures, while calculated LC50s for released glochidia ranged from 26 to 347 ug Cu/L (hardness = 55-190 mg/l).

Wang et al. (2007a; 2007b) evaluated the acute and chronic toxicity of copper to the early life stages (glochidia and juveniles) of 11 unionid species. Reported EC50s for glochidia varied widely between species, ranging from 10 to >100 ug Cu/L during 24-hour exposures. The most sensitive species to acute exposures of copper included Wavyrayed Lampmussel (*Lampsilis fasciola*), Oyster Mussel (*Epioblasma capsaeformis*), Ellipse (*Venustaconcha ellipsiformis*), Scaleshell (*Leptodea leptodon*), and Pink Papershell (*Potamilus ohiensis*). As a result of their study, Wang et al. (2007a) suggested that the U.S. EPA 1996 acute WQC for copper may not be protective of the early life stages of freshwater mussels.

March et al. (2007) evaluated toxicity data in the derivation of water quality guidance and standards for copper. Freshwater mussel SMAVs were generally similar to the more sensitive species in the U.S. EPA database. The Ellipse (*Venustaconcha ellipsiformis*), Oyster Mussel (*E. capsaeformis*), and Pink Papershell (*Potamilus ohiensis*) were among the most sensitive aquatic species to copper. On the basis of established ASTM standards, in addition to historical and ongoing research, the researchers advocated that state and federal agencies consider using freshwater mussel toxicity data in determining water quality standards.

Zinc. Zinc is commonly discharged into surface waters as a result of mining activities, industrial processes, and urban runoff. While studies suggest zinc is not as acutely toxic to freshwater mussels as copper or cadmium (McCann 1993), it may accumulate to high concentrations in surface waters impacted by mining waste or industrialization (Adams et al. 1981). At high concentrations, zinc may elicit sublethal responses or cause mortality.

Results reported by McCann (1993) for a pair of Cumberlandian species and the Rainbow (*Villosa iris*), with LC50s ranging from 274 to 1230 ug Zn/L during 48-hour exposures (hardness = 40-160). Likewise, Cherry et al. (1991) documented LC50s ranging from 212 to 656 ug Zn/L during 48-hour exposures to four species of unionids (hardness = 170).

Mercury. Mercury contamination in surface waters may result from pesticides, hazardous waste disposal, waste incineration, and fossil fuel combustion. Mercury is a concern in freshwater ecosystems due to its ability to biomagnify up the food chain and cause various health problems in humans and wildlife.

Valenti et al. (2005) evaluated the acute and chronic toxicity of mercury to the early life stages *V. iris*. A glochidial LC50 of >107 ug Hg/L was reported during 24-hour exposures. A juvenile LC50 of 99 ug Hg/L was reported during 96-hour exposures. Glochidial Rainbow were determined to be more acutely sensitive to mercury than two month old juveniles.

Valenti et al. (2006b) also assessed the acute toxicity of inorganic and organic mercury salts to the glochidia of four freshwater mussel species. Included as test subjects were two federally endangered species, the oyster mussel (*Epioblasma capsaeformis*) and Cumberlandian combshell (*Epioblasma brevidens*). Reported LC50s ranged from 25 to 54 ug HgCl/L during 24-hour exposures to mercuric chloride ($HgCl_2$). Methylmercuric chloride (CH_3ClHg) was more acutely toxic to *E. capsaeformis* and *E. brevidens*, with reported LC50s of 21 to 26 ug/L during 24-hour exposures. The Rainbow (*V. iris*) was found to be far more tolerant to methylmercuric chloride than both *E. capsaeformis* and *E. brevidens*, with less than 50% mortality observed at 120 ug Hg/L after 24 hours.

Ammonia

Anthropogenic sources of ammonia include livestock waste, sewage treatment plants, faulty septic systems, and industrial wastewater. Like copper, recent toxicity studies have suggested that freshwater mussels are particularly sensitive to ammonia (e.g. Goudreau et al. 1993; Bartsch et al. 2003; Augspurger et al. 2003; 2006; Newton et al. 2003; Wang et al. 2007a; 2007b) (Figs. 13 and 14).

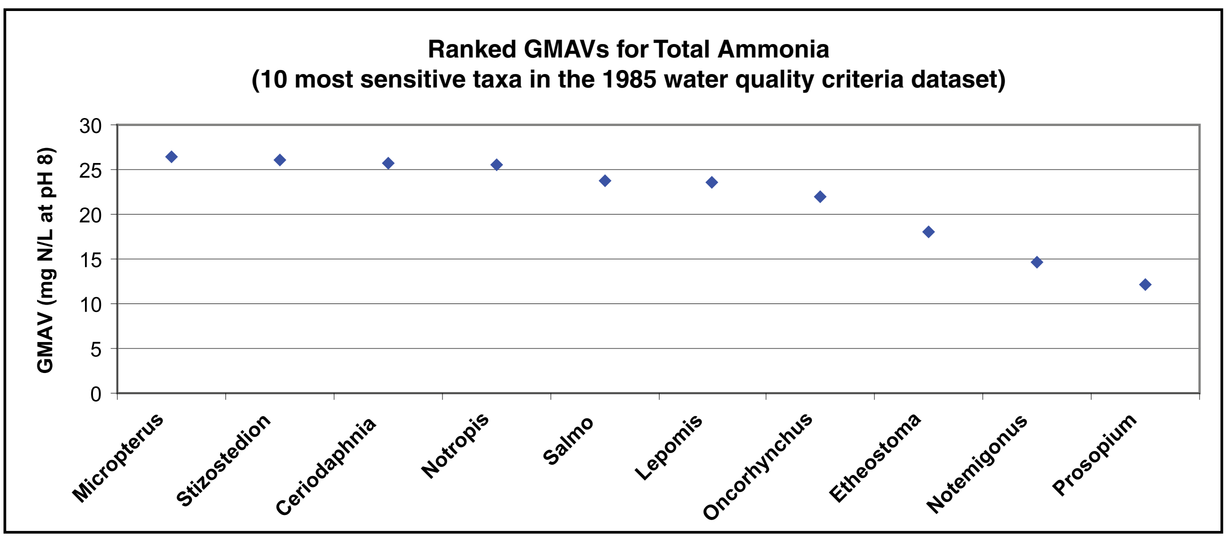


Figure 13: A listing of the most sensitive aquatic genera to ammonia excluding freshwater mussel taxa (Augspurger et al. 2006). Used with permission.

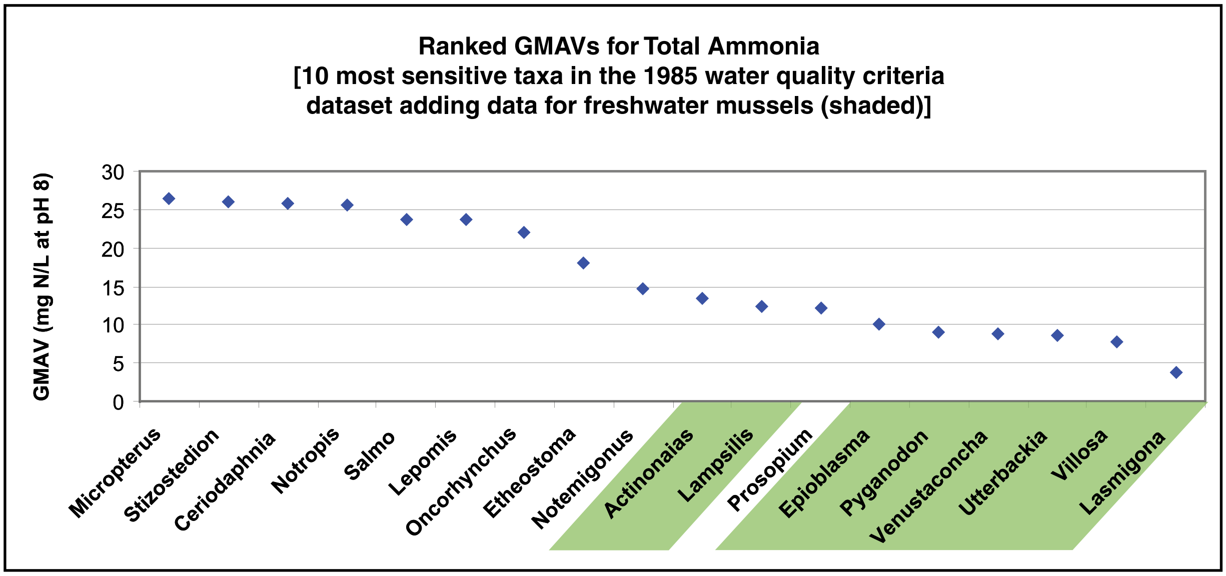


Figure 14: A listing of the most sensitive aquatic genera to ammonia including freshwater mussel taxa (Augspurger et al. 2006). Used with permission.

Goudreau et al. (1993) assessed the toxicity of ammonia and monochloroamine (MCH) to Rainbow glochidia and investigated the effects of wastewater treatment plant (WWTP) effluents on freshwater mussels. In laboratory toxicity studies, *V. iris* glochidia were exposed to ammonia and MCH for 24 hours. Reported EC50s were 0.237 and 0.042 mg/L for unionized ammonia and MCH, respectively. Reported LC50s were 0.284 and 0.084 mg/L for unionized ammonia and MCH, respectively. In field studies of treatment plant effluents, researchers examined unionid communities above and below a pair of WWTPs in the upper Clinch River, VA. River segments directly downstream (up to 3.7 km) of both WWTPs were devoid of mussels, while live unionids were found above each plant. Researchers suggested that even if glochidia were not killed outright by MCH or ammonia, the sublethal impacts may reduce glochidial viability and prevent the colonization of river segments near WWTPs.

Newton et al. (2003) and Newton and Bartsch (2007) studied the effects of ammonia in sediments and water-only exposures to juvenile Plain Pocketbook (*L. cardium*) and Higgins' Eye (*Lampsilis higginsii*). Newton et al. (2003) documented mortality at concentrations as low as 93 ug NH_3-N/L and growth reduction at 31 ug NH_3-N/L. These results are at or below acute national water quality criteria. Researchers also noted that control survival was much higher when compared with assays where sediments were not part of the study. Because juveniles may collect food particles from sediments by pedal feeding (Yaeger and Cherry 1994), this observation further accentuated the need to examine sediments and pore water as an important exposure route.

Wang et al. (2007a) examined the acute toxicity of ammonia to the early life stages of several unionid species. Glochidial mussels exhibited an array of tolerances, with reported EC50s ranging from 5 to >16 mg N /L during 24-hour exposures. Glochidia of the Oyster Mussel (*E. capsaeformis*) and Ellipse (*V. ellipsiformis*) were among the most sensitive species tested. During 4-day and 10-day exposures to juvenile mussels, reported EC50s ranged from 5.7 to 11 mg N/L and 1.7 to 4.5 mg N/L, respectively. The authors concluded that the 1999 acute WQC for ammonia many not be protective of the freshwater mussels species tested.

Chlorine

Anthropogenic sources of chlorine include wastewater treatment plants and industrial facilities (Valenti 2006a). Chlorine is generally considered highly toxic to most forms of life and is commonly used as a disinfectant.

Valenti et al. (2006a) evaluated the toxicity of total residual chlorine (TRC) to the early life stages of five unionid species, including three federally endangered taxa: the Dwarf Wedgemussel (*Alasmidonta heterodon*), Cumberland Combshell (*E. brevidens*), and Oyster Mussel (*E. capsaeformis*). Mean LC50s ranged from 70 to 220 ug TRC/L during 24-hour exposures. Federally endangered mussels were found to be slightly to far more sensitive than Wavyrayed Lampmussel (*L. fasciola*) and Rainbow (*V. iris*), respectively. The study also reported reduced growth in juvenile *E. capsaeformis* at concentrations as low as 20 ug TRC/L during 21-day chronic exposures. The authors suggested that while endpoints were above U.S. EPA WQC for TRC, potential sublethal effects to federally endangered juvenile mussels were still a concern.

Wang et al. (2007a) evaluated the acute toxicity of chlorine to the early life stages of several unionid species. Reported EC50s for mussel glochidia during 24-hour exposures ranged from 58 to >100 ug TRC/L. Reported EC50s for juvenile mussels during 4-day and 10-day exposures ranged from 68 to >100 ug TRC/L and 16 to >100 ug TRC/L, respectively. Researchers suggested that the early life stages of mussels were relatively tolerant of chlorine.

Insecticides, Herbicides, and Fungicides

Insecticides, herbicides, and fungicides are common contaminants in both rural and urban settings. In fact, scientists estimate that approximately 1.1 billion pounds of pesticides are spread in the United States annually (Aspelin 1994). Freshwater mussels exhibit an array of tolerances to current-use pesticides, largely dependent on the species of mussel, identity of the contaminant, and length of exposure.

Recent research has provided new insights into the acute effects of various insecticides, herbicides, and fungicides (e.g. Keller 1993; Moulton et al. 1996; Keller and Ruessler 1997; Milam et al. 2005; Bringolf et al. 2007a). Keller (1993) evaluated the toxicity of several organic compounds to Paper Pondshell (*U. imbecillis*) and contrasted the results with Daphnia (*Daphnia magna*) and Bluegill Sunfish (*Lepomis macrochirus*). *U. imbecillis* was generally less sensitive to most contaminants when compared with other test organisms, including the pesticides toxaphene, chlordane, and PCP (pentachlorophenol).

Keller and Ruessler (1997) evaluated the toxicity of malathion, a commonly used mosquito and fruit fly insecticide, to the early life stages of several unionid species. Glochidia trials yielded LC50s ranging from 7 to 374 mg/L during exposures of 4 to 48 hours. Glochidial Paper Pondshell were by far the most tolerant species, with reported LC50s of 324 to 374 mg/L. Reported LC50s for juvenile mussels ranged from 74 to 129 mg/L during exposures of 96 hours in hard water. Researchers concluded that "expected environmental concentrations should not be lethal to unionids."

Bringolf et al. (2007a) assessed the toxicities of various current-use pesticides to the glochidia and juveniles of several freshwater mussel species. Fatmucket (*Lampsilis siliquoidea*) glochidia and juveniles were found to be highly sensitive to chlorothalonil, propiconazole, and pyraclostrobin, with reported glochidial EC50s ranging from 0.09 to 20.75 mg/L during 24-hour exposures. Juvenile 96-hour EC50s ranged from 0.03 to 10.01 mg/L. Technical grade atrazine, permethrin, fipronil, and pendimethalin were not acutely toxic to the unionids tested. However, chronic studies found juvenile Fatmucket to be sensitive to atrazine at low concentrations, with reported EC50s of 15.8 mg/L and 4.3 mg/L during 14-day and 21-day exposures, respectively.

Glyphosate is one of the most widely used herbicides today, yet few studies have analyzed its effects on freshwater mussels. Bringolf et al. (2007b) investigated the toxicity of several forms of glyphosate, its formulations, and a surfactant (MON 0818) to juvenile and glochidial Fatmucket (*L. siliquoidea*). Reported 24-hour EC50s were as low as 3.0 mg/L and 0.6 mg/L for Roundup and MON 0818, respectively. Reported 96-hour EC50s for juvenile *L. siliquoidea* were 5.9 mg/L and 3.8 mg/L for Roundup and MON 0818, respectively. Researchers concluded that the early life stages of the Fatmucket are among the most sensitive aquatic organisms to glysphosate-based chemicals and MON 0818 tested to date.

Shells as Indicators

The use of freshwater mussel shells as indicators of ecological integrity and environmental stress has been informally exercised by scientists since the early 1900s (Ortman 1909; Coker et al. 1921). However, only recently have researchers started to collect quantitative information from shell material (Imlay 1982; Ravera et al. 2005; Brown et al. 2005). Because spent valves persist in aquatic ecosystems for decades or more, shell-based studies often offer information inaccessible to investigators through traditional bioassessment strategies.

Mussel shells are comprised of five primary layers: the periostracum, prismatic layer, peripheral layer, laminar layer, and inner nacreous layer (Imlay 1982). The periostracum is mainly proteinaceous in nature, while the other four layers are comprised of calcium carbonate, in the form of calcite or aragonite. Periods of rest are delineated by internal and external rings (Fig. 15) laid down during periods of latency. These rings are often used to age mussels, with each well defined line constituting a rest period during cold weather. In addition to growth rings, disturbance rings may also be present, possibly reflecting periods of pollution, drought, displacement, or handling. While aging studies have utilized both internal and external annuli, some debate remains in regards to which is more accurate (Metcalfe-Smith and Green 1992). Uncertainty is often due to shell weathering, the presence of disturbance rings, and ring crowding resulting from old age (Ray 1977; Strayer 1981; Anthony et al. 2001). Although aging remains a precarious endeavor with certain specimens, the information gleaned from growth and disturbance rings can provide useful insights into historical growth rates, disturbance, and water quality (Imlay 1982; Haag 2007).

Figure 15: External rings of the Ohio Pigtoe (*Pleurobema cordatum*).

Metals may be present in shell material as a result of surface adsorption or as metabolic analogues of calcium. The metal content of shell material often varies greatly from what is found in soft tissues. For example, Anderson (1977) found overall metal concentrations to be higher in soft tissues than shell material during a study of the Fox River (IL, WI). Zinc, in particular, was reportedly accumulated to levels 10-40 times the concentration found in shell material. Ravera et al. (2003) found shells to contain higher concentrations of Ca, Cr, Mn, Ni, and Mo than soft tissues, while concentrations of As, Cd, Cu, Ni, and Pb were lower in shells than soft tissues. Considerable variation was also observed in heavy metal concentrations between different species.

Chatters et al. (1995) utilized the valves of freshwater mussels to recreate ancient stream environments in the Columbia River basin (western North America). By analyzing the archaeological presence of Western Ridged Pearlshell (*Gonidea angulata*) and Western Pearlshell (*Margaritifera falcata*), two species with markedly different habitat requirements, scientists inferred the crude substrate composition and suspended sediments of historical stream systems. In addition, researchers analyzed growth increments of Western Pearlshell to determine historical temperature patterns. The report concluded that the study area was likely poor for salmon 6,000-7,000 B.P., due mainly to higher stream temperatures, greater quantities of fine sediments, and lower flows.

Perhaps one of the most interesting application of shell-based strategies is the examination of heavy metal trends over long periods of time. For example, Brown et al. (2005) found freshwater mussel shells of the North Fork Holston River to provide an otherwise unavailable record of mercury contamination at five sites near Saltville, VA. Through analysis of over 350 shells, researchers verified significant differences in mercury concentrations between shell assemblages above, within, and below an area of contamination.

Similarly, Ravera et al. (2005) analyzed shell material from a pair of Italian lakes to document changes in metal concentrations over two distinct time periods. Using recently collected shells and preserved valves from a museum, researchers were able to analyze metal concentrations from 1928-1934 and 1995-2000. Several metals significantly differed in concentration between the two periods, which also varied greatly between the two lakes.

Genus Profile - *Alasmidonta*

Photo 19: Swan Creek, OH, headwater habitat of the Slippershell Mussel (*Alasmidonta viridis*).

Species Diversity and Conservation: A total of 12 species have been assigned to the genus *Alasmidonta* (Turgeon et al. 1998). Williams et al. (1993) reviewed the conservation status of unionoids in North America and reported three *Alasmidonta* as special concern, two as threatened, and six species as endangered. Currently, three species are listed as endangered by the U.S. Fish and Wildlife Service (USFWS 2007), while three species are considered extinct (Turgeon et al. 1998).

Shell Characteristics: Shell rhomboidal, elongate, or subquadrate; often quite thin when young, becoming moderately stout with age. Maximum shell length 2.0 to 4.5 inches (50-115 mm). Periostracum light yellowish-green to yellowish tan, often with green rays. Some species with green spots. Beak sculpture of elevated and heavy double-looped ridges, concentric loops, or double-looped bars. Pseduocardinal teeth well developed but not massive; generally small. Lateral teeth poorly developed. Nacre white, often with salmon tinge.

Photo 20: Slippershell Mussel (*A. viridis*), Swan Creek, OH.

Habitat: The *Alasmidonta* are a wideranging group, inhabiting the lower and upper Mississippi River basin, Great Lakes-St. Lawrence basin, Atlantic Slope, and Gulf drainages. Several species are endemics and have limited distributions (e.g. Cumberland River drainage, Altamaha River drainage, etc.). This group may be found in both headwaters and large rivers in sluggish or swift current. The *Alasmidonta* may occur in a variety of substrates, from mud to sand, gravel, and cobble (Gordon and Layzer 1989; Parmalee and Bogan 1998).

Reproduction: Researchers have identified suitable host fishes for many of the *Alasmidonta*. Confirmed hosts belong to one of six families: Cyprinidae (minnows), Catostomidae (suckers), Ictaluridae (catfishes), Cottidae (sculpins), Centrarchidae (sunfishes), and Percidae (perches) (Howard and Anson 1923; Gordon and Layzer 1993; Moorman and Gordon 1993; Michaelson and Neves 1995; Schulz and Marbain 1998; Watters et al. 1998c). Many of the *Alasmidonta* have been documented as bradytictic (Ortmann 1921; Baker 1928).

Tolerance to Habitat Alteration: In general, the *Alasmidonta* are sensitive to alterations that change habitat dynamics. Watters (1995) noted that the Elktoe (*A. marginata*) and Slippershell Mussel (*A. viridis*) do not tolerate impoundment. Several members of the genus have experienced population declines rangewide due to dams and associated hypolimnetic discharges, coal mine runoff, sedimentation, and pollutants (Oesch 1984; Master 1986; USFWS 1993b; Parmalee and Bogan 1998; USFWS 2004; Natureserve).

Taxa List (Turgeon et al. 1998)
Altamaha Arcmussel (*Alasmidonta arcula*)
Cumberland Elktoe (*Alasmidonta atropurpurea*)
Dwarf Wedgemussel (*Alasmidonta heterodon*)
Elktoe (*Alasmidonta marginata*)
Coosa Elktoe (*Alasmidonta mccordi*)
Appalachian Elktoe (*Alasmidonta raveneliana*)
Carolina Elktoe (*Alasmidonta robusta*)
Southern Elktoe (*Alasmidonta triangulata*)
Triangle Floater (*Alasmidonta undulata*)
Brook Floater (*Alasmidonta varicosa*)
Slippershell Mussel (*Alasmidonta viridis*)
Ochlockonee Arcmussel (*Alasmidonta wrightiana*)

Sensitivity to Toxic Contaminants: Recently, Wang et al. (2007a) evaluated the acute toxicity of copper, ammonia, and chlorine to the federally endangered Dwarf Wedgemussel (*Alasmidonta heterodon*) and 10 other species. The glochidia of *A. heterodon* were among the most tolerant species tested to copper and ammonia. Reported 24-hour EC50s were >100 ug/L and >16 mg N/L for copper and ammonia, respectively.

Keller and Augspurger (2005) evaluated the toxicity of fluoride to the federally endangered Appalachian Elktoe (*Alasmidonta raveneliana*) in response to concerns regarding feldspar mining operations. The reported 24-hour LC50 for glochidial *A. raveneliana* was 288 mg F/L. The reported 96-hour LC50 for juvenile Appalachian Elktoe was 303 mg F/L. The study concluded that acute fluoride toxicity was unlikely although longer tests would be helpful to determine sublethal effects.

Indicator Use: Bedford et al. (1968) utilized *A. marginata* as a biomonitor of pesticides in the Red Cedar River (MI). Reported concentrations ranged from 0.0153-0.198 ppm total DDT and metabolites. The study concluded that mussels were excellent indicators of pesticide contamination; mainly because of their ability to concentrate contaminants.

The *Alasmidonta* are valuable indicators of habitat and water quality, as they generally inhabit clear, good quality, flowing habitats with stable substrates (Watters 1995; Nedeau et al. 2000; Bogan 2002; Natureserve).

Turgeon et al. 1998 Taxa	12
Presumed Extinct Taxa	3 (25.0%)
Federally Listed Taxa	3 (25.0%)
Williams et al. 1993	
Special Concern	3 (25.0%)
Threatened	2 (16.7%)
Endangered	6 (50.0%)
Total	11 (91.7%)
Natureserve	
G5	0 (0.0%)
G4-G5	1 (8.3%)
G4	2 (16.7%)
G3	1 (8.3%)
G2	1 (8.3%)
G1-G2	2 (16.7%)
G1	3 (25.0%)
GH	1 (8.3%)
GX	1 (8.3%)


Slippershell Mussel (*Alasmidonta viridis*) Elktoe (*Alasmidonta marginata*)

Genus Profile - *Epioblasma*

Species Diversity and Conservation: A total of 17 species and eight subspecies comprise the genus *Epioblasma* (Turgeon et al. 1998), 14 of which are considered extinct (Hoggarth et al. 1995; Turgeon et al. 1998). The remaining 11 *Epioblasma* are classified as vulnerable, highly imperiled, or critically imperiled (Natureserve). A total of 14 taxa are listed as endangered by the U.S. Fish and Wildlife Service (USFWS 2007).

Photo 21: The Oyster Mussel (*Epioblasma capsaeformis*), Clinch River, TN.

Shell Characteristics: Shell shape highly variable; adults usually solid and small (< 70 mm). Most taxa exhibit strong sexual dimorphism; which varies in pronouncement and morphology. Females generally possess an expanded and rounded posterior, elongated posterior, or a pronounced marsupial swelling along the posterior ridge. Males are often shallow to moderately sulcate; although some taxa lack a sulcus altogether (e.g *Epioblasma triquetra*). The periostracum is yellowish-tan to brown with green rays or chevron markings. Pseudocardinal teeth and lateral teeth are generally well developed; often heavy in large specimens. Nacre is usually white or purple.

Photo 22: The Powell River (TN, VA) was historically home to several species of *Epioblasma*, including the extinct Forkshell (*Epioblasma lewisii*) and Acornshell (*Epioblasma haysiana*).

Habitat: The *Epioblasma* were formerly widespread throughout the eastern United States, inhabiting the Mississippi River basin, Great Lakes basin, and Mobile basin. Today, their ranges have been dramatically reduced, and for the most part, are small and disjunct (USFWS 1983b; 1985a; 1990; 1994; 2004). As a group, this genus inhabits shallow riffles, runs, or shoals of moderate-sized creeks and rivers (Stansberry 1970; Watters 1995; Parmalee and Bogan 1998). They are often most abundant in clear water and clean substrates comprised of sand, gravel, and cobble.

Taxa List (Turgeon et al. 1998)
Altamaha Arcmussel (*Alasmidonta arcula*)
Angled Riffleshell (*Epioblasma biemarginata*)
Cumberland Combshell (Epioblasma brevidens)
Oyster Mussel (*Epioblasma capsaeformis*)
Leafshell (*Epioblasma flexuosa*)
Curtis Pearlymussel (*Epioblasma florentina curtisii*)
Yellow Blossom (*Epioblasma florentina florentina*)
Tan Riffleshell (*Epioblasma florentina walkeri*)
Acornshell (*Epioblasma haysiana*)
Narrow Catspaw (*Epioblasma lenoir*)
Forkshell (*Epioblasma lewisii*)
Upland Combshell (*Epioblasma metastriata*)
Catspaw (*Epioblasma obliquata obliquata*)
White Catspaw (*Epioblasma obliquata perobliqua*)
Southern Acornshell (*Epioblasma othcaloogensis*)
Southern Combshell (*Epioblasma penita*)
Round Combshell (*Epioblasma personata*)
Tennessee Rifflshell (*Epioblasma propinqua*)
Wabash Riffleshell (*Epioblasma sampsonii*)
Cumberland Leafshell (*Epioblasma stewardsonii*)
Green Blossom (*Epioblasma torulosa gubernaculum*)
Northern Riffleshell (*Epioblasma torulosa rangiana*)
Tubercled Blossom (*Epioblasma torulosa torulosa*)
Snuffbox (*Epioblasma triquetra*)
Turgid Blossom (*Epioblasma turgidula*)

Reproduction: Because the *Epioblasma* have experienced such a precipitous decline, very little information is available regarding the reproductive habits of most taxa. However, observations made by several researchers suggest that some *Epioblasma* employ brutal tactics to entrap host fishes. Much of the following is paraphrased from Barnhart (2007):

> *Dubbed "fish snappers" by Jess Jones (Virginia Tech University), this moniker aptly describes a technique utilized by gravid females to trap unwary fishes. To initiate glochidia-host interaction when brooding, females migrate to the surface and lie-in-wait. While resting (or slightly burrowed) on the substrate some of the Epioblasma gape widely, exposing their spongy "mantle pads" (termed cymapallia by Barnhart). When contact is initiated with the shell or mantle pads, the female quickly snaps her shell shut. This action essentially traps unsuspecting fish, allowing the female to directly infect her captive with glochidia. This technique seems especially brutal when fishes are observed ensnared by the snout or head.*

Identified hosts include fishes from families Percidae (perches), Cottidae (sculpins), and Salmonidae (trout) (Buchanan 1987; Sherman 1993; Yaeger and Saylor 1995; O'Dee and Watters 2000; Rogers et al. 2001). More specifically, the most commonly reported hosts are darters from two genera, *Etheostoma* and *Percina*, and sculpin belonging to the genus *Cottus*.

Turgeon et al. 1998 Taxa	25
Presumed Extinct Taxa	14 (56.0%)
Federally Listed Taxa	14 (56.0%)
Williams et al. 1993	
Special Concern	0 (0.0%)
Threatened	1 (4.0%)
Endangered	24 (96.0%)
Total	11 (91.7%)
Natureserve	
G5	0 (0.0%)
G4	0 (0.0%)
G3	1 (4.0%)
G2	0 (0.0%)
G1	2 (8.0%)
G2TX	1 (4.0%)
G2T2	3 (12.0%)
G1	1 (4.0%)
G1TX	1 (4.0%)
G1T1	4 (16.0%)
GHQ	1 (4.0%)
GH	1 (4.0%)
GX	11 (44.0%)

Tolerance to Habitat Alteration: The *Epioblasma* are, with few exceptions, habitat specialists adapted to shallow segments of large creeks and rivers. The ubiquitous damming and modification of river habitats has likely impacted this specialized group more than any other genera of unionids (USFWS 1983b; 1985a). Many of the now extinct *Epioblasma* formerly occured in riffles of large rivers, a habitat that has been virtually eliminated by impoundment (Stansberry 1970).

Sensitivity to Toxic Contaminants: Recently Wang et al. (2007a) assessed the acute toxicity of copper, ammonia, and chlorine to the early life stages of 11 species, including the oyster mussel (*E. capsaeformis*). Newly-transformed Oyster Mussel juveniles were among the more sensitive species tested during 96-hour exposures. Reported EC50s were 17 ug/L and 5.7 mg N/L for copper and ammonia, respectively.

Indicator Use: While generally not used for contaminant biomonitoring studies, the *Epioblasma* are certainly among the most sensitive genera to anthropogenic disturbance and have great value for measuring the biological integrity of surface waters (Ahlstedt 1991; Neves et al. 1997). As such, this group has been utilized as a sensitive indicator. For example, Kearns and Karr (1994) used *Epioblasma* as an intolerant mussel genera when developing a benthic index of biotic integrity (B-IBI) for rivers of the Tennessee Valley.

Genus Profile – *Fusconaia*

Species Diversity and Conservation: A total of 13 species belong to the genus *Fusconaia* (Turgeon et al. 1998). Williams et al. (1993) reviewed the conservation status of unionoids in North America and reported six *Fusconaia* as special concern, two as threatened, and two species as endangered. At present, two species are listed as endangered by the U.S. Fish and Wildlife Service (USFWS 2007).

Taxa List (Turgeon et al. 1998)
Texas Pigtoe (*Fusconaia askewi*)
Tennessee Pigtoe (*Fusconaia barnesiana*)
Southern Pigtoe (*Fusoconaia cerina*)
Shiny Pigtoe (*Fusconaia cor*)
Finerayed Pigtoe (*Fusconaia cuneolus*)
Ebonyshell (*Fusconaia ebena*)
Narrow Pigtoe (*Fusconaia escambia*)
Wabash Pigtoe (*Fusconaia flava*)
Triangle Pigtoe (*Fusconaia lanaensis*)
Atlantic Pigtoe (*Fusconaia masoni*)
Ozark Pigtoe (*Fusconaia ozarkensis*)
Longsolid (*Fusconaia subrotunda*)
Purple Pigtoe (*Fusconaia succissa*)

Shell Characteristics: Shell shape highly variable; often subtriangular, subovate, or oval. Valves usually moderately thick and more often inflated than not (especially big river forms). Beaks raised above hinge-line. Shell surface smooth and devoid of sculpture. Maximum length ranges from approximately 2.5 to 4.5 inches (65-110 mm). Shell sexual dimorphism absent or very weakly pronounced. Periostracum yellowish-tan, reddish-brown, brown, or dark brown; often with faint green rays when young. Teeth well developed. Nacre white, rarely with a salmon tinge.

Habitat: The *Fusconaia* are widely distributed throughout the lower and upper Mississippi River basin, Great Lakes-St. Lawrence basin, several Gulf drainages, and the southern Atlantic drainage. They occur in small to large creeks, rivers, lakes, and reservoirs in both fine and coarse substrates.

Photo 23: Roanoke River, VA, home to the Atlantic Pigtoe (*Fusconaia masoni*).

Reproduction: Researchers have identified suitable host fishes for several *Fusconaia*. Confirmed hosts belong to one of five families: Clupeidae (herrings), Cyprinidae (minnows), Centrarchidae (sunfishes), Percidae (darters), and Cottidae (sculpins) (Coker et al. 1921; Wilson 1916; Bruenderman and Neves 1993; O'Dee and Watters 2000; Haag and Warren 2003). The *Fusconaia* are tachytictic, with the reproductive period extending from May to August (Baker 1928).

Photo 24: The Wabash Pigtoe (*Fusconaia flava*), Swan Creek, OH.

Photo 25: Streamline chubs (*Erimystax dissimilis*) foraging above a Longsolid (*Fusconaia subrotunda*), French Creek, PA.

Female *Fusconaia* package glochidia in semi-cohesive capsules (termed "conglutinates") that are expelled into the water column (Utterback 1915: 1916). Conglutinates are fed on by fishes, thereby infecting potential hosts.

Tolerance to Habitat Alteration: The *Fusconaia* exhibit varying degrees of tolerance to habitat alteration. The Wabash Pigtoe (*Fusconaia flava*), for example, is a habitat generalist capable of tolerating turbid streams, impounded habitats, and a variety of substrates (Gordon and Layzer 1989; Watters 1995; Strayer and Jirka 1997). Likewise, the Ebonyshell (*Fusconaia ebena*) has exhibited the ability to adapt to impoundment in reaches of the lower Ohio River (Payne and Miller 2001). Other species, such as the Cumberlandian endemic Finerayed Pigtoe (*Fusconaia cuneolus*), are adapted to shallow, swiftly flowing waters of creeks and rivers. Habitat alterations such as impoundment and siltation have contributed to the decline of this species (USFWS 1984). The Finerayed Pigtoe is currently listed as endangered by the U.S. Fish and Wildlife Service.

Sensitivity to Toxic Contaminants: Relatively little laboratory toxicity testing has been performed with the *Fusconaia*.

Waller et al. (1998b) evaluated the acute toxicity of 3-trifluoromethyl-4-nitrophenol (TFM), a common lampricide, to the Wabash Pigtoe and Threehorn Wartyback (*Obliquaria reflexa*). The Wabash Pigtoe was less sensitive than the Threehorn Wartyback, with reported LC50s of 3.81 and 1.80 mg/L, respectively. Researchers concluded that sea lampricide treatments would likely have negligible effects on the species tested.

Photo 26: Cumberland River, KY, home to the Ebonyshell (*Fusconaia ebena*), Longsolid (*Fusconaia subrotunda*), and Wabash Pigtoe (*Fusconaia flava*).

Indicator Use: Pip (1995) evaluated heavy metal contamination in the Assiniboine River (Manitoba, Canada) using several species of unionids as biomonitors. The Wabash Pigtoe accumulated levels of cadmium, lead, and copper comparable to other species. However, the Mapleleaf (*Quadrula quadrula*) accumulated significantly more copper in the gill, while the Fatmucket (*Lampsilis siliquoidea*) and Black Sandshell (*Ligumia recta*) accumulated substantially more cadmium in the heart.

Turgeon et al. 1998 Taxa	13
Presumed Extinct Taxa	0 (0.0%)
Federally Listed Taxa	2 (15.4%)
Williams et al. 1993	
Special Concern	6 (46.2%)
Threatened	2 (15.4%)
Endangered	2 (15.4%)
Total	10 (76.9%)
Natureserve	
G5	2 (15.4%)
G4-G5	1 (7.7%)
G4	0 (0.0%)
G3-G4	2 (15.4%)
G3	1 (7.7%)
G2-G3	2 (15.4%)
G2	2 (15.4%)
G1Q	1 (7.7%)
G1	2 (15.4%

Finerayed Pigtoe (*Fusconaia cuneolus*)

Imlay (1982) advocated the use of several *Fusconaia* as biomonitors of heavy metals based on annual shell growth, including the Longsolid (*Fusconaia subrotunda*), Finerayed Pigtoe, Wabash Pigtoe, Tennesse Pigtoe (*Fusconaia barnesiana*), and Shiny Pigtoe (*Fusconaia cor*).

Genus Profile – *Lampsilis*

Taxa List (Turgeon et al. 1998)
Pink Mucket (*Lampsilis abrupta*)
Finelinded Pocketbook (*Lampsilis altilis*)
Southern Sandshell (*Lampsilis australis*)
Lined Pocketbook (*Lampsilis binominata*)
Texas Fatmucket (*Lampsilis bracteata*)
Plain Pocketbook (*Lampsilis cardium*)
Yellow Lampmussel (*Lampsilis cariosa*)
Atlamaha Pocketbook (*Lampsilis dolabraeformis*)
Wavyrayed Lampmussel (*Lampsilis fasciola*)
Waccamaw Fatmucket (*Lampsilis fullerkati*)
Haddleton Lampmussel (*Lasmpsilis haddletoni*)
Higgins Eye (*Lampsilis higginsii*)
Louisiana Fatmucket (*Lampsilis hydiana*)
Southern Pocketbook (*Lampsilis ornata*)
Pocketbook (*Lampsilis ovata*)
Orangenacre Mucket (*Lampsilis perovalis*)
Arkansas Fatmucket (*Lampsilis powellii*)
Carolina Fatmucket (*Lampsilis radiata conspicua*)
Eastern Lampmussel (*Lampsilis radiata radiata*)
Neosho Mucket (*Lampsilis rafinesqueana*)
Ozark Brokenray (*Lampsilis reeveiana brevicula*)
Northern Brokenray (*Lampsils reeveiana brittsi*)
Arkansas Brokenray (*Lampsilis reeveiana reeveiana*)
Sandbank Pocketbook (*Lampsilis satura*)
Fatmucket (*Lampsilis siliquoidea*)
Rayed Pink Fatmucket (*Lampsilis splendida*)
Southern Fatmucket (*Lampsilis straminea claibornensis*)
Rough Fatmucket (*Lampsilis straminea straminea*)
Speckled Pocketbook (*Lampsilis streckeri*)
Shinyrayed Pocketbook (*Lampsilis subangulata*)
Yellow Sandshell (*Lampsilis teres*)
Alabama Lampmussel (*Lampsilis virescens*)

Species Diversity and Conservation: A total of 25 species and seven subspecies have been assigned to the genus *Lampsilis* (Turgeon et al. 1998). A single species, the Lined Pocketbook (*Lampsilis binominata*), is presumed extinct (Turgeon et al. 1998). Williams et al. (1993) reviewed the conservation status of unionoids in North America and reported nine *Lampsilis* as special concern, 10 as threatened, and six species as endangered. Currently, eight *Lampsilis* are listed as endangered by the U.S. Fish and Wildlife Service (USFWS 2007).

Shell Characteristics: Shell elliptical, subovate, elongate, or subquadrate; moderately thin to heavy and moderately compressed to inflated. Most *Lampsilis* exhibit strong sexual dimorphism. Females are expanded and rounded posteriorly or obliquely flared posteriorly. Males are usually bluntly pointed. Maximum shell length variable; usually ranging from 2.5 to 7.0 inches (65-170 mm). Periostracum often yellow, yellowish-green, yellowish-tan or brown; thin to wide green rays common but not always present. Beak nearly even or raised well above hinge-line; sculpture often

Photo 27: Lake Michigan, home to the Plain Pocketbook (*Lampsilis cardium*) and Fatmucket (*Lampsilis siliquoidea*).

double-looped. Teeth well developed; may be large and heavy in old individuals. Nacre usually white, bluish-white, pink, or salmon.

Habitat: The *Lampsilis* are a widely distributed group, ranging geographically from the Central United States to the East Coast and north into Canada. They are known from the upper and lower Mississippi River basin, Great Lakes-St. Lawrence basin, Atlantic slope, several Gulf drainages, and a few Canadian drainages. *Lampsilis* are found in small to large creeks, rivers, and lakes; occurring in both fine and coarse substrates.

Reproduction: Researchers have identified suitable host fishes for several *Lampsilis*. Confirmed hosts belong to one of seven families: Acipenseridae (sturgeons), Lepisosteidae (gars), Cyprinidae (minnows), Fundulidae (topminnows), Centrarchidae (sunfishes), Percidae (perches), or Sciaenidae (drums) (Surber 1913; Coker et al. 1921; Fuller 1974; Zale and Neves 1982; Waller and Holland-Bartels 1988; O'Dee and Watters 2000).

Turgeon et al. 1998 Taxa	32
Presumed Extinct Taxa	1 (3.1%)
Federally Listed Taxa	8 (25.0%)
Williams et al. 1993	
Special Concern	9 (28.1%)
Threatened	10 (31.2%)
Endangered	6 (18.8%)
Total	25 (84.0%)
Natureserve	
G5	7 (24.1%)
G5T5	2 (6.9%)
G5T3	1 (3.4%)
G5T2Q	1 (3.4%)
G5T1Q	1 (3.4%)
G4	1(3.4%)
G4T3	1 (3.4%)
G3G4	2 (6.9%)
G3	1 (7.7%)
G2	3 (10.3%)
G1Q	2 (6.9%)
G1	3 (10.3%)
GXQ	1 (7.7%)
GX	1 (7.7%)

The *Lampsilis* have evolved some of the most extraordinary reproductive adaptations found in freshwater bivalves. To enhance glochidia-host interaction, many *Lampsilis* possess a conspicuous mantle flap "lure" that appears, in form and pigmentation, similar to a small fish (photo 28). Mantle lures may rapidly or occasionally "pulse" or "swim," distinctive movements that expose the charged gills. This motion can be quite variable among species, season, and time of day, ranging from 180 movements per minute to virtually no movement at all (Kraemer 1970). Gravid females use this amazing tool to lure potential host fishes into striking the mantle flap, thereby rupturing the marsupia and liberating hundreds to thousands of glochidia.

Female Wavyrayed Lampmussel (*Lampsilis fasciola*)

Female Plain Pocketbook (*Lampsilis cardium*)

Tolerance to Habitat Aleration: The *Lampsilis* vary widely in their tolerance to habitat alteration. Widespread species such as the Plain Pocketbook (*Lampsilis cardium*) and Fatmucket (*Lampsilis siliquoidea*) may tolerate impoundment, turbidity, and sedimentation (Parmalee and Bogan 1998). Conversely, several federally listed taxa, many endemic to southern drainages, have been severely reduced in number by siltation, dredging, channelization, impoundment, and hypolimnetic releases (USFWS 1985b; USFWS 1991; USFWS 1992).

Sensitivity to Toxic Contaminants: The *Lampsilis* have been widely used to evaluate the toxicity of various contaminants to unionids (e.g. Jacobson et al.1993; Jacobson et al. 1997; Wang et al. 2007a; Wang et al. 2007b). Refer to the Wavyrayed Lampmussel, Fatmucket, and Plain Pocketbook species accounts for more information.

Indicator Use: Several of the *Lampsilis* have been used to successfully biomonitor heavy metals, including Plain Pocketbook (*Lampsilis cardium*), Eastern Lampmussel (*Lampsilis radiata radiata*), and Fatmucket (*Lampsilis siliquoidea*). Refer to the species accounts for more information.

Photo 28: In-situ mantle flap lure of the Wavyrayed Lampmussel.

Photo 29: In-situ apertures of the Plain Pocketbook.

Genus Profile - *Lasmigona*

Taxa List (Turgeon et al. 1998)
Alabama Heelsplitter (*Lasmigona complanata alabamensis*)
White Heelsplitter (*Lasmigona complanata complanata*)
Creek Heelsplitter (*Lasmigona compressa*)
Flutedshell (*Lasmigona costata*)
Carolina Heelsplitter (*Lasmigona decorata*)
Tennessee Heelsplitter (*Lasmigona holstonia*)
Green Floater (*Lasmigona subviridis*)

Species Diversity and Conservation: A total of five species and two subspecies have been assigned to the genus *Lasmigona* (Turgeon et al. 1998). Williams et al. (1993) reviewed the conservation status of unionoids in North America and reported two *Lasmigona* as special concern, one as threatened, and one species as endangered. Currently, the Carolina Heelsplitter (*Lasmigona decorata*) is listed as endangered by the U.S. Fish and Wildlife Service (USFWS 2007).

Shell Characteristics: Shell variable; generally rhomboidal, trapezoidal, or subovate; often quite thin when young. A few members of *Lasmigona* possess distinctive undulations or "flutes" posteriorly (e.g. *Lasmigona c. complanata* and *Lasmigona costata*). Maximum shell length from 2.5 to 7.0 inches (70-180 mm). Periostracum usually yellowish-brown or green when young; some species may have fine rays. Shell becoming dark with age. Beak sculpture often of well formed double-loops or moderately heavy bars. Pseudocardinal teeth well developed although variable in form; may be low and serrated or elevated. Nacre white, often with a salmon tinge.

Flutedshell
(*Lasmigona costata*)

White Heelsplitter
(*Lasmigona c. complanata*)

Green Floater
(*Lasmigona subviridis*)

Habitat: The *Lasmigona* are a wideranging group, inhabiting the lower and upper Mississippi River basin, Great Lakes-St. Lawrence basin, Lake Winnipeg drainage, Atlantic Slope, and Gulf drainages. This group may be found in both headwaters and large rivers, as well as lakes and reservoirs.

Photo 30: The Flutedshell (*Lasmigona costata*) in French Creek, PA.

Reproduction: Researchers have identified suitable host fishes for many of the *Lasmigona*. Confirmed hosts belong to one of nine families: Lepisosteidae (gars), Clupeidae (herrings and shad), Cyprinidae (minnows), Catostomidae (suckers), Ictaluridae (catfishes), Fundulidae (topminnnows), Cottidae (sculpins), Centrarchidae (sunfishes), and Percidae (perches) (Lefevre and Curtis 1910; Young 1911; Lefevre and Curtis 1912; Hove et al. 1995; Steg and Neves 1997; Watters 1998a; Watters et al. 1998b; McGill et al. 2002; Watters et al. 2005).

While the reproductive traits of each species belonging to *Lasmigona* have not been thoroughly investigated, most members have been confirmed as bradytictic.

Turgeon et al. 1998 Taxa	7
Presumed Extinct Taxa	0 (0.0%)
Federally Listed Taxa	1 (14.3%)
Williams et al. 1993	
Special Concern	2 (28.6%)
Threatened	1 (14.3%)
Endangered	1 (14.3%)
Total	4 (57.2%)
Natureserve	
G5	4 (57.2%)
G4	0 (0.0%)
G3	2 (28.6%)
G2	0 (0.0%)
G1	1 (14.3%)

Tolerance to Habitat Alteration: The *Lasmigona* exhibit a wide array of responses to habitat alteration. The White Heelpslitter (*L.c. complanata*), for example, has been reported to tolerate impoundment, eutrophication, and disturbed or silty substrates (Watters 1995; Strayer and Jirka 1997; Parmalee and Bogan 1998; Metcalfe-Smith et al. 2003; Sietman 2003). Furthermore, Watters (1995) noted that *L.c. complanata* may be abundant below sewage outfalls. Conversely, the federally endangered Carolina Heelsplitter (*L. decorata*) has unfortunately exhibited sensitivity to a suite of disturbances and stressors, including stream impoundment, unstable stream banks, channelization, siltation, road construction and maintenance, and mining runoff (Keferl 1991; USFWS 1996).

Photo 31: Green River, KY, home to the Flutedshell (*L. costata*) and White Heelsplitter (*L.c. complanata*).

Sensitivity to Toxic Contaminants: The *Lasmigona* are rarely used in laboratory toxicity testing. However, Black (2001) did utilize the Green Floater (*L. subviridis*) as a surrogate to derive water quality standards for the protection of North Carolina's endangered mussels.

Indicator Use: The *Lasmigona* are valuable indicators of habitat and water quality. For example, Metcalfe-Smith et al. (2003) considered the range expansion of the White Heelsplitter and Flutedshell in the Sydenham River basin a biological indicator of environmental deterioration.

Bedford et al. (1968) utilized the Flutedshell as a biomonitor of pesticides in the Red Cedar River (MI). Reported concentrations ranged from 0.0153-0.198 ppm total DDT and metabolites. The study concluded that mussels were excellent indicators of pesticide contamination; mainly because of their ability to concentrate contaminants.

Pip (1995) assessed the bioaccumulation and biomonitoring potential of the White Heelsplitter and several other species in the Assiniboine River, Manitoba (Canada). Unlike the other test unionids, cadmium, lead, and copper were concentrated to higher levels in the mantle tissue of *L.c. complanata* than the heart, gills, gonad, muscle, or foot. It should be noted, however, that only a single White Heelsplitter was analyzed.

GENUS PROFILE – *PLEUROBEMA*

Species Diversity and Conservation: A total of 32 species belong to the genus *Pleurobema* (Turgeon et al. 1998). Williams et al. (1993) reviewed the conservation status of unionoids in North America and reported four *Pleurobema* as special concern, one as threatened, and 22 species as endangered. At present, 12 species are listed as endangered by the U.S. Fish and Wildlife Service (USFWS 2007) while a total of 13 species are presumed extinct (Turgeon et al. 1998).

Shell Characteristics: Shell shape highly variable; often subtriangular or subelliptical; less often subrhomboidal or subquadrate. Shells usually moderately thick to thick and more often inflated than not (especially big river forms). With rare exception (e.g. James spinymussel), shell surface devoid of sculpture. Maximum lengths range from approximately 1.5 to 5.0 inches (35-120 mm). Shell sexual dimorphism absent or weakly pronounced. Periostracum often yellowish-tan, brown, or dark brown; clubshells and some pigtoes with rays extending from umbo. Teeth well developed and heavy. Nacre usually white or pink.

Habitat: The *Pleurobema* are a wideranging genus, with species richness maximized in the large creeks and rivers of the Cumberland Plateau and Mobile River basin. As a group, they inhabit the lower and upper Mississippi River basin, Great Lakes basin, James River drainage, Roanoke

Taxa List (Turgeon et al. 1998)
Highnut (*Pleurobema altum*)
Hazel Pigtoe (*Pleurobema avellanum*)
Mississippi Pigtoe (*Pleurobema beadleianum*)
Scioto Pigtoe (*Pleurobema bournianum*)
Painted Clubshell (*Pleurobema chattanoogaense*)
Clubshell (*Pleurobema clava*)
James Spinymussel (*Pleurobema collina*)
Ohio Pigtoe (*Pleurobema cordatum*)
Black Clubshell (*Pleurobema curtum*)
Southern Clubshell (*Pleurobema decisum*)
Yellow Pigtoe (*Pleurobema flavidulum*)
Dark Pigtoe (*Pleurobem furvum*)
Southern Pigtoe (*Pleurobema georgianum*)
Cumberland Pigtoe (*Pleurobema gibberum*)
Brown Pigtoe (*Pleurobema hagleri*)
Georgia Pigtoe (*Pleurobema hanleyianum*)
Alabama Pigtoe (*Pleurobema johannis*)
Flat Pigtoe (*Pleurobema marshalli*)
Coosa Pigtoe (*Pleurobema murrayense*)
Longnut (*Pleurobema nucleopsis*)
Tennessee Clubshell (*Pleurobema oviforme*)
Ovate Clubshell (*Pleurobema perovatum*)
Rough Pigtoe (*Pleurobema plenum*)
Oval Pigtoe (*Pleurobema pyriforme*)
Louisiana Pigtoe (*Pleurobema riddellii*)
Warrior Pigtoe (*Pleurobema rubellum*)
Pyramid Pigtoe (*Pleurobema rubrum*)
Round Pigtoe (*Pleurobema sintoxia*)
Fuzzy Pigtoe (*Pleurobema strodeanum*)
Heavy Pigtoe (*Pleurobema taitianum*)
Alabama Clubshell (*Pleurobema troschelianum*)
True Pigtoe (*Pleurobema verum*)

Photo 32: The Green River (KY), home of the federally endangered Rough Pigtoe (*Pleurobema plenum*).

River drainage, and several Gulf drainages. The *Pleurobema* are often most abundant in small and large rivers, where substrates are comprised of sand, gravel, and cobble.

Reproduction: Researchers have identified suitable host fishes for many of the *Pleurobema*. Confirmed hosts belong to one of four families - Cyprinidae (minnows), Fundulidae (topminnows), Percidae (perches), or Centrarchidae (sunfishes) (Surber 1913; Yokley 1972; Weaver et al. 1991; Hove 1995a; O'Dee and Watters 2000; Haag and Warren 2003). Although the reproductive traits of numerous species remain undocumented, studies have reported several *Pleurobema* as tachytictic, with the reproductive period extending from May to August (Ortmann 1909; Baker 1928; Haag and Warren 2003).

Tolerance to Habitat Alteration: The *Pleurbema* have been severely impacted by habitat alterations that have changed free-flowing, riffle-pool river segments to impounded, lentic habitats. For example, widespread modification of the Upper Tombigbee River (Mobile River basin) occurred when construction of the Tombigbee-Tennessee Waterway was completed in 1984. The Waterway shortened the river by 48 miles, destroyed and fragmented suitable streambed habitat, profoundly altered the flow regime, and initiated geomorphic instability (ARA et al. 1999). Once home to 50 species of freshwater mussels, including several pleurobemids, approximately 30% of the fauna is now imperiled, extirpated, or extinct as a direct result of river impoundment and related impacts (ARA et al. 1999). Four federally endangered species, the Black Clubshell (*Pleurobema curtum*), Southern Clubshell (*Pleurobema decisum*), Ovate Clubshell (*Pleurobema perovatum*), and Heavy Pigtoe (*Pleurobema taitianum*) once occurred in the Tombigbee River (USFWS 2000). They are now considered extirpated or limited to small segments where suitable habitat still exists (Hartfield and Jones 1989; USFWS 2000).

Photo 33: The federally endangered Clubshell (*Pleurobema clava*), French Creek, PA.

Photo 34: East Fork West Branch St. Joseph River, MI, habitat of the Clubshell (*P. clava*).

Sensitivity to Toxic Contaminants: The *Pleurobema* have not been used in laboratory toxicity testing.

Indicator Use: The *Pleurobema* are among the most imperiled mollusks in North America, with 78% of the genus either listed as federally endangered or extinct (Turgeon et al. 1998; USFWS 2007). Many are endemic to Mobile Basin, including over a dozen extinct species (Neves et al. 1997; Turgeon et al. 1998). They are sensitive to habitat alterations such as river impoundment and channelization, in addition to stressors such as water quality degradation and sedimentation (USFWS 2000).

The use of *Pleurobema* in bioaccumulation studies has not been reported on. However, Imlay (1982) recommended the use of the Ohio Pigtoe (*Pleurobema cordatum*), Tennessee Clubshell (*Pleurobema oviforme*), and Round Pigtoe (*Pleurobema sintoxia*) as biomonitors of heavy metals on the basis of annual shell growth. This recommendation was based on “widespread distribution, age, pollution tolerance, and/or conchological reflection of stream location.”

Turgeon et al. 1998 Taxa	32
Presumed Extinct Taxa	13 (41.0%)
Federally Listed Taxa	12 (38.0%)
Williams et al. 1993	
Special Concern	4 (13.0%)
Threatened	1 (3.0%)
Endangered	22 (69.0%)
Total	27 (84.0%)
Natureserve	
G4G5	1 (3.0%)
G4	1 (3.0%)
G3	1 (3.0%)
G2G3	3 (9.1%)
G2	3 (9.1%)
G1G2Q	1 (3.0%)
G1G2	1 (3.0%)
G1Q	3 (9.1%)
G1	10 (30.3%)
GHQ	1 (3.0%)
GH	1 (3.0%)
GX	7 (21.2%)

GENUS PROFILE - *QUADRULA*

Species Diversity and Conservation: A total of 16 species and four subspecies have been assigned to the genus *Quadrula* (Turgeon et al. 1998). A single species, the rough rockshell (*Quadrula tuberosa*), is presumed extinct (Turgeon et al. 1998). Williams et al. (1993) reviewed the conservation status of unionoids in North America and reported five *Quadrula* as special concern, three as threatened, six species as endangered, and one as possibly extinct. Currently, five taxa are listed as endangered by the U.S. Fish and Wildlife Service (USFWS 2007).

Rabbitsfoot
(*Quadrula cylindrica cylindrica*)

Pimpleback
(*Quadrula pustulosa pustulosa*)

Monkeyface
(*Quadrula metanevra*)

Shell Characteristics: Shell quadrate or round; often heavy and moderately inflated to inflated. Maximum shell length variable; usually ranging from 2.5 to 6.0 inches (64-153 mm). Shell sexual dimorphism weakly pronounced or absent. Periostracum often yellowish-tan or brown; with green smudges, chevrons, or faint rays commonly found in several taxa. If present, shell sculpture consists of few to numerous bumps, pustules, or knobs. Teeth well developed and heavy. Nacre usually white.

Habitat: The *Quadrula* are a wideranging group, inhabiting the lower and upper Mississippi River basin, Great Lakes basin, and several Gulf drainages. In general, this group is most abundant in small and large rivers, where substrates are comprised of packed sand, gravel, and cobble. Several *Quadrula* may also occur in lakes and reservoirs.

Reproduction: Researchers have identified suitable host fishes for several *Quadrula*. Confirmed hosts belong to one of three families - Cyprinidae (minnows), Ictaluridae (catfishes), or Centrarchidae (sunfishes) (Surber 1913; Coker 1921; Yeager and Neves 1986; Barnhart 2000; Hove et al. 2001; Haag and Warren 2003). However, host studies have not been performed on a fair number of taxa (many endemic to southern drainages). The genus is apparently tachytictic, with the reproductive period extending from May to August (Utterback 1915; Baker 1928).

Taxa List (Turgeon et al. 1998)
Southern Mapleleaf (*Quadrula apiculata*)
Alabama Orb (*Quadrula asperata*)
Golden Orb (*Quadrula aurea*)
Rio Grande Monkeyface (*Quadrula couchiana*)
Rabbitsfoot (*Quadrula cylindrica cylindrica*)
Rough Rabbitsfoot (*Quadrula cylindrica strigillata*)
Winged Mapleleaf (*Quadrula fragosa*)
Smooth Pimpleback (*Quadrula houstonensis*)
Cumberland Monkeyface (*Quadrula intermedia*)
Monkeyface (*Quadrula metanevra*)
Wartyback (*Quadrula nodulata*)
Texas Pimpleback (*Quadrula petrina*)
Western Pimpleback (*Quadrula pustulosa mortoni*)
Pimpleback (*Quadrula pustulosa pustulosa*)
Mapleleaf (*Quadrula quadrula*)
Purple Pimpleback (*Quadrula refulgens*)
Ridged Mapleleaf (*Quadrula rumphiana*)
Appalachian Monkeyface (*Quadrula sparsa*)
Stirrupshell (*Quadrula stapes*)
Rough Rockshell (*Quadrula tuberosa*)

Photo 35: Rabbitsfoot (*Quadrula cylindrica cylindrica*), French Creek, PA.

Tolerance to Habitat Alteration:

Members of genus *Quadrula* have demonstrated a wide array of sensitivities to habitat alteration. For example, species such as the Wartyback (*Quadrula nodulata*), Pimpleback (*Quadrula pustulosa pustulosa*), and Mapleleaf (*Quadrula quadrula*) appear capable of tolerating river impoundment (Oesch 1984; Parmalee and Bogan 1998; ESI 2001; WDNR 2003). Conversely, unionids such as the Rabbitsfoot (*Q.c. cylindrica*) have experienced widespread population reductions due to river impoundment and associated hypolimnetic releases (Bates 1962; Butler 2005b). The Rabbitsfoot is currently under assessment for federal status, while the Wartyback, Pimpleback, and Mapleleaf remain secure throughout their respective ranges (Williams et al. 1993; Butler 2005b).

Mapleleaf (*Quadrula quadrula*)

Photo 36: French Creek, PA, habitat of the Rabbitsfoot (*Q.c. cylindrica*).

Sensitivity to Toxic Contaminants: The *Quadrula* are not commonly used in laboratory toxicity testing.

Indicator Use: Foster and Bates (1978) reported the use of *Q. quadrula* as a biomonitor of copper electroplating wastes in the Muskingum River, OH. Caged mussels were placed at various intervals downstream of the study outfall for 14, 30, and 45 days. Mortality of caged mussels was observed after 11 days and associated with body burdens of 20 ug Cu/g wet tissue weight. Researchers concluded that elevated levels of copper were likely responsible for mass mortalities of freshwater mussels.

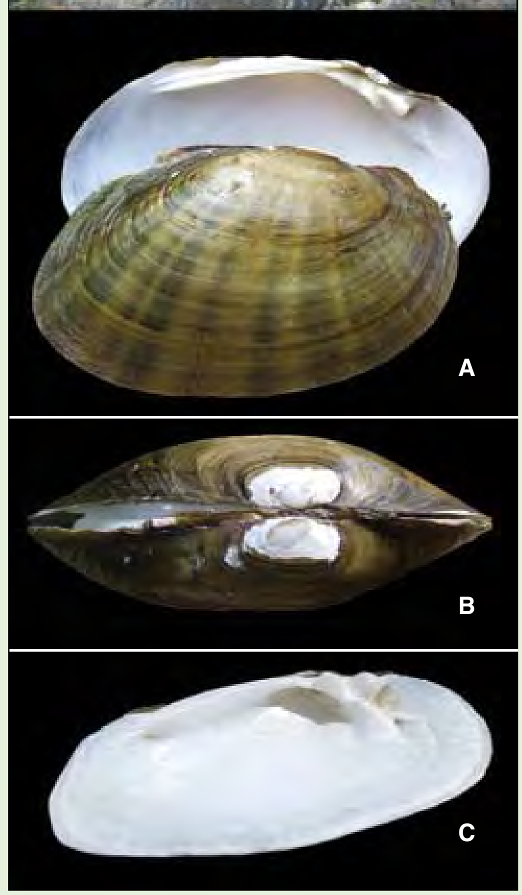
Turgeon et al. 1998 Taxa	20
Presumed Extinct Taxa	1 (5.0%)
Federally Listed Taxa	5 (25.0%)
Williams et al. 1993	
Special Concern	4 (20.0%)
Threatened	3 (15.0%)
Endangered	7 (35.0%)
Total	14 (70.0%)
G5	3 (13.6%)
G5T5	1 (4.5%)
G5T3Q	1 (4.5%)
G4	4 (18.1%)
G3G4	2 (9.1%)
G3G4T3	1 (4.5%)
G3G4T2	1 (4.5%)
G2	2 (9.1%)
G1	4 (18.1%)
GH	2 (9.1%)
GXQ	1 (4.5%)

In addition to the study above, *Q. quadrula* has been used as a biomonitor of iron-dominated mine discharges (Milam and Farris 1998) and ambient cadmium, lead, and copper levels in the Assiniboine River, Canada (Pip 1995). The Monkeyface (*Quadrula metanevra*) and Pimpleback were utilized by Allen et al. (2001) to assess potential heavy metal contamination within the habitat range of the federally threatened Neosho Madtom (*Noturus placidus*).

Imlay (1982) advocated the use of several species as biomonitors of heavy metals based on annual shell growth, including the Rabbitsfoot, Pimpleback, and Monkeyface. This recommendation was based on “widespread distribution, age, pollution tolerance, and/or conchological reflection of stream location.”

Mucket

Actinonaias ligamentina (Lamarck, 1819)



Identification tips: Shell oval to elliptical, thick, and somewhat compressed when young, becoming inflated with age. Periostracum light tannish-green to brown; young individuals often with wide green rays (A) Beak slightly raised above hinge-line; sculpture of a few concentric ridges that are often eroded (B) Teeth well developed; especially heavy in older individuals. Nacre white. Shell up to 7 inches in length.

Indicator use: A widespread and often abundant species, the Mucket is currently stable throughout its range (Williams et al. 1993; Natureserve).

Spooner et al. (2005) studied the physiological effects of high water temperatures on eight species of unionids, including *A. ligamentina*. The mucket was reported as the most thermally sensitive species studied, with reduced respiration rates at 32˚C. The authors suggested the use of *A. ligamentina* as an indicator species for mussel bed health in the Kiamachi River, OK. It was also advised that managing to protect Mucket populations should translate into thermal protection for federally listed species.

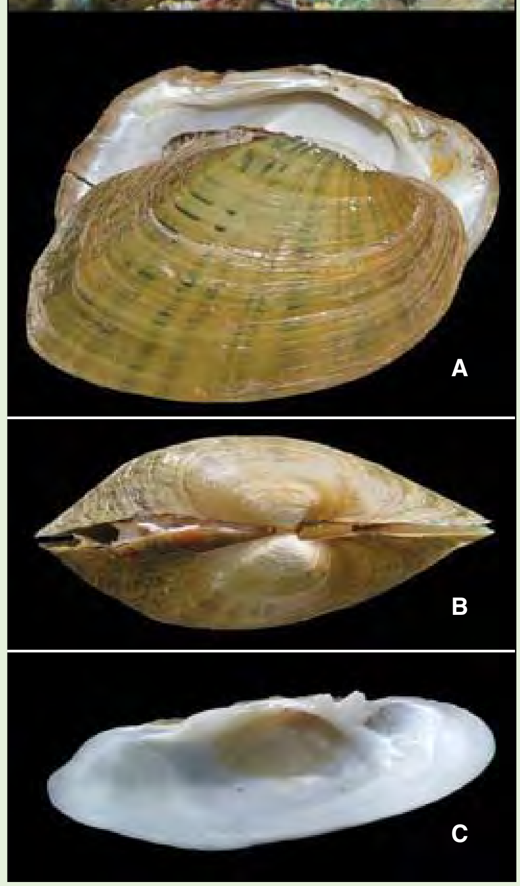
GMAVs compiled and ranked by Augspurger et al. (2003), Augspurger et al. (2006), and March et al. (2007) placed *Actinonaias* as "intermediately tolerant" of ammonia and copper when compared to other unionid genera.

Habitat: Widespread in the Mississippi River basin and Great Lakes-St. Lawrence basin. The Mucket is found in creeks and rivers where substrates are comprised of stable sand, gravel, and cobble.

Reproduction: Identified host species include the American Eel, Central Stoneroller, Silverjaw Minnow, Common Carp, Tadpole Madtom, Banded Killifish, White Bass, Rock Bass, Green Sunfish, Orangespotted Sunfish, Bluegill Sunfish, Black and White Crappie, Smallmouth Bass, Largemouth Bass, Tippecanoe Darter, and Yellow Perch (Young 1911; Lefevre and Curtis 1912; Coker et al. 1921; Watters et al. 1998b). The Mucket is bradytictic, with the reproductive period extending from May to August (Surber 1912).

Pheasantshell

Actinonaias pectorosa (Conrad, 1834)



Identification tips: Shell elliptical, moderately thick, and moderately inflated. Posterior ridge usually well defined. Periostracum greenish-yellow, yellowish-tan, or brown; often with distinctive, broken green rays. Beak sculpture of indistinct lines (B); usually eroded. Teeth well developed. Nacre white. Shell up to 7 inches in length.

Indicator use: A Cumberlandian endemic that has experienced declines in portions of its range, the Pheasantshell is considered a species of "special concern" (Williams et al. 1993; Parmalee and Bogan 1998).

GMAVs compiled and ranked by Augspurger et al. (2003), Augspurger et al. (2006), and March et al. (2007) placed Actinonaias among the "intermediately tolerant" unionid genera to ammonia and copper.

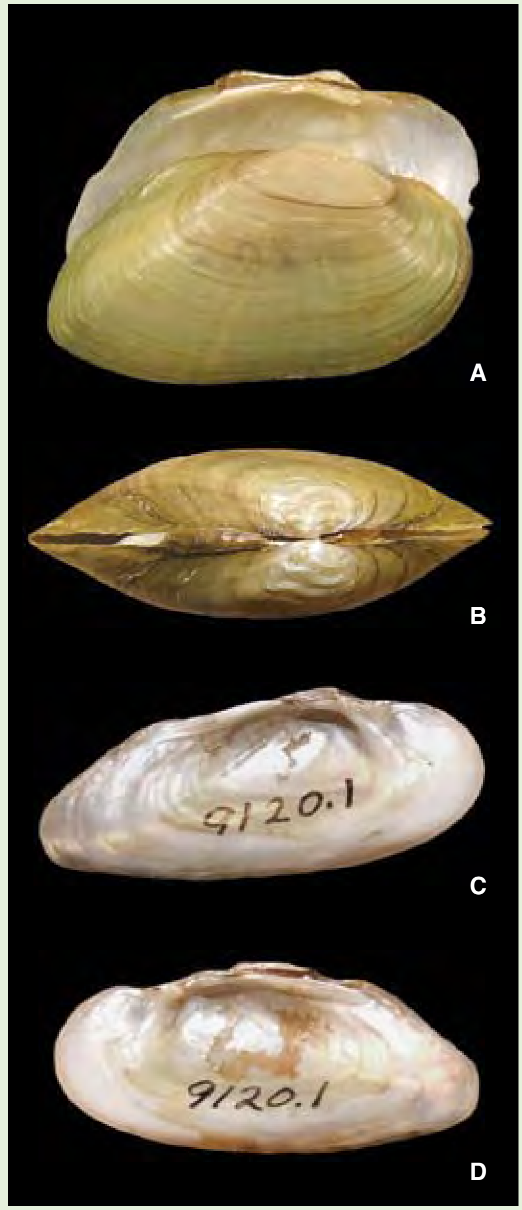
Keller and Augspurger (2005) evaluated the toxicity of fluoride from feldspar mining operations as a limiting factor in the recovery of the federally endangered Appalachian Elktoe (*Alasmidonta raveneliana*). Four unionid species were tested, with 96-hour LC50s of 178 ug/L and 303 ug/L observed for juvenile *A. pectorosa* and *A. raveneliana*, respectively. The researchers concluded that acute toxicity from fluoride was unlikely, although further sublethal tests at lower concentrations and longer durations would be worthwhile.

Habitat: Endemic to the Cumberland River system and Tennessee River system. The Pheasantshell is a species of large creeks and rivers where the water is shallow and flow is swift (Gordon and Layzer 1989; Parmalee and Bogan 1998). Occurs in sand, gravel, and cobble substrates.

Reproduction: Layzer and Khym (2005) identified several suitable hosts species, including the Rock Bass, Smallmouth Bass, Largemouth Bass, Spotted Bass, Banded Sculpin, and Sauger. Successful transformation was most often observed on *Micropterus spp.* with reported percentages of 35-43%. Several species (e.g. *Etheostoma* and cyprinids) sloughed glochidia and were found to be unsuitable hosts (Layzer and Khym 2005).

Dwarf Wedgemussel

Alasmidonta heterodon (I. Lea, 1830)



Identification tips: Shell subovate to subtrapezoidal, somewhat elongate, moderately thin, and moderately inflated. Periostracum yellowish-tan to brown; green rays may be present in young individuals (A). Beak elevated slightly above hinge-line; sculpture of a few conspicuous ridges (B), may be eroded. Teeth well developed, although small (C); two lateral teeth in right valve. Nacre bluish-white or white. Shell up to 2 inches in length.

Indicator use: Widely distributed but rare throughout its range, the Dwarf Wedgemussel is currently listed as endangered by the U.S. Fish and Wildlife Service. Like many other freshwater mussel species, the Dwarf Wedgemussel is considered relatively intolerant of impoundment and chemical pollutants (Master 1986; USFWS 1993c).

GMAVs compiled and ranked March et al. (2007) placed *Alasmidonta heterodon* among the 15 most sensitive taxa to copper.

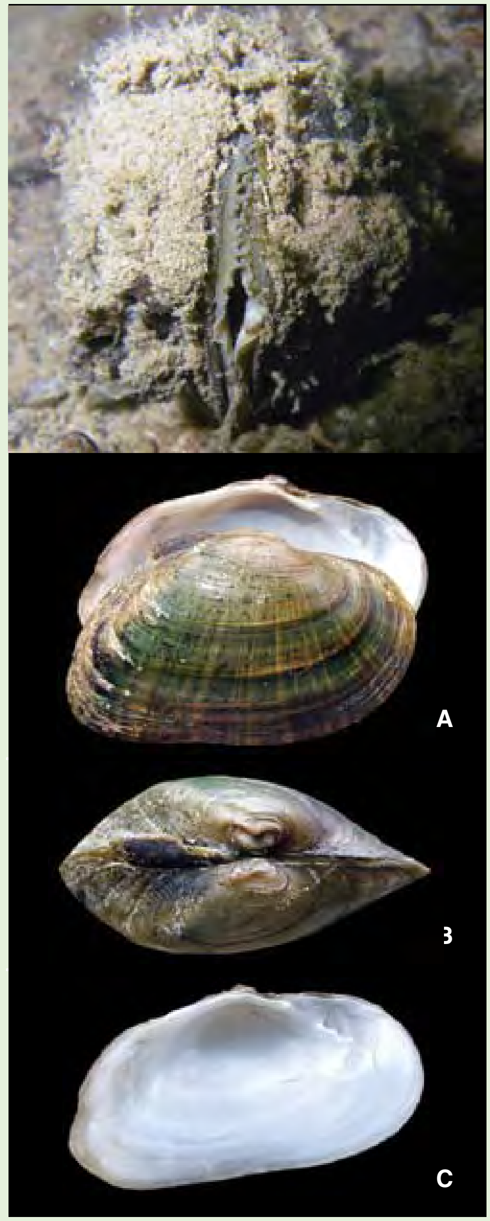
Habitat: Distributed throughout the Atlantic Slope, from North Carolina to New Brunswick, Canada. Populations are often very patchily distributed (Nedeau 2008). Occurs in headwaters to rivers where the current is slow to moderate. Generally found in stable muddy sand, sand, or sand and gravel substrates (USFWS 1993c; Nedeau 2008).

Reproduction: Confirmed host fishes include the Atlantic Salmon, Mottled Sculpin, Tessellated Darter, and Johnny Darter (Michaelson and Neves 1995; Wicklow 1999). Michaelson and Neves (1995) reported glochidial metamorphosis on 3 of 15 fish species.

The Dwarf Wedgemussel is bradytictic, with glochidia released during April and May (Michaelson and Neves 1995; McLain and Ross 2005).

Elktoe

Alasmidonta marginata (Say, 1818)



Identification tips: Shell elongate to elliptical, somewhat thin and inflated, with an abruptly angled posterior (A). Periostracum yellowish-tan to brownish; with wide green rays and flecks (A). Beak sculpture of distinctive, heavy ridges (B); usually conspicuous in both young and old individuals. Pseudocardinal teeth weakly developed, lateral teeth present as a thickened hinge (C). Nacre white. Shell up to 4 inches in length. Notes: Orange foot. Live Elktoe are often covered with periphyton (see upper right photo).

Indicator use: While widely distributed, the Elktoe occurs sporadically throughout its range and is considered a species of "special concern" (Williams et al. 1993; USFWS 2007c). It is characteristic of flowing streams of good quality and does not appear to tolerate impoundment (Watters 1995; Parmalee and Bogan 1998). Oesch (1984) reported that wastes from mining activities reduced its abundance in the Big River, MO.

Bedford et al. (1968) harvested Elktoe and several other unionid species from the Red Cedar River (MI) for pesticide analysis. Reported concentrations ranged from 0.0153-0.198 ppm total DDT and metabolites. Concentrations did not significantly vary between species. The study concluded that mussels were excellent indicators of pesticide contamination; mainly because of their ability to concentrate contaminants.

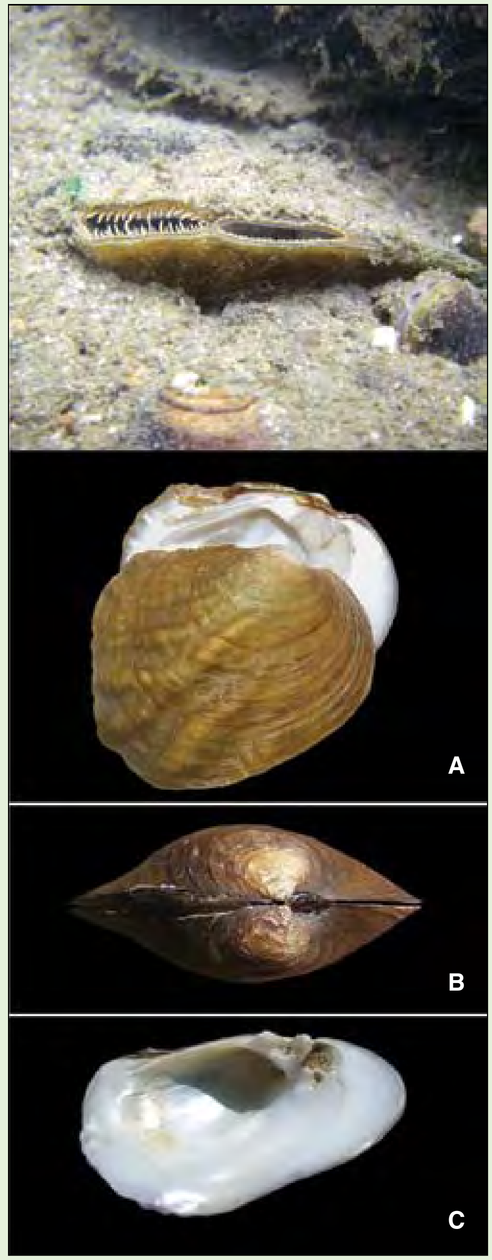
Habitat: Distributed throughout the Mississippi River basin, Great Lakes-St. Lawrence basin, and Susquehanna drainage. Occurs in moderate-sized streams to small rivers where the current is swift and streambed comprised of sand, gravel, and small cobble substrates.

Reproduction: Identified host species include the White Sucker, Northern Hog Sucker, Shorthead Redhorse, Rock Bass, and Warmouth Sunfish (Howard and Anson 1922; Howard and Anson 1923).

The Elktoe is bradytictic, with the reproductive period extending from June to July (Baker 1928).

Threeridge

Amblema plicata (Say, 1817)



Identification tips: Shell subquadrate or subrhomboidal, thick, and somewhat compressed to inflated. Periostracum light tannish-green (A), brown, or dark brown; rayless. Beak nearly even to raised above hinge-line; sculpture of a few coarse ridges (B). Teeth well-developed (C); especially heavy in older individuals. Nacre white. Shell up to 7 inches in length.

Indicator use: A widely distributed species, the Threeridge has demonstrated tolerance to impoundment, pollutants, and regular harvest (Starrett 1971; Oesch 1984; WDNR 2003). ESI (2000) reported *A. plicata* as common to dominant in several of the navigational pools of the upper Ohio River. The Threeridge is currently considered secure throughout its range (Williams et al. 1993; Natureserve).

Spooner et al. (2005) studied the physiological effects of high water temperatures to eight species of unionids, including *A. plicata*. The Threeridge was the among the more tolerant unionid species to high temperatures, exhibiting stress at 34-35˚C and maximal stress at 42˚C. The authors suggested the use of *A. ligamentina* as an indicator species in lieu of more thermally tolerant species such as the Threeridge.

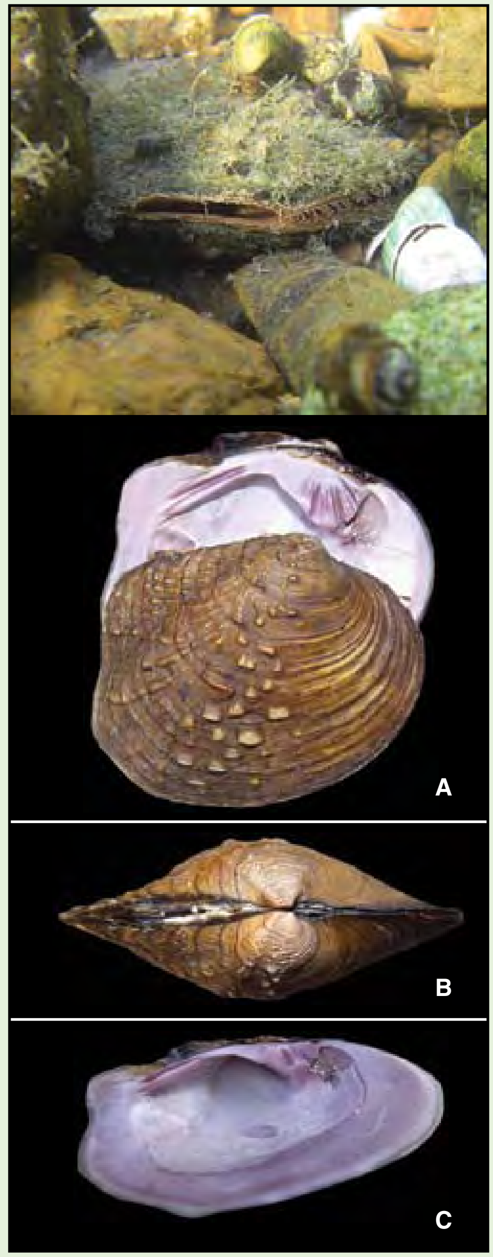
The Threeridge has been used extensively to biomonitor pollutants, for more information see Adams et al. (1980; 1981), Naimo et al. (1992), and Pip (1995).

Habitat: Widespread in the Mississippi basin, Great Lakes-St. Lawrence basin, north into Canada, and several Gulf drainages. The Threeridge occurs in small creeks to rivers, embayments, and lakes. It may be found at depths ranging from 0.5-30 feet, in both fine and coarse substrates.

Reproduction: Over 20 species of fish belonging to eight taxonomical families have been identified as suitable hosts for *A. plicata* (Howard 1914; Wilson 1916; Coker et al. 1921; Stein 1968; Weiss and Layzer 1995).

Purple Wartyback

Cyclonaias tuberculata (Rafinesque, 1820)



Identification tips: Shell round or subquadrate, thick, and moderately compressed. Shell surface with numerous pustules, usually most abundant medially and posteriorly (A). Periostracum brown to dark brown, with well defined rest lines (A). Beak even or slightly raised above hinge-line; sculpture of numerous ridges (B). Teeth well developed (C); may be particularly heavy in old individuals. Nacre purple (C) or white. Shell up to 6 inches in length.

Indicator use: Widely distributed but sporadically occurring, the Purple Wartyback is an inhabitant of good quality creeks and rivers where the water is clear (Watters 1995; Badra and Goforth 2002). *C. tuberculata* has also been recorded from lentic or impounded habitats, although the long-term viability of these populations remains unclear (Bates 1962; Parmalee and Bogan 1998). Williams et al. (1993) considered it a species of special concern.

Imlay (1982) suggested of the use of *C. tuberculata* as a biomonitor of heavy metals on the basis of annual shell growth. This recommendation was based on "widespread distribution, age, pollution tolerance, and/or conchological reflection of stream location."

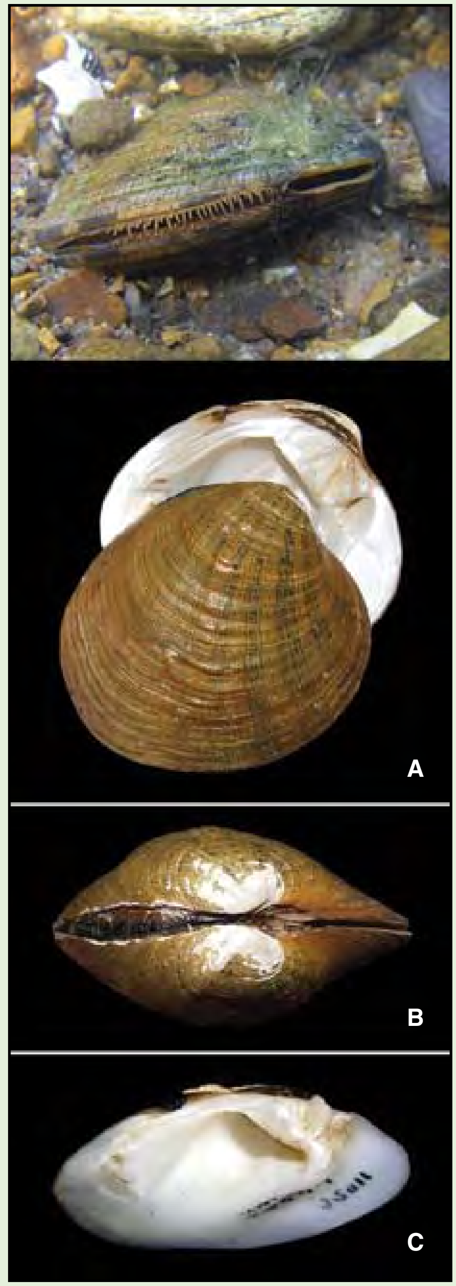
Habitat: Fairly widespread throughout the Mississippi River basin and Great Lakes basin. Occurs in both creeks and rivers where the current is slow to swift. May also be found in lentic habitats. Often most abundant in a mixture of mud, sand, and gravel.

Reproduction: Confirmed host fishes include the Black Bullhead, Yellow Bullhead, Channel Catfish, and Flathead Catfish (Hove 1994b; Hove et al. 1997).

The Purple Wartyback is tachytictic, with the reproductive period extending from June to August (Ortmann 1919).

Dromedary Pearlymussel

Dromus dromas (Lea, 1834)



Identification tips: A round, deep, thick, and slightly inflated shell. Periostracum yellowish-tan with very fine, broken green rays or lines; often more prominent anteriorly (A). Beak sculpture of indistinct ridges; often eroded (B). Teeth well developed and large (C). Nacre white or pink. Shell up to 4 inches in length.

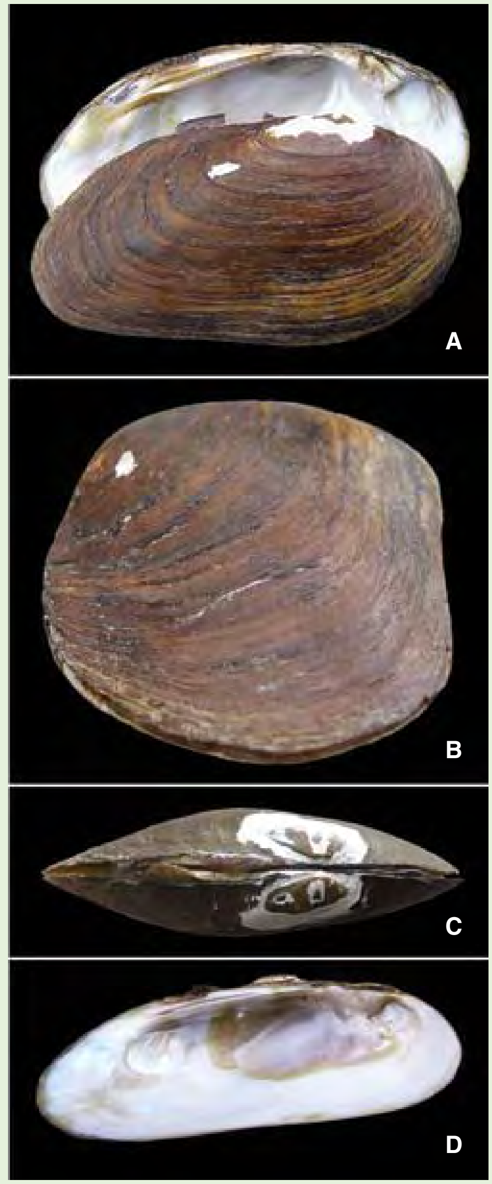
Indicator use: This once widespread and abundant Cumberlandian species has declined dramatically during the 20th century. A study by Hughes and Parmalee (1999) reported the notable abundance of *D. dromas* at prehistoric aboriginal sites along the Tennessee River. Of the 159,450 freshwater mussel shells recovered from 15 sites, the Dromedary Pearlymussel constituted 32% of the identified specimens. The widespread impoundment of the Tennessee and Cumberland drainages has probably contributed more to the decline of *D. dromas* than any other factor, although dredging, sand and gravel mining, coal mining, and sewage wastes have also been implicated (USFWS 1983a; Hughes and Parmalee 1999; Jones et al. 2004). This species is now listed as endangered by the U.S. Fish and Wildlife Service.

Habitat: Endemic to the Cumberland River and Tennessee River drainages. Viable populations of *D. dromas* occur in the Clinch and Powell rivers (Jones et al. 2004). Historically, this species occurred in moderate sized streams to rivers in shallow water (<3 ft.). Most often found in packed sand, gravel, and cobble substrates.

Reproduction: Identified host fishes include numerous darter and sculpin species, including the Black Sculpin, Greenside Darter, Fantail Darter, Snubnose Darter, Tangerine Darter, Blotchside Logperch, Logperch, Channel Darter, Gilt Darter, and Roanoke Darter (Jones et al. 2004). Glochidia are packed into 20-40 mm conglutinates that resemble leeches or flatworms (Jones et al. 2004). *D. dromas* is bradytictic, although the species shares some traits of tachytictic taxa (Ortmann 1912; Jones et al. 2004).

Eastern Elliptio

Elliptio complanata (Lightfoot, 1786)



Identification tips: Shell variable; subtrapezoidal, elongate, moderately thin to thick, and compressed to slightly inflated. Periostracum yellowish-tan to dark brown; green rays may be present in young individuals. Beak roughly even to slightly elevated above hinge-line; sculpture of several ridges, usually eroded (C). Teeth well developed (D). Nacre white, salmon, or purple. Shell up to 5 inches in length.

Indicator use: Widely distributed in eastern North America, the Eastern Elliptio has been reported as a habitat generalist that tolerates disturbance (Ortmann 1919; Johnson 1970; Nedeau 2008; Natureserve).

Of the freshwater mussels found in North America, no other species has been so extensively used as a biomonitor of pollutants (e.g. Campbell and Evans 1991; Renaud et al. 1995; Beckvar et al. 2000; Gagne et al. 2001; Mierzykowski and Carr 2001; Gewurtz et al. 2002; Gewurtz et al. 2003; Martel et al. 2003). In addition, *E. complanata* has been frequently employed to better understand the bioavailability, bioaccumulation, and biotransformation of pollutants (e.g. Day et al. 1990; Metcalfe-Smith 1994; Tessier et al. 1994; Muncaster et al. 2002; Gewurtz et al. 2002; O'Rourke et al. 2004; Thorsen et. al 2004).

Habitat: Distributed throughout the northern and southern Atlantic Slope, Hudson Bay basin, and parts of the Great Lakes-St. Lawrence basin. Occurs in a wide variety of habitats, including creeks, rivers, embayments, and lakes. May be found in both coarse and fine substrates.

Reproduction: Confirmed host fishes include the Banded Killifish, Green Sunfish, Redear Sunfish, Orangespotted Sunfish, Largemouth Bass, White Crappie, and Yellow Perch (Young 1911; Watters 1994; Watters et al. 2005).

The Eastern Elliptio is tachytictic, with the reproductive period extending from May to July. Ortmann (1919) reported that the glochidia of *E. complanata* are packaged in conglutinates.

Spike

Elliptio dilatata (Rafinesque, 1820)

Identification tips: Shell elongate, moderately thick, and somewhat compressed. Periostracum yellowish-tan to brown; young often with faint green rays (A). Older individuals brown to dark brown and rayless. Beak with distinctive, coarse ridges (C). Teeth well developed. Nacre white, salmon, or purple (B). Shell up to 6 inches in length.

Indicator use: A wideranging unionid that may be locally abundant, the Spike is secure throughout its range (Williams et al. 1993; Natureserve). Stansberry (1965) considered the spike intolerant of water pollution and Oesch (1984) reported a reduction in its range where severe channelization and siltation had occurred.

Wren and MacCrimmon (1983) analyzed the bioaccumulation and biomagnification of metals in an undisturbed lake in Ontario, Canada. Tissue samples were collected from a number of fish, birds, mammals, and the freshwater mussel – *E. dilatata*. The following wet weight metal concentrations (ug/g) were reported: Cd 5.8; Cu 2.0; Pb 4.5; Hg 0.17; Zn 78.5. In general, *E. dilatata* bioaccumulated higher concentrations of cadmium, copper, lead, and zinc than fish species. However, mercury was found to biomagnify up the food chain, with concentrations of 1.0 and 1.7 ug/g found in the Northern Pike (*Esox lucius*) and Herring Gull (*Larus argentatus*), respectively.

Habitat: Widespread in the Mississippi River basin and Great Lakes-St. Lawrence basin. The Spike occurs in small to large creeks, rivers, lakes, and impoundments. Often most abundant in flowing habitats where the streambed is comprised of stable sand and gravel substrates.

Reproduction: Identified host fishes include the Flathead Catfish, Gizzard Shad, Rock Bass, White and Black Crappie, Banded Sculpin, Rainbow Darter, Yellow Perch, and Sauger (Howard 1914; Wilson 1916; Clark 1981; Luo 1993).

The Spike is tachytictic, with the reproductive period extending from mid-May to August (Baker 1928).

Oyster Mussel

Epioblasma capsaeformis (Lea, 1834)

Identification tips: General: Shell elliptical, somewhat thin, and moderately inflated. Sexually dimorphic: Females (A) expanded and rounded posteriorly, males (B) elliptical and without expansion. General: Periostracum yellowish-tan to light brown with numerous green rays of varying widths. Beak sculpture of indistinctive loops; often eroded. Teeth well developed. Nacre white. Shell up to 3 inches in length.

Indicator use: The Oyster Mussel is listed as federally endangered, occupying just a minute fraction of its former range (USFWS 2004). Historically, it was one of the most widely distributed and common Cumberlandian species (Ortmann 1918; 1924; 1925). The decline of *E. capsaeformis* is most often associated with impoundment, channelization, and mineral extraction (Bates 1962; USFWS 2004).

Recent toxicological studies have evaluated the sensitivity of the Oyster Mussel to a variety of pollutants. For example, Valenti et al. (2006a) evaluated the toxicity of chlorine to five unionid species, including three federally listed taxa. Federally listed species were reportedly more sensitive to TRC (total residual chlorine) than two non-listed species. Mean 24-hr LC50s for non-listed species ranged from 145 to 220 TRC ug/L, while federally listed LC50s ranged from 70 to 107 TRC ug/L. The reported 24-hr mean LC50 for *E. capsaeformis* was 107 ug/L.

Habitat: Endemic to the Cumberland River system and Tennessee River system. Occurs in moderate-sized streams to rivers where the current is swift. Generally most abundant at shallow depths (< 3 ft.) where substrates are comprised of stable sand, gravel, and cobble.

Reproduction: Identified host fishes include the Banded Sculpin, Wounded Darter, Redline Darter, Spotted Darter and Dusky Darter (Hill 1986; Yaeger and Saylor 1995).

The Oyster Mussel has been documented with mature glochidia during May, June, and July (Gordon and Layzer 1989; Yaeger and Saylor 1995).

Northern Riffleshell

Epioblasma torulosa rangiana (Lea, 1838)

Identification tips: General: Shell moderately thick and moderately inflated. Sexually dimorphic: Females (A) expanded, rounded, and compressed posteriorly, males (B) somewhat triangular and sulcate. General: Periostracum yellowish-tan to light brown with fine green rays. Beak sculpture of double-loops; often eroded or indistinct (C). Teeth well developed (D). Nacre white. Shell up to 3 inches in length.

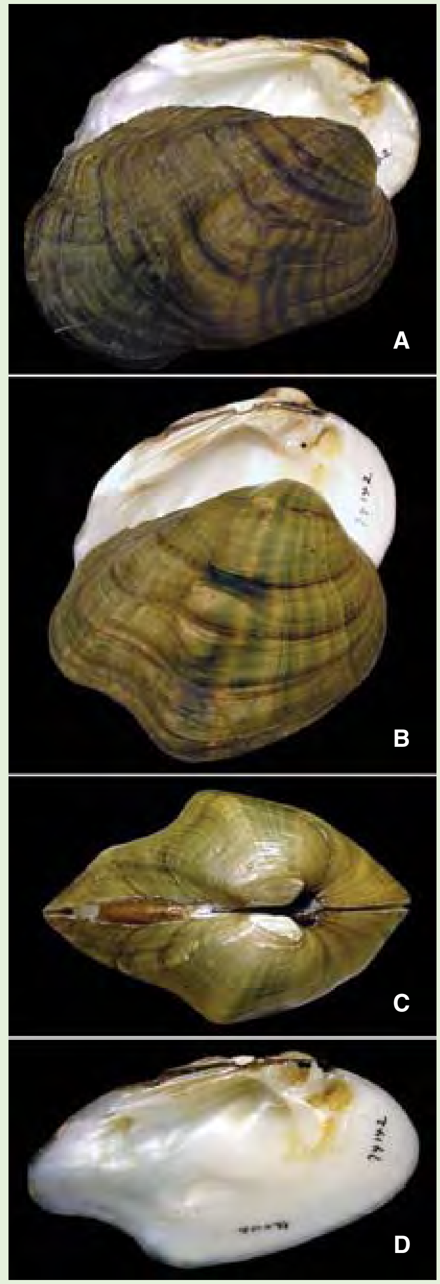
Indicator use: This once widespread subspecies has declined sharply and is now listed as federally endangered, occupying less than 5% of its former range (USFWS 2007). *E.t. torulosa* is thought to be sensitive to siltation, impoundment, and water pollution (USFWS 1994; USFWS 1997). Toxicity testing of a congener (*Epioblasma capsaeformis*) suggests that the *Epioblasma* may be among the most sensitive aquatic genera to copper and ammonia.

Habitat: Occurs in the Mississippi River basin and Great Lakes basin. Found in flowing reaches of large creeks and rivers where substrates are comprised of stable sand, gravel, and cobble. The largest remaining populations occur in the Allegheny River and French Creek, PA (USFWS 1994).

Reproduction: Identified host fishes include the Brown Trout, Banded Darter, Bluebreast Darter, and Banded Sculpin (Watters 1996a). Anecdotal evidence and recent investigations suggest that *E.t. rangiana* may capture host fishes to facilitate glochidia transfer (Barnhart 2006). The Northern Riffleshell is likely bradytictic, with gravid females having been observed in September (Ortmann 1919).

Tubercled Blossom

Epioblasma torulosa torulosa (Rafinesque, 1820)



Identification tips: General: Shell moderately thick and moderately inflated; with a row of irregular medial knobs often extending from the beak to ventral margin. Sexually dimporphic: Females (A) greatly expanded and rounded posteriorly, males (B) sulcate and with a distinctive posterior-ventral indentation. General: Periostracum yellowish-tan with fine green rays. Beak sculpture of indistinct ridges, often absent in adults (C). Teeth well developed (D). Nacre white. Shell up to 3 inches in length.

Indicator use: The Tubercled Blossom is a federally endangered species and may now be extinct (Parmalee and Bogan 1998; USFWS 2007a; USFWS 2007b). *E.t. torulosa* formerly occurred throughout the Tennessee River drainage, Cumberland River, and upper Ohio River drainage (USFWS 1985a). Investigations of archaeological shell middens along the Tennessee River suggest that this species was once fairly common in the Tennessee mainstem (Hughes and Parmalee 1999). It was last found fresh dead below Kanawha Falls (WV) in 1969 (USFWS 2007a).

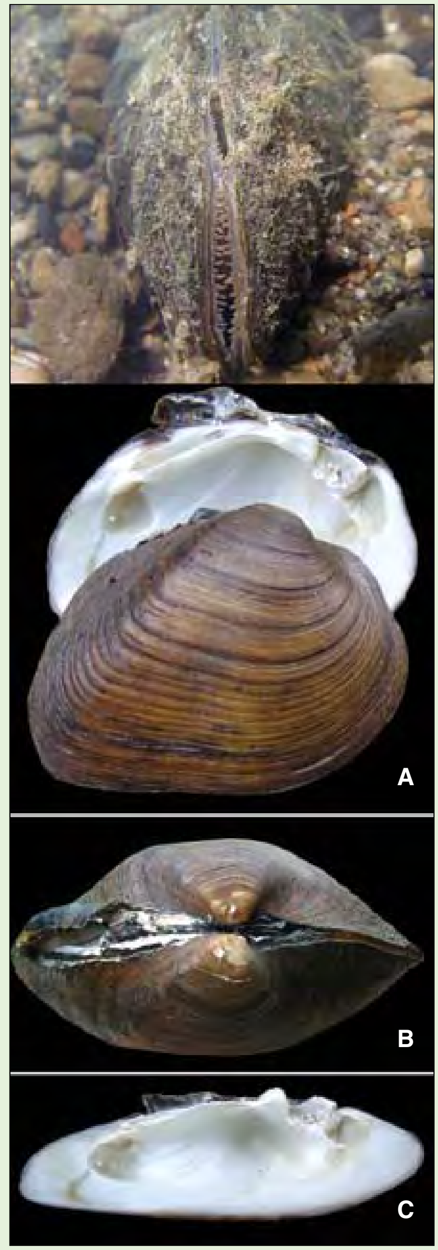
The decline of *E.t. torulosa* (and many of its congeners) has been attributed to ubiquitous river impoundment, increased turbidity and siltation associated with agriculture and deforestation, and pollution (USFWS 1985a; USFWS 2007a).

Habitat: Formerly occurred in the Tennessee River drainage, Cumberland drainage, and upper Ohio drainage. *E.t. torulosa* has been found in shallow reaches of rivers with swift current and substrates comprised of stable sand and gravel.

Reproduction: Unknown.

Wabash Pigtoe

Fusconaia flava (Rafinesque, 1820)



Identification tips: Shell highly variable; usually subtriangular, moderately thick, and moderately inflated. Ventral margin of shell may have a velvet-like texture. Big river forms usually with greater inflation and umbo often more anterior. Periostracum yellowish-tan to brown, rest lines distinctive; young often with fine green rays. Beak sculpture of indistinct ridges as adult (B). Teeth well developed (C). Nacre white, may have a salmon tinge. Shell up to 4 inches in length.

Indicator use: A unionid that occurs in a broad range of habitats, the Wabash Pigtoe is one of the most ubiquitous mussels in North America. It reportedly adapts to a variety of substrate types and habitat conditions (Watters 1995; Parmalee and Bogan 1998). Strayer (1983) commented that the Wabash Pigtoe "seems to do well in muddy, hydrologically unstable, low-gradient streams."

Spooner et al. (2005) studied the physiological effects of high water temperatures on eight species of unionids, including *F. flava*. The Wabash Pigtoe was reported as among the more thermally tolerant species, exhibiting stress at 34-35˚C and maximal stress at 38˚C. The authors suggested the use of *A. ligamentina* as an indicator species in lieu of more thermally tolerant species, such as the Wabash Pigtoe.

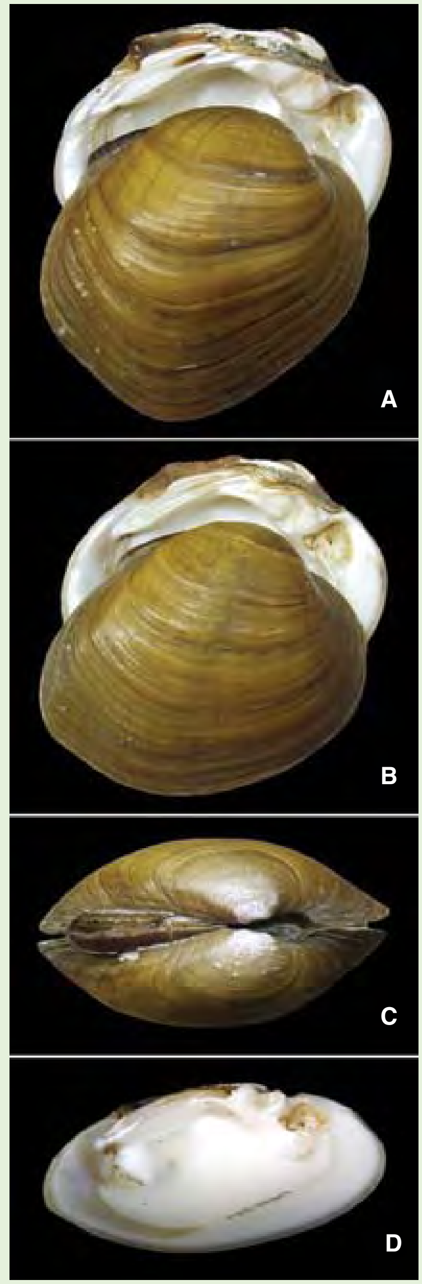
Waller and Fisher (1998a) exposed *F. flava* and a number of other unionids to various chloride salts. The Wabash Pigtoe was among the most tolerant unionids to the various salt treatments, while the Threehorn Wartyback (*Obliquaria reflexa*) and Fragile Papershell (*Leptodea fragilis*) were among the more sensitive.

Habitat: Occurs throughout the Mississippi River basin, Great Lakes-St. Lawrence basin, and Mobile basin. Found in creeks, rivers, embayments, and lakes. Often most abundant where substrates are comprised of stable sand, gravel and cobble, although *F. flava* may also occur in fine substrates.

Reproduction: Identified host fishes include the Creek Chub, Silver Shiner, Bluegill Sunfish, Black Crappie, and White Crappie (Howard 1914; Wilson 1916; Watters and O'Dee 1997). The Wabash Pigtoe is tachytictic, with the reproductive period extending from May to August.

Pink Mucket

Lasmpsilis abrupta (=orbiculata) (Say, 1831)



Identification tips: General: Shell elliptical or subquadrate, thick, and slightly inflated to inflated. Sexually dimorphic: Females expanded and inflated posteriorly (A), males bluntly pointed (B). General: Periostracum yellowish-tan or brown; often rayless, although faint rays may be seen near the beak (A) and in young individuals. Beak sculpture of indistinct double-loops; often eroded (C). Teeth well developed (D); pseudocardinal teeth large and heavy in older individuals. Nacre white or pink. Shell up to 5 inches in length.

Indicator use: Although widely distributed, the Pink Mucket remains imperiled or critically imperiled throughout its range (Natureserve). Collections made by early naturalists suggest that *L. abrupta* may have also been uncommon in the recent past (USFWS 1985c). The Pink Mucket is currently listed as endangered by the U.S. Fish and Wildlife Service (USFWS 1985c; USFWS 2007).

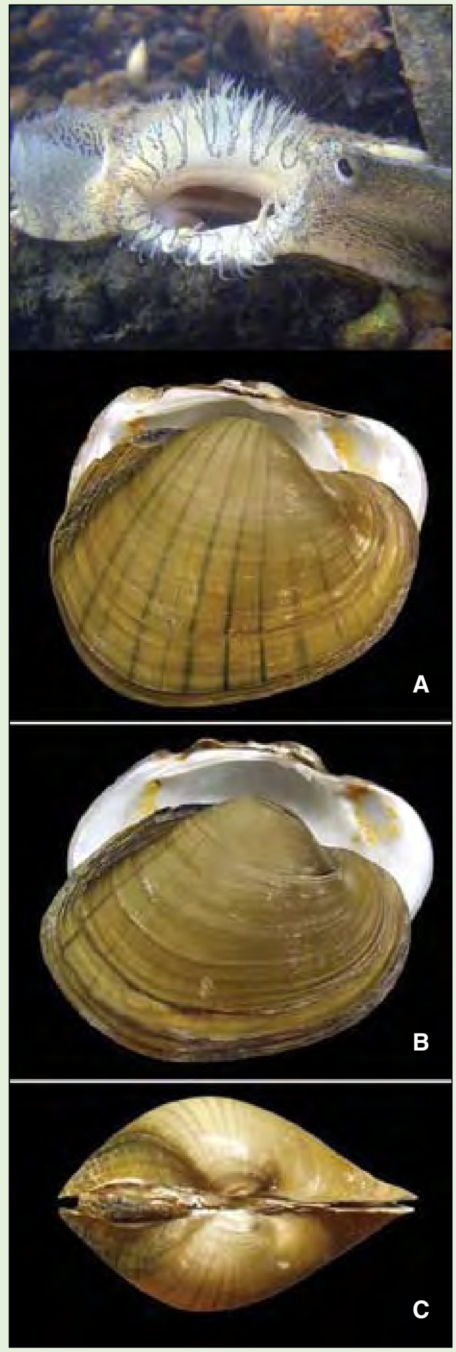
Wang et al. (2007a) evaluated the toxicity of copper, and ammonia to the early life stages of *L. abrupta* and several other unionid species. Short-term exposures of copper to *L. abrupta* glochidia yielded a 24-hr EC50 of 34 ug Cu/L, a test result comparable to other species. Juvenile (2-month old) *L. abrupta* were slightly more sensitive than other test species during 96-hour exposures to ammonia, with a reported EC50s of 2.3 mg N/L.

Habitat: Widespread throughout the Mississippi Basin, Tennessee River, Cumberland River, and Ohio River drainage (USFWS 1985c). The Pink Mucket is found in small to large rivers where substrates are comprised of stable sand, gravel, and cobble. *L. abrupta* typically inhabits shallow, swiftly flowing areas, which may include the tailwaters and upper reaches of navigational pools where adequate habitat is present (USFWS 1985).

Reproduction: Identified host fishes include the Smallmouth Bass, Largemouth Bass, Spotted Bass, and Walleye (Barnhart et al.1997). The confirmed hosts of a relative, *Lampsilis higginsi*, include the Sauger, Freshwater Drum, and Yellow Perch, in addition to some of the fishes named above (Surber 1913; Waller and Holland-Bartels 1988).

Plain Pocketbook

Lampsilis cardium (Rafinesque, 1820)



Identification tips: General: Shell moderately thick to thick and inflated. Sexually dimorphic: Females (A) inflated and rounded posteriorly, males (B) pointed posteriorly. General: Periostracum yellowish-tan to brown; with few to numerous green rays (A-B). Beak elevated above hingeline; sculpture double-looped (C), often more distinctive in younger individuals. Teeth well developed. Nacre white. Shell up to 7 inches in length.

Indicator use: The Plain Pocketbook is a widespread species that occurs in a variety of habitats. In Tennessee, it has been reported to tolerate impoundment, poor water quality, and substrates comprised of mud and silt (Parmalee and Bogan 1998).

In an effort to assess lead and cadmium contamination from tailing ponds and chat piles in the Big River watershed (MO), Czarnezki (1987) used *L. cardium* to biomonitor contaminant levels at five sites. The mussels were found to accumulate metals quickly and assisted in identifying the main sources of contamination.

Under laboratory conditions, juvenile *L. cardium* exhibited sensitivity to ammonia during acute pore water exposures (Newton et al. 2003). Fifty percent mortality was observed at concentrations as low as 93 ug NH_3-N/L and sublethal effects (50% reduced growth) occurred at 31 ug NH_3-N/L. An in-situ companion study performed by Bartsch et al. (2003) deployed caged juveniles below the substrate surface in the St. Croix River, WI. Survival and growth were reported as highly variable and generally unrelated to ammonia concentrations found at the study sites.

Habitat: Widely distributed throughout the Mississippi River basin, Great Lakes-St. Lawrence Basin, and north into Canada. Occurs in moderate-sized streams to rivers, lakes, reservoirs, and coastal marshes. Found in a variety of substrates, from sand, gravel, and cobble to mud and silt.

Reproduction: Identified host fishes include the Pumpkinseed Sunfish, Bluegill Sunfish, Green Sunfish, Largemouth Bass, Smallmouth Bass, White Crappie, Black crappie, Yellow Perch, Sauger and Walleye (Coker 1921; Waller et al. 1985; Watters 1996b; Draxler et al. 2006). The Plain Pocketbook utilizes a minnow-like lure to attract host fishes (partially visible in upper right photo).

Wavyrayed Lampmussel

Lasmpsilis fasciola (Rafinesque, 1820)

Identification tips: General: Shell oval, moderately thick, and moderately inflated to inflated. Sexually dimorphic: Females (A) expanded and rounded posteriorly, males (B) bluntly pointed. General: Shell periostracum with distinctive, wavy green rays (A-B). Beak slightly raised above hinge-line; sculpture of somewhat irregular double-loops (C). Teeth well developed. Nacre white. Shell up to 5 inches in length.

Indicator use: The Wavyrayed Lampmussel is a species of hydrologically stable and good quality streams (Strayer 1983; Watters 1995). It may be locally abundant when found and is considered stable throughout its range (Williams et al. 1993; Natureserve).

Several researchers have used *L. fasciola* as a test organism when evaluating the sensitivity of unionids to contaminants (e.g. Jacobson et al. 1997; Cherry et al. 2002; Keller and Augspurger 2005; Valenti et al. 2006; Bringolf et al. 2007; Wang et al. 2007a; 2007b). Wang et al. (2007) conducted a series of ammonia toxicity trials using *L. fasciola* glochidia and juveniles, in addition to the early life stages of several other unionid species. Reported EC50s for Wavyrayed glochidia ranged from 6.2 to 8.7 mg N/L during 24-hour exposures. These results were generally comparable to the values reported for other species, with the exception of two particularly sensitive species - the Ellipse (*Venustaconcha ellipsiformis*) and Oyster Mussel (*E. capsaeformis*). GMAVs compiled and by Augpsurger et al. (2003), Augspurger et al. (2003), and March et al. (2007) rank *L. fasciola* among the most sensitive aquatic species to ammonia and copper.

Habitat: Occurs disjunctly throughout the Mississippi River basin and Great Lakes basin. Generally found in creeks to small rivers at shallow depths in stable sand and gravel. This species has also been documented to occur at depths of 15 feet or more in the Tennessee River and Allegheny River.

Reproduction: Identified host fishes include the Smallmouth Bass (Zale and Neves 1982). The Wavyrayed Lampmussel utilizes a mantle flap lure (upper right photo) to entice host fishes. The striking action of predators triggers the expulsion of hundreds to thousands of glochidia, thereby facilitating the parasitization of the host fish.

Fatmucket

Lampsilis siliquoidea (Barnes, 1823)

Identification tips: General: Shell moderately thick and somewhat compressed to moderately inflated. Sexually dimorphic: Females (A) inflated and rounded posteriorly, males (B) bluntly pointed posteriorly. General: Periostracum yellowish-tan to brown; with few to numerous green rays (A-B). Beak elevated slightly above hinge-line; sculpture double-looped (C), often more prominent in younger individuals. Teeth well developed. Nacre white. Shell up to 5 inches in length.

Indicator use: Widely distributed and often abundant, the Fatmucket has been described as tolerant of silt and disturbance (Dawley 1947; Watters 1995; McRae et al. 2004).

Manny and Kenaga (1991) reported the use of *L. siliquoidea* (= *L. radiata siliquoidea*, see Turgeon et al. 1998) as a biomonitor of heavy metals, PCBs, and octachlorostyrene in the Detroit River, a heavily urbanized watershed. Researchers found toxic contaminants concentrated by *L. siliquoidea* to levels 59 times nearby sediments (GLI 1984; Pugsley et al. 1985).

Bringolf et al. (2007b) investigated the toxicity of several forms of glyphosate, its formulations, and a surfactant (MON 0818) to juvenile and glochidial Fatmucket (*L. siliquoidea*). Reported 24-hour EC50s were as low as 3.0 mg/L and 0.6 mg/L for Roundup and MON 0818, respectively. Reported 96-hour EC50s for juvenile *L. siliquoidea* were 5.9 mg/L and 3.8 mg/L for Roundup and MON 0818, respectively. Researchers concluded that the early life stages of the Fatmucket are among the most sensitive aquatic organisms to glysphosate-based chemicals and MON 0818 tested to date.

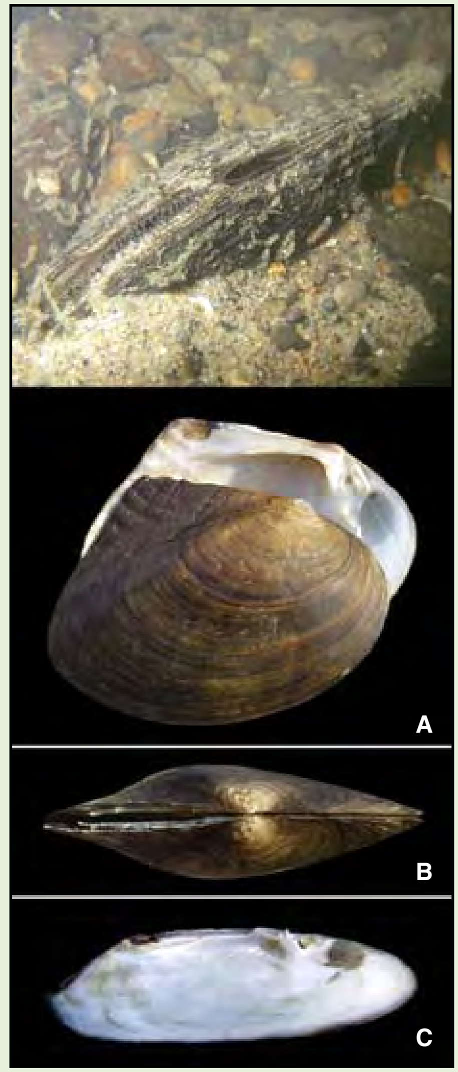
Habitat: Widely distributed throughout the Mississippi River basin, Great Lakes-St. Lawrence drainage, and north into Canada. Occurs in a wide variety of habitats, including creeks, rivers, lakes, and backwaters. Generally most abundant in sluggish to moderate currents, in both fine and coarse substrates.

Reproduction: A total of 20 fishes have been identified as suitable host species for *L. siliquoidea* (Evermann and Clark 1918; Coker et al. 1921; Fuller 1978; Trdan 1981; Watters and O'Dee 1997; O'Dee and Watters 2000; Watters et al. 2005).

The Fatmucket is bradytictic, with the reproductive period extending from August to July (Baker 1928).

White Heelsplitter

Lasmigona complanata complanata (Barnes 1823)



Identification tips: Shell large, compressed, and moderately thin to moderately thick; with a distinctive, often ribbed dorsal wing (A-B). Periostracum light to dark brown; usually with fine green rays in young individuals. Beak sculpture of conspicuous double-loops (C). Pseudocardinal teeth well developed although low and irregularly serrated; lateral teeth present as an under developed raised and striated ridge. Nacre white. Shell up to 8 inches in length.

Indicator use: This wideranging unionid has been reported to be tolerant of silt, habitat disturbance, and impoundment by numerous authors (Stansberry 1965; Watters 1995; Dean et al. 2002; Metcalfe-Smith et al. 2003; Sietman 2003). Stayer and Jirka (1997) noted that *L.c. complanata* was "one of the few unionoids that seemed to do well in disturbed substrates."

The White Heelsplitter may potentially exploit areas that other unionids find unfavorable for colonization. For example, in the early 1900s, Goodrich and van der Schalie (1932) observed the colonization of Michigan's Saginaw Bay by *L.c. complanata* during a period of eutrophication resulting from increased sewage wastes. Metcalfe-Smith et al. (2003) recently noted the range expansion of *L.c. complanata* in the Sydenham River, Ontario. The researchers speculated that the rapid expansion of such an opportunistic unionid indicated deteriorating conditions within the study area.

Habitat: Distributed throughout the Mississippi River basin, Great Lakes-St. Lawrence basin, and north into Canada. Occurs in creeks, rivers, reservoirs, lakes, and embayments. Adapts well to turbid waters. Tolerates a wide range of substrates, including unstable sand and gravel, silt, and mud.

Reproduction: Identified host fishes include the Common Carp, Banded Killifish, Green Sunfish, Orangespotted Sunfish, Largemouth Bass, and White Crappie (Lefevre and Curtis 1910; Young 1911).

The White Heelsplitter is bradytictic, with the reproductive period extending from September to May (Baker 1928).

Flutedshell

Lasmigona costata (Rafinesque, 1820)

Identification tips: Shell elongate, moderately thick, and somewhat compressed; with several undulations or "flutes" present on the posterior slope (A-B). Periostracum brownish with striking green rays in young individuals; adults often dark brown and rayless. Beak even with hinge-line; sculpture of a few concentric ridges that are often eroded (C). Pseudocardinal teeth distinctive, low, and heavy (D). Lateral teeth weakly developed (D). Nacre white. Shell up to 7 inches in length.

Indicator use: While not often locally abundant, this widespread species is secure throughout its range (Williams 1993; Natureserve). Kidd (1973) documented an increase in *L. costata* in the the polluted waters of the Grand River, indicating that this species may be capable of colonizing disturbed or polluted habitats.

Tetzloff (2001) investigated the survival rates of unionid species following a low dissolved oxygen (DO) event in Big Darby Creek, OH. The event was initiated by an agribusiness spill of molasses, fermented grain, and other organic substances. The Flutedshell, a common species within the study area, experienced lower rates of mortality than several other species at the site (~10%). The Kidneyshell (*P. fasciolaris*) and Wavyrayed Lampmussel (*L. fasciola*) were among the most sensitive species to the event.

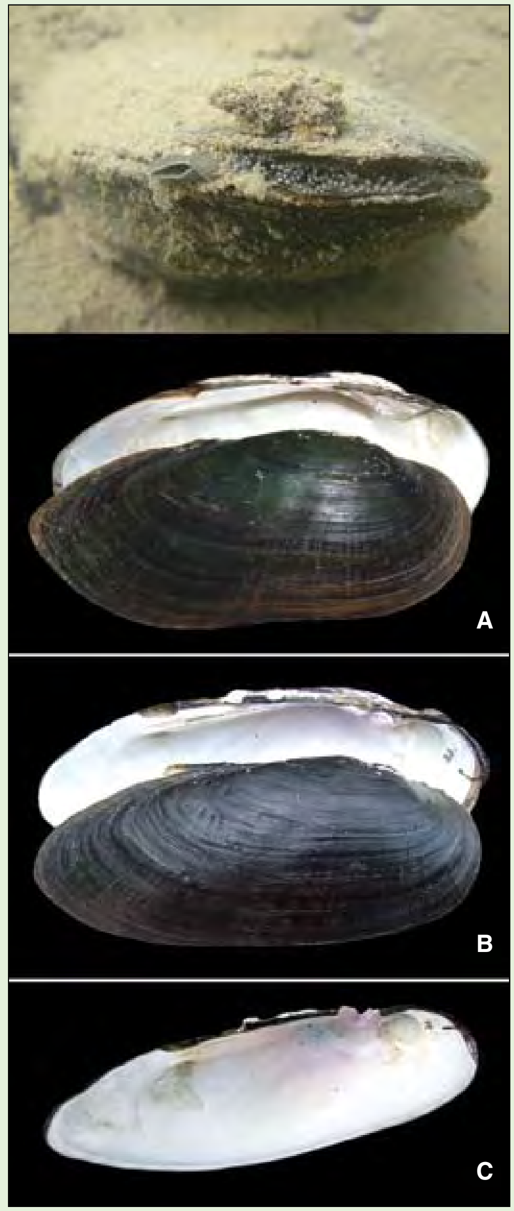
Habitat: Widespread throughout the Mississippi River basin and Great Lakes-St. Lawrence basin. The Flutedshell is found in small creeks to rivers where substrates are comprised of stable sand, gravel, and cobble. While usually most abundant in shallow water, *L. costata* has been documented from depths of 15-20 feet.

Reproduction: Identified host species include the Creek Chub, Central Stoneroller, Longnose Dace, Common Carp, Northern Hog Sucker, Bluegill Sunfish, Pumpkinseed Sunfish, Largemouth Bass, and Banded Darter (Lefevre and Curtis 1910; Watters et al. 1998c; Watters et al. 2005).

The Flutedshell is tachytictic, with the reproductive period extending from September until May (Baker 1928).

Black Sandshell

Ligumia recta (Lamarck, 1819)



Identification tips: General: Shell elongate, thick, and moderately inflated. Sexually dimorphic: Females obliquely flared posteriorly (A), males bluntly pointed (B). General: Periostracum dark brown to black, smooth, and lustrous; young individuals often with brillant green rays. Beak raised slightly above hinge-line; sculpture of a few indistinct ridges that are often eroded. Teeth well developed; lateral teeth distinctive, long, narrow, and straight (C). Nacre white; often with purplish tinge near beak cavity and pseudocardinal teeth. Shell up to 9 inches in length.

Indicator Use: Although widespread, *L. recta* is relatively uncommon throughout its range and has significantly declined in some states (e.g. Kansas, Illinois). Khym and Layzer (2000) observed that the "decline and low abundance of *L. recta* is concordant with a decline in sauger (*Sander canadensis*) runs," a suitable host species. Williams et al. (1993) considered the Black Sandshell a species of "special concern".

Pip (1995) evaluated the use of *L. recta* and eight other unionids as biomonitors of heavy metals in the Assiniboine River, Manitoba, Canada. Of the nine unionids studied, the Black Sandshell and Mapleleaf (*Quadrula quadrula*) were determined to have sequestered the highest concentrations of copper.

Habitat: Known from the Mississippi River basin, Great Lakes-St. Lawrence River basin, a few Gulf Coast drainages, and north into Canada. The Black Sandshell is found in large creeks, rivers, and lakes where substrates consist of mud, sand, gravel, or cobble. In riverine habitats, it occurs in both current and slackwater areas.

Reproduction: Identified host species include the Banded Killifish, Green Sunfish, Bluegill Sunfish, Orangespotted Sunfish, White Crappie, Largemouth Bass, and Sauger (Young 1911; Surber 1913; Pearse 1924; Watters 1994; Hove 1994; Barnhart 2000; Khym et al. 2000). Khym and Layzer (2000) reported poor glochidia metamorphosis in Black and White Crappie, Bluegill Sunfish, and Largemouth Bass (<5%). Conversely, Sauger proved an excellent host, with 53% of glochidia transforming into juveniles.

The Black Sandshell is bradytictic, with the reproductive period extending from August to July (Ortmann 1919).

Cumberland Moccasinshell

Medionidus conradicus (Lea, 1834)

Identification tips: Shell small, elongate, moderately thin, and compressed. Periostracum glossy and yellowish-tan with numerous green rays (A). Beak sculpture of fine, broken double-looped ridges (B); usually eroded in adults. Teeth well developed although delicate (C). Nacre bluish-white, often iridescent. Shell up to 3 inches in length.

Indicator use: A Cumberlandian endemic that has experienced declines in portions of its range (Williams et al. 1993; Natureserve), the Cumberland Moccasinshell occurs in unimpounded, high quality stream and river reaches. Williams et al. (1993) considered *M. conradicus* a species of "special concern".

Jacobson et al. 1997 evaluated the toxicity of copper to the glochidial stages of *M. conradicus* and four additional unionid species. Reported LC50s for released glochidia ranged from 37 to 81 ug Cu/L during 24-hour exposures. Similar results were documented by Cherry et al. (2002), who reported an acute mean LC50 of 41 ug Cu/L. GMAVs compiled and ranked by Augspurger (2006) and March et al. (2007) placed *Medionidus* among the most sensitive aquatic genera to copper.

Cherry et al. (1991) and McCann (1993) assessed the acute toxicity of zinc to the early life stages of *M. conradicus* and several other unionid species. Reported LC50s ranged from 492 to 570 ug Zn/L during 48-hour exposures (hardness = 60 to 170).

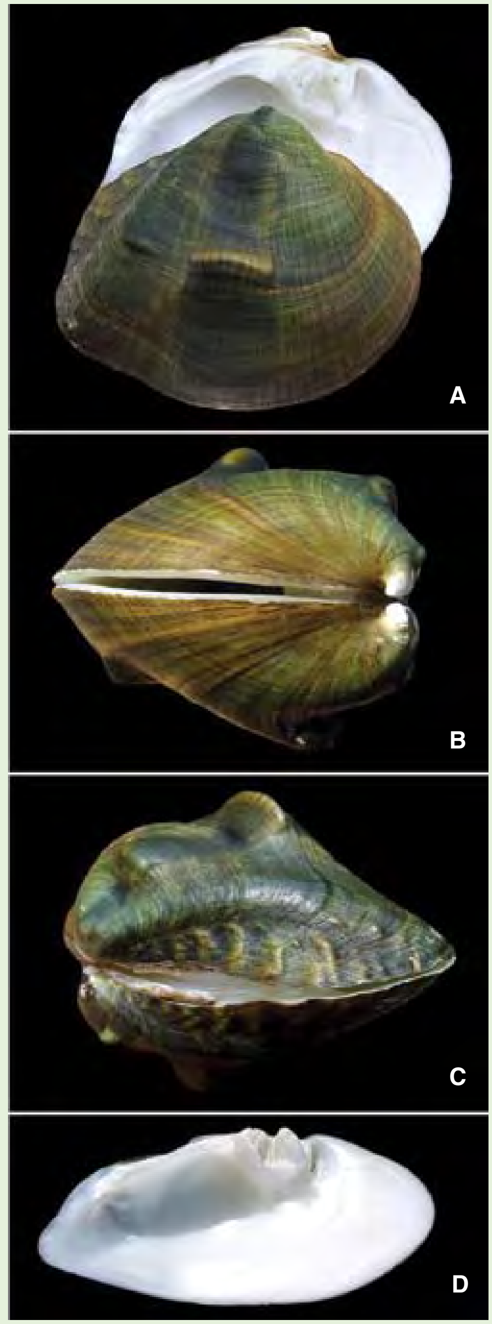
Habitat: Endemic to the Cumberland River system and Tennessee River system. Occurs in small streams to small rivers where the current is swift. Generally most abundant at shallow depths (< 3 ft.), where substrates are comprised of stable sand, gravel, cobble, and slab rock (Gordon and Layzer 1989; Parmalee and Bogan 1998).

Reproduction: Identified host fishes include the Warmouth Sunfish, Redline Darter, Fantail Darter, Striped Darter, and Rainbow Darter (Stern and Felder 1978; Zale and Neves 1982; Luo and Layzer 1993).

Cumberland Moccasinshell glochidia have been documented in Big Moccasin Creek (VA) drift from January to June, September to October, and infrequently during November (Zale and Neves 1982).

Threehorn Wartyback

Obliquaria reflexa (Rafinesque, 1820)



Identification tips: Shell round, moderately thick, and moderately inflated; anterior of shell noticeably thicker than posterior. A single row of large medial knobs extends from the umbo to dorsal margin (A). Knobs alternate in position on left and right valve (B). Posterior edge with fine ribs or small undulations (C). Shell periostracum variable, usually tan or green with fine green rays. Beak sculpture of fine, indistinctive lines often with small knob near hinge-line. Teeth well developed (D). Nacre white. Shell up to 3 inches in length.

Indicator use: This wideranging unionid has exhibited tolerance to river impoundment and a wide variety of substrates. It often sustains or increases in relative abundance where impoundment has occurred (Fuller 1985; Parmalee and Bogan 1998; WDNR 2003). ESI (2000) consistently reported *O. reflexa* as a dominant species in the impounded pools of the upper Ohio River.

Levengood et al. (2004) evaluated contaminant concentrations in freshwater mussels at the confluence of the Mississippi River and Illinois River. Five regionally abundant mussels, including *O. reflexa*, were used to evaluate contaminant burdens of local unionids. Cadmium and arsenic were below detection limits in *O. reflexa*, while most EPA priority metals were accumulated to comparable concentrations by *Amblema plicata*, *Obovaria olivaria*, and *O. reflexa* upstream of the Mississippi-Illinois confluence. Threehorn wartyback were not collected below the confluence.

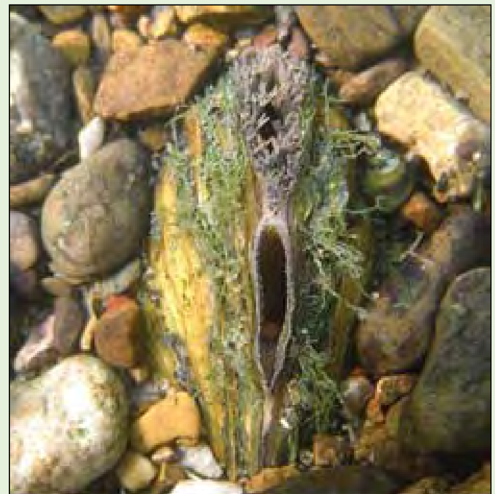
Habitat: Widespread in the lower and upper Mississippi basin, Great Lakes basin, and Gulf drainages. Found in small to large rivers, lakes, reservoirs, and embayments. Often most abundant in substrates comprised of mud, sand, and gravel where the current is slow to moderate.

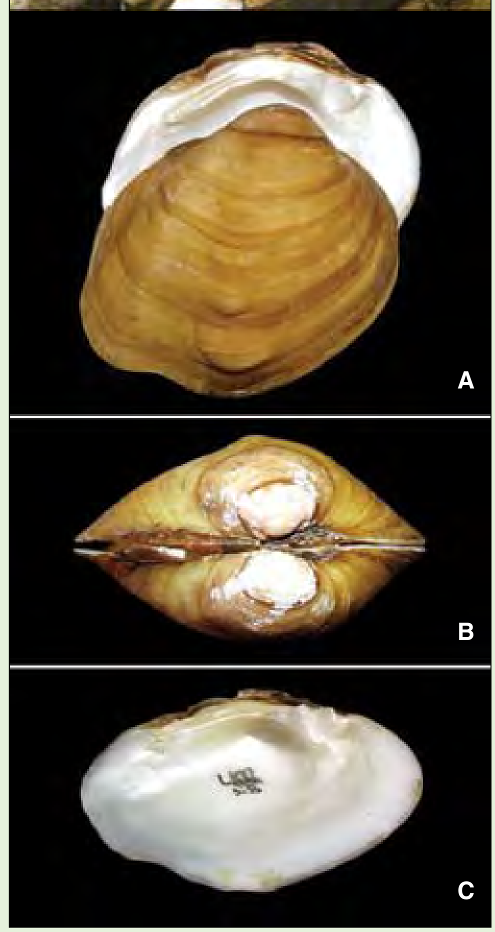
Reproduction: Identified host fishes include the Common Shiner, Longnose Dace, and Silverjaw Minnow (Watters et al. 1998). However, only a few juveniles were recovered from the above species, giving credence to the possibility that the true host(s) has yet to be found.

The Threehorn Wartyback is tachytictic, with the reproductive period extending from June to August (Utterback 1915).

Sheepnose

Plethobasus cyphyus (Rafinesque, 1820)





Identification tips: Shell subovate, thick, and moderately inflated; often with a row of medial tubercles extending from below the umbo to the ventral margin. The tubercles may vary in number, size, and shape. Periostracum yellowish-tan and rayless (A) usually brown to dark brown in old individuals. Beak slightly raised above hinge-line; sculpture of indistinct ridges, often eroded in adults (B). Teeth well developed (C). Nacre white. Shell up to 5 inches in length.

Indicator use: Once widespread in the small and large rivers of the Mississippi drainage, the Sheepnose now occupies just 34% of its former range (Butler 2002). It is currently a candidate for federal listing and is considered threatened, imperiled, or critically imperiled throughout its range (Cummings and Mayer 1992; Williams et al. 1993; Natureserve). Interestingly, archaeological evidence suggests that this species was rare in some systems historically (Parmalee et al. 1980; Parmalee and Hughes 1994; Hughes and Parmalee 1999; Butler 2002).

Perhaps the largest contributing factor to the decline of *P. cyphyus* has been habitat fragmentation and associated hypolimnetic releases resulting from the construction of dams (Butler 2002). Other suspected contributors include large channel maintenance, mine drainage, in-stream gravel mining, sedimentation, turbidity, and chemical contaminants (Hartfield and Hartfield 1996; Butler 2002).

Habitat: Widespread in the upper and lower Mississippi River, Ohio River, Tennessee River, and Cumberland River drainages. Occurs in small to large rivers where the current is moderate to swift. Often found at shallow depths (<3 ft.) where the streambed is comprised of sand and gravel substrates (Parmalee and Bogan 1998).

Reproduction: Identified host fishes include the Central Stoneroller Minnow and Sauger (Wilson 1916; Watters et al. 2005). Glochidia are packaged in “narrow, lanceolate shapes which are solid, red and discharge in unbroken form” (Oesch 1984).

The Sheepnose is tachytictic, with the reproductive period occurring in early summer (Parmalee and Bogan 1998).

Clubshell
Pleurobema clava (Lamarck, 1819)

Identification tips: Shell triangular, elongate, and moderately inflated; noticeably thicker anteriorly than posteriorly. The shell is perhaps best described as "wedge-shaped" (Watters 1995). Periostracum yellowish-tan; umbo with prominent, broken green rays (upper right photo) (A). Rays generally less conspicuous in older individuals. Beak slightly raised above hinge-line and set anteriorly; sculpture of indistinct ridges, usually eroded (B). Teeth well developed (C). Nacre white. Shell up to 3 inches in length.

Indicator use: The Clubshell was formerly widespread and abundant throughout the upper Ohio River drainage and western Lake Erie tributaries. It now occupies less than 5% of its former range (USFWS 1993; Natureserve). The dramatic decline of *P. clava* has been attributed to siltation, impoundment, in-stream sand and gravel mining, pollutants, and exotic species (USFWS 1993a; USFWS 1994). While there is little doubt the Clubshell is a sensitive species, the causal factors of decline have not been evaluated, quantitatively or otherwise, for their individual impacts. It is now listed as an endangered species by the U.S. Fish and Wildlife Service.

Habitat: Formerly widespread in the upper Ohio River basin and the western tributaries of Lake Erie. Occurs in creeks and rivers where the streambed is comprised of clean sand, gravel, and small cobble substrates. Many authors have reported on its propensity to burrow deep into the streambed (Ortmann 1919; Watter 1995; USFWS 1997), although it may also be found in the more typical life position assumed by most unionids.

Reproduction: Identified host fishes include the Central Stoneroller Minnnow, Striped Shiner, Blackside Darter, and Logperch (Watters and O'Dee 1997; O'Dee and Watters 2000).

The Clubshell is apparently tachytictic, with the reproductive season extending from May to mid-June (Ortmann 1919).

Ohio Pigtoe

Pleurobema cordatum (Rafinesque, 1820)

Identification tips: Shell subtriangular, deep, heavy, and inflated; usually with a shallow sulcus. Periostracum light brown to reddish-brown; young individuals may have faint green rays. Rest lines prominent (A). Beak raised and turned forward (A-B); sculpture generally indistinct or of elevated ridges (Cummings and Mayer 1992). Teeth well developed (C). Nacre white. Shell up to 4 inches in length.

Indicator use: The Ohio Pigtoe is a large river species that is of conservation concern throughout its range (Williams 1993; Roe 2002; Natureserve). Parmalee and Bogan (1998) reported *P. cordatum* to be intolerant of impounded reservoirs in Tennessee. Conversely, Gordon and Layzer (1989) commented that it may be somewhat tolerant of lentic habitats. Investigations into the impounded pools of the upper Ohio River found *P. cordatum* to be "fairly abundant" at Greenup and Meldahl (ESI 2000). Thus, the tolerance of this unionid (and hosts) to impoundment may depend on local habitat conditions or undetermined factors. It is also suspected to be sensitive to poor water quality, siltation, and zebra mussels (Roe 2002).

Chen (1998) analyzed the ability of *P. cordatum* and several other unionid species to regulate oxygen consumption (OC) with declining dissolved oxygen levels. The study results suggested that *P. cordatum* was likely vulnerable to hypoxia due to its poor ability to regulate OC.

Habitat: Distributed throughout the upper Mississippi River, Ohio River, Cumberland River, and Tennessee River basins. Generally occurs in flowing sections of medium to large rivers in shallow or deep water (up to 25 ft.). Often found in stable sand, gravel, and cobble substrates.

Reproduction: Identified host fishes include the Guppy, Brook Stickleback, Creek Chub, Rosefin Shiner, and Bluegill Sunfish (Fuller 1974; Watters and Kuehnl 2004).

The Ohio Pigtoe is apparently tachytictic, with the reproductive period occurring in late spring to summer.

Round Pigtoe

Pleurobema sintoxia (Rafinesque, 1820)

Identification tips: Shell highly variable; generally round to subquadrate and moderately thick. Shell inflation variable; often compressed in smaller systems and inflated in large rivers. Periostracum yellowish-tan, reddish-brown, or dark brown; young individuals may have faint rays. Rays often absent in older individuals. Beak sculpture somewhat indistinct, usually of irregular ridges. Beaks often low in creek and small river forms; higher in large river forms. Teeth well developed (B). Nacre white or pink (B). Shell up to 5 inches in length.

Indicator use: The Round Pigtoe is widely distributed although rarely abundant throughout its range (Cummings and Mayer 1992; Sietman 2003; WDNR 2003; Natureserve). It most commonly occurs in areas of current and good water quality (Watters 1995; Parmalee and Bogan 1998; Zanatta and Metcalfe-Smith 2004). *P. sintoxia* has apparently tolerated impoundment in some rivers, although this may be dependent on localized conditions. For example, while historically reported from the Upper Ohio River, recent sampling has found it to be rare with no evidence of recent recruitment (Taylor 1989; ESI 2000). Populations of *P. sintoxia* may also be vulnerable to zebra mussel infestations, as recent reports suggest from the Detroit River (tributary between Lake St. Clair and Lake Erie) (Schloesser et al. 2006).

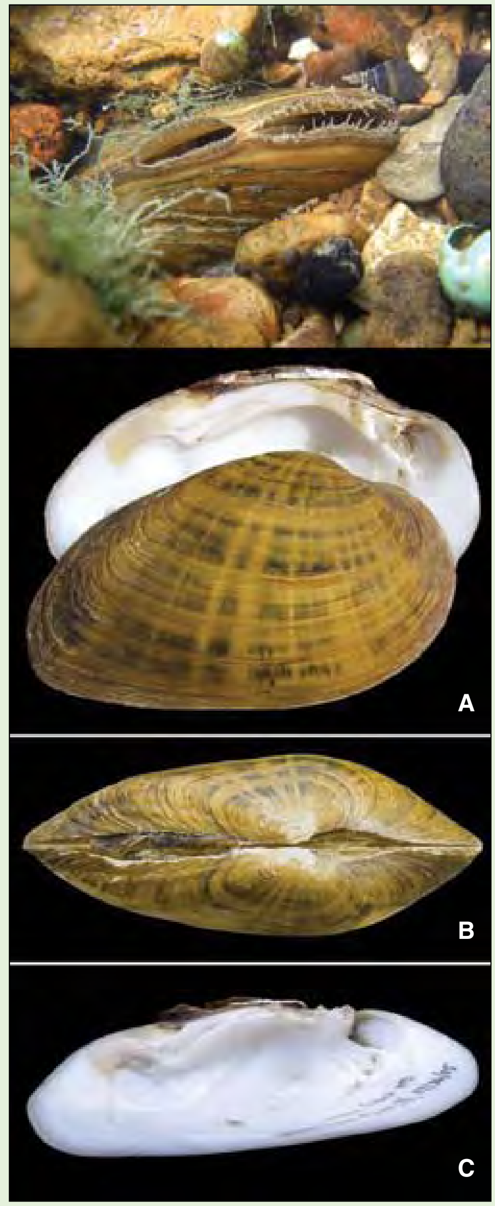
Habitat: Widespread in the Mississippi River basin and lower Great Lakes. Often most abundant in large creeks or rivers with moderate current (Watters 1995; Parmalee and Bogan 1998). However, it is also known from Lake Erie and Lake St. Clair. Occurs in packed mud, sand, and gravel substrates (Oesch 1984; Parmalee and Bogan 1998).

Reproduction: Identified host fishes include the Central Stoneroller Minnow, Spotfin Shiner, Northern Redbelly Dace, Southern Redbelly Dace, Bluntnose Minnow, and Bluegill Sunfish (Surber 1913; Coker et al. 1921; Hove 1995a; Hove et al. 1997; Watters et al. 2005).

The Round Pigtoe is apparently tachytictic, with the reproductive season extending from May to late July (Baker 1928).

Kidneyshell

Ptychobranchus fasciolaris (Rafinesque, 1820)



Identification tips: Shell somewhat elongate and sub-elliptical, moderately thick to thick, and compressed to slightly inflated. Periostracum yellow, yellowish-tan, or light brown; often with numerous broken green rays (A). Beak sculpture of indistinct ridges; usually eroded (B). Beak roughly even to slightly elevated above hinge-line. Teeth well developed (C). Nacre white. Shell up to 6 inches in length.

Indicator use: Widely distributed but sporadically occurring, the Kidneyshell may be locally abundant in good habitat. It has reportedly tolerated impoundment in Tennessee (Parmalee and Bogan 1998), but is more typical of shallow, flowing creeks and rivers (van der Schalie 1938; Gordon and Layzer 1989; Watters 1995). Williams et al. (1993) considered it secure throughout its range.

Positive associations have been documented between Kidneyshell populations and other species of unionids, including the Spike (*Elliptio dilatata*), Wavyrayed Lampmussel (*Lampsilis fasciola*), Clubshell (*Pleurobema clava*), and Rainbow (*Villosa iris*) (van der Schalie 1938; Metcalfe-Smith et al. 1999; Badra and Goforth 2001). These reports suggest the use of the Kidneyshell as an indicator of suitable conditions for the presence or reintroduction of the species listed above.

Tetzloff (2001) investigated the survival rates of unionid species following a low dissolved oxygen (DO) event in Big Darby Creek, OH. The Kidneyshell, an abundant species within the study area, was reported with the Wayrayed Lampmussel *(L. fasciola)* as experiencing the highest mortality rates (~95%).

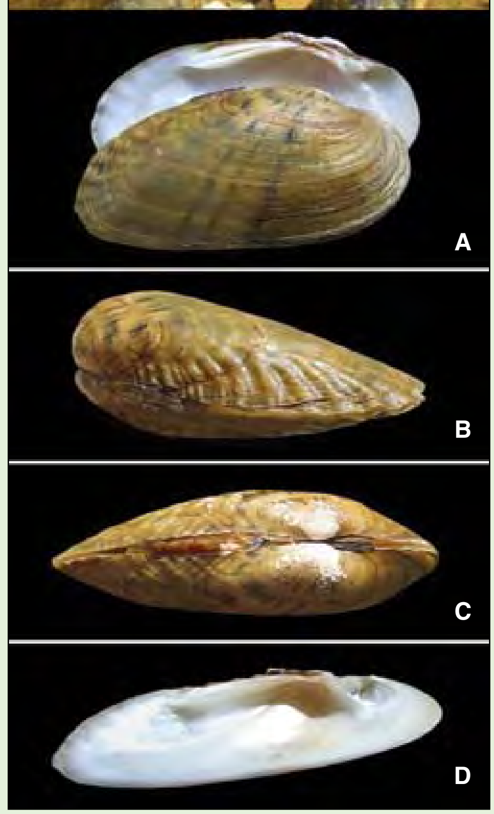
Habitat: Fairly widespread throughout the Mississippi River basin and Great Lakes basin. Occurs in creeks and rivers where the current is moderate to swift. Often most abundant in sand and gravel substrates.

Reproduction: Confirmed host fishes include the Brook Stickleback (Watters et al. 2005). Hosts observed infected in the field include the Johnny Darter, Fantail Darter, Greenside Darter, and Banded Darter (White et al. 1996).

The Kidneyshell is bradytictic, with glochidia overwintering in the marsupia (Ortmann 1919).

Fluted Kidneyshell

Ptychobranchus subtentum (Say, 1825)



Identification tips: Shell elongate, moderately thick, with a fluted or undulating posterior dorsal slope (A-B). Periostracum usually yellowish-tan with few to several wide green rays (A). Rays generally fade with age. Beak sculpture of indistinct loops; often eroded (C). Teeth well developed (D). Nacre white. Shell up to 5 inches in length.

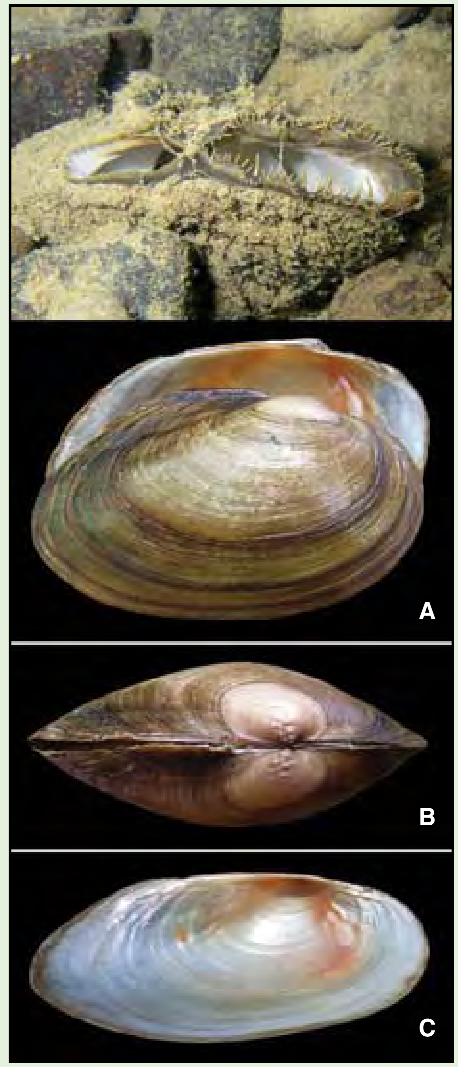
Indicator use: The Fluted Kidneyshell has undergone a drastic range reduction in the past 100 years, a result of stream and river impoundment, toxic contaminants, and siltation (Butler 2005a). This sensitive species is currently a candidate for federal listing.

Habitat: Endemic to the Cumberland River system and Tennessee River system. Occurs in moderate-sized streams to small rivers where the current is swift. Generally most abundant at shallow depths (< 2 ft.) where substrates are comprised of packed sand and gravel. This species requires flowing, well-oxygenated waters to thrive (Butler 2005a).

Reproduction: Identified host fishes include many riffle-dwelling species, including the Banded Sculpin, Redline Darter, Rainbow Darter, Barcheek Darter, and Fantail Darter (Luo and Layzer 1993). The Fluted Kidneyshell utilizes a fascinating tool for reproduction: a gelatinous capsule shaped like insect. These “conglutinates” are packed with glochidia and liberated into the stream current where they adhere to stones. Unsuspecting host fishes then strike the conglutinates, infecting their gill tissue with glochidia.

Giant Floater

Pyganodon grandis (Say, 1829)



Identification tips: Shell elongate, thin, and inflated (A) Periostracum yellow, yellowish-tan, or green when young; often with faint green rays. Older individuals light brown to dark brown; usually rayless. Beak elevated above hinge-line; sculpture of pronounced double-loops (B). Teeth poorly developed; hinge thickened. Nacre white; beak cavity may be tinged with salmon (C). Shell up to 9 inches in length.

Indicator use: This wideranging unionid adapts well to impoundments and tolerates moderate levels of silt (Watters 1995; WDNR 2003). Pip (2006) described the Giant Floater as one of the most tolerant unionids in Manitoba, Canada. It may also persist in soft substrates where heavier shelled species sink or suffocate (Coker 1921).

GMAVs compiled and ranked by Augspurger et al. (2003) and Augspurger (2006) placed *Pyganodon* among the more sensitive aquatic genera to copper and ammonia.

Black et al. (1995) exposed the Giant Floater to lead in the laboratory and field and found that DNA strand breakage occurred only at the lowest exposure level (50 ug/L). They attributed this to higher lead concentrations inducing DNA repair processes, whereas lower concentrations may have not initiated or maximized repair processes. A secondary hypothesis was localized cellular necrosis (cell death and breakage) of the foot.

The Giant Floater has been used extensively as a surrogate in contaminant uptake and loss studies by several researchers (e.g. Bedford and Zabik 1973; Heit et al. 1980; Perry et al. 1980; Malley et al. 1995; Stewart 1999; Wang et al. 1999; Perceval et al. 2002). Additionally, *P. grandis* has been used to evaluate potential biomarkers to assess heavy metal exposure (Chamberland et al. 1995; Couillard et al. 1995; Perceval 2002).

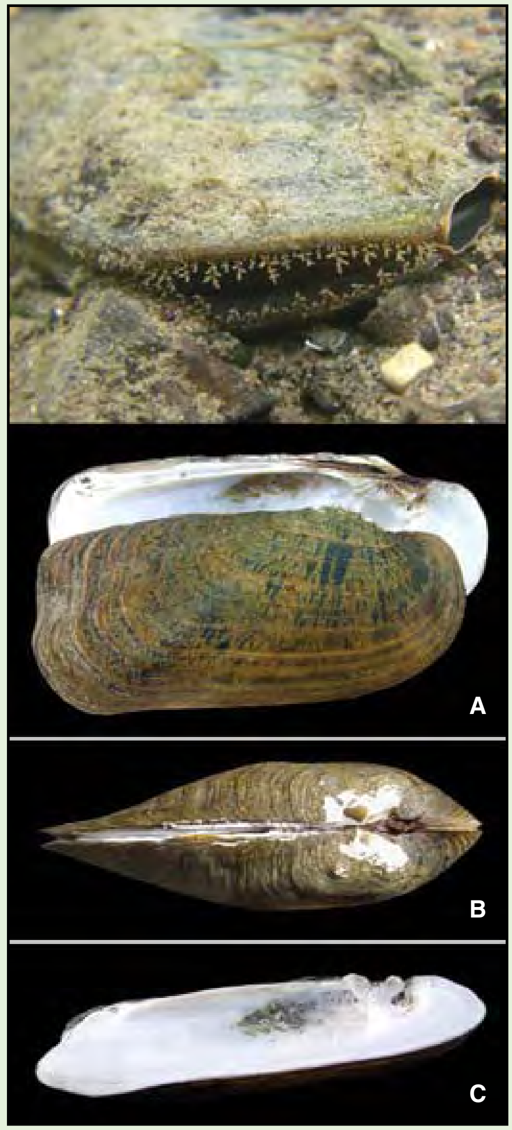
Habitat: Distributed throughout the Mississippi River basin, Great Lakes-St. Lawrence basin, several Gulf drainages, and north into Canada. Typically found in low-gradient stream reaches, backwaters, lakes, and impoundments. Often most abundant in fine substrates.

Reproduction: Over 35 species of fish (including some exotic species) have been identified as hosts for the Giant Floater. Jacobson et al. (1997) reported that glochidia of *P. grandis* survived longer in natural river water than did the glochidia of three lampsiline species.

*converted to mg/L total ammonia as N, normalized to pH 8.

Rabbitsfoot

Quadrula cylindrica cylindrical (Say, 1817)



Identification tips: Shell elongate, rectangular, moderately thick, and somewhat compressed to inflated; sculpturing often present in the form of knobs, bumps, or ribs. Shell periostracum and sculpturing often variable intraspecifically. Periostracum usually yellowish-tan or green, with numerous dark green chevrons; streaking may also be present (A). Beak slightly raised above hinge-line; sculpture often eroded or indistinct (B). Teeth well developed; lateral teeth very long and narrow (C). Nacre white. Shell up to 5 inches in length.

Indicator use: A rare taxon throughout its range (Williams et al. 1993; Natureserve), the Rabbitsfoot is a unionid of clear, high quality streams (Oesch 1984). It is listed as endangered by several midwestern states (IL, IN, KS, OH). A close relative and Tennessee River endemic, *Quadrula cylindrica strigillata*, is currently listed as federally endangered (USFWS 2004).

Butler (2005b) noted the elimination of *Q.c. cylindrica* from 66% of the waterways where it formerly occurred, although realistically he remarked that total range reductions and population losses were closer to 90%. This dramatic decline was primarily attributed to the inability of the Rabbitsfoot to persist in impounded habitats and tolerate cold hypolimnetic tailwater releases. Other causal factors included channelization, mining activities, chemical contaminants, and sedimentation (Butler 2005b).

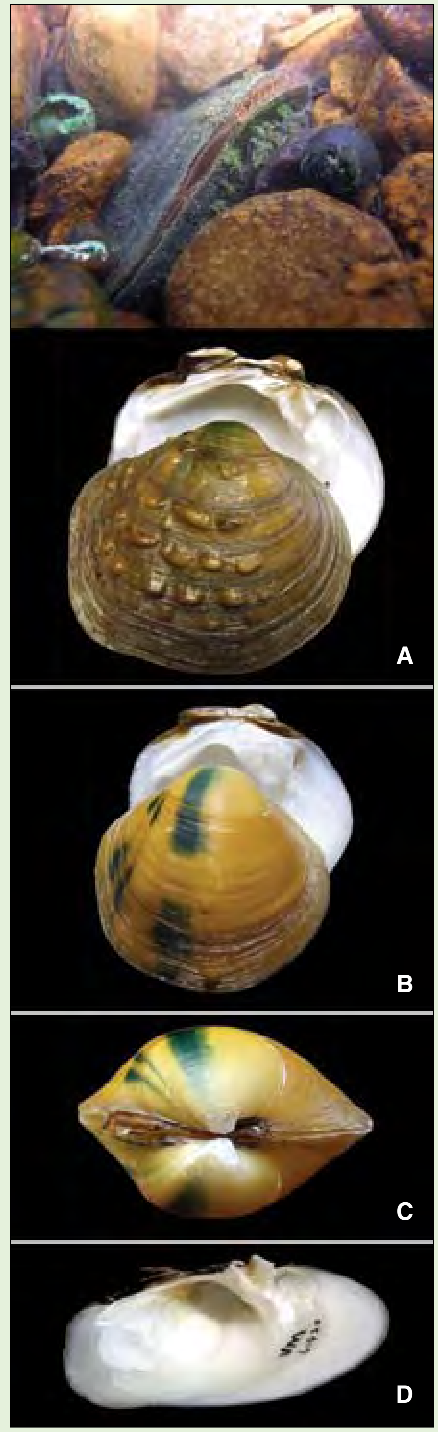
Habitat: Distributed throughout the upper and lower Mississippi River basin and western Lake Erie basin. Occurs in both moderate-sized streams and rivers in swift flow at depths up to 12 feet (Parmalee and Bogan 1998). Most abundant in sand, gravel, and cobble substrates. This interesting mussel does not exhibit the burrowing tendencies of its congeners, preferring instead to rest on the substrate surface (photo - upper right).

Reproduction: Identified hosts for *Q.c. cylindrica* include the Blacktail Shiner, Spotfin Shiner, and Rosyface Shiner (Barnhart and Baird 2000; Butler 2005b). Yeager and Neves (1986) identified the Bigeye Chub, Spotfin Shiner, and Whitetail Shiner as suitable hosts for *Q.c. strigillata*, a Tennessee River basin endemic.

The Rabbitsfoot packages its glochidia into lanceolate conglutinates, generally orange or yellowish-brown in color (Ortmann 1919).

Pimpleback

Quadrula pustulosa pustulosa (Lea, 1831)



Identification tips: Shell round or quadrate, thick, and usually inflated. Periostracum yellowish-tan to brown with few to numerous pustules (A). A conspicuous green smudge or broken, wide green ray(s) present in young individuals (B) less apparent or absent in adults (A) Beak sculpture of indistinct lines; often eroded (C). Teeth well developed and heavy (D). Nacre white. Shell up to 4 inches in length.

Indicator use: The Pimpleback tolerates a wide range of substrates and adapts well to impounded conditions (Oesch 1984; Parmalee and Bogan 1998; WDNR 2003). ESI (2000) consistently reported *Q. pustulosa* from the navigational pools of the Upper Ohio River, where it comprised 1.4% - 18.4% of the mussel community.

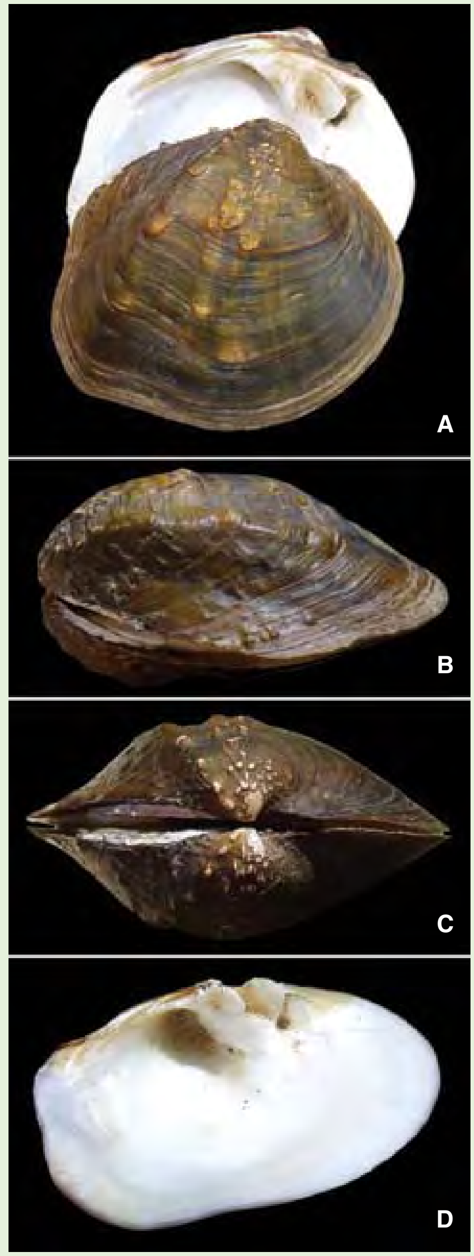
In Kansas, researchers utilized tissue samples from *Q. pustulosa* to evaluate the bioavailability of heavy metals in the Neosho River, home of the federally threatened Neosho Madtom (*Noturus placidus*) (Allen et al. 2001). Most of the metals of concern were found in low concentrations.

Habitat: A wideranging species, the Pimpleback occurs in large streams, rivers, lakes, and reservoirs. It may be found in both shallow and deep water (~20 ft.). Generally most abundant in packed sand and gravel.

Reproduction: Identified host fishes include the Shovelnose Sturgeon, Black Bullhead, Brown Bullhead, Channel Catfish, Flathead Catfish, and White Crappie (Surber 1916; Coker 1921). The reproductive period is from June through August (Howard 1914).

Mapleleaf

Quadrula quadrula (Rafinesque, 1820)



Identification tips: Shell subquadrate, thick, and slightly inflated. Two rows of pustules present on shell; separated by a shallow to well-defined sulcus (A). Small flute-like projections or bumps often present on posterior slope and posterior-dorsal margin (B). Periostracum yellowish-tan, brown, or dark brown; green rays often present in younger individuals. Beak sculpture of double-looped ridges; often eroded or indistinct (C). Teeth well-developed (D); pseudocardinal teeth may be large and heavy in older individuals. Nacre white. Shell up to 6 inches in length.

Indicator use: The Mapleleaf is an adaptable species, tolerant of (and perhaps exploiting) impoundment, moderate levels of turbidity, and a variety of substrates (Oesch 1984; Parmalee and Bogan 1998; Metcalfe-Smith et al. 2003; WDNR 2003). ESI (2000) documented *Q. quadrula* as one of the most abundant species in the navigational pools of the upper Ohio River.

The Mapleleaf has been utilized extensively as a biomonitor and surrogate to evaluate the potential impacts of industrial effluents and coal mine discharges. In the early 1970s, Foster and Bates (1978) employed juvenile *Q. quadrula* as in-stream biomonitors of copper electroplating wastes in the Muskingum River, OH. Body burdens as high as 20.64 ug Cu/g (10x background levels) were reported for caged *Q. quadrula* 0.1 km below electroplating discharges. Ultimately, the study concluded that electroplating wastes were responsible for the decimation of 60% and 39% of all mussels up to 5 km and 21 km downstream, respectively.

Habitat: Distributed throughout the Mississippi River basin, Great Lakes-St. Lawrence drainage, and north in to Canada. Occurs in small to large rivers, embayments, and lakes. Found in firm of substrates of mud, sand, gravel, and cobble at depths ranging from several inches to 30 ft.

Reproduction: Identified host fishes include the Flathead Catfish and Channel Catfish (Howard and Anson 1923; Schwebach et al. 2002). The Mapleaf is tachytictic, with the reproductive period extending from May and August (Baker 1928).

Creeper

Strophitus undulatus (Say, 1817)

Identification tips: Shell highly variable; generally subelliptical to subtrapezoidal, thin to moderately thick, and compressed to inflated. Periostracum usually light brown to dark brown (A); young individuals often with bold green rays. Beak raised slightly above hinge-line; sculpture of concentric, oblique ridges (B). Pseudocardinal teeth present as a thickened, indented hinge (C). Lateral teeth also present as a thickened hinge. Shell up to 4 inches in length.

Indicator use: Widely distributed and relatively common, the Creeper is frequently described as a tolerant species (Gordon and Layzer 1989; Watters 1995; Parmalee and Bogan 1998). Williams et al. (1993) reported the conservation status of *S. undulatus* as “currently stable”.

Harman (1997) utilized molluscan and macroinvertebrate communities as indicators of water quality and habitat degradation in Otsego Lake, NY. Over a period of 25 years, he reported a decline in molluscan and intolerant Ephemeroptera, Plecoptera and Trichoptera (EPT) richness of 52.9% and 56.1%, respectively. The Creeper was among the declining bivalve species, having been eliminated from two sites where it formerly occurred.

Pip (2002) utilized bivalves and gastropods in a water quality study of southern Lake Winnipeg, Canada. Occurrences of *S. undulatus* were correlated with lower lead values, while the Giant Floater (*Pyganodon grandis*) was linked to higher dissolved solids and the Fatmucket (*Lampsilis siliquoidea*) to higher dissolved organic matter

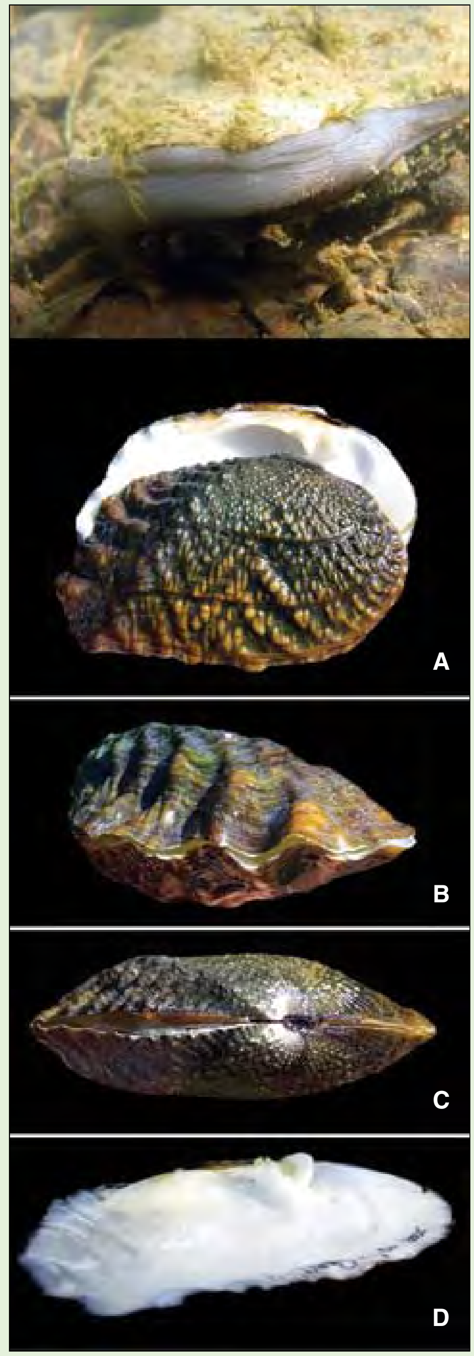
Habitat: Widespread in the Mississippi River basin, Great Lakes-St. Lawrence basin, and northern Atlantic drainages. Occurs in creeks, rivers, and lakes in both still waters and moderate current. Found in both coarse and fine substrates.

Reproduction: Well over 30 fishes from 9 taxonomical families have been confirmed hosts for the Creeper (Baker 1928; Hove 1995b; Hillegrass and Hove 1997; Hove 1997; Watters et al. 1998c; Wicklow and Beisheim 1998; Van Snik Gray et al. 1999; 2002; Cliff 2001).

The Creeper is bradytictic, with the reproductive period extending from July to May (Baker 1928).

Pistolgrip

Tritogonia verrucosa (Rafinesque, 1820)



Identification tips: Shell subquadrate, somewhat compressed to moderately inflated, and thick. Shell covered with numerous tubercles anterior of the posterior ridge (A). Posterior with wavy undulations or irregular flutes (B). Shell periostracum dark green or yellowish-brown, sometimes with V-shaped markings. Beak with indistinct ridges and tubercles (C). Teeth well developed and heavy (D). Nacre white (D). Shell up to 8 inches in length.

Indicator use: While intolerant of pollution, the Pistolgrip has demonstrated the ability to adapt to a variety of habitat conditions (Watters 1995; Parmalee and Bogan 1998). In the state of Ohio, *T. verrucosa* strongly repopulated a decimated stretch of the Scioto River following major sewage treatment plant upgrades (Tetzloff and Akison 1999).

Habitat: Well distributed throughout the Mississippi River basin and Alabama River system. Generally found in large streams where substrates are comprised of stable sandy mud, gravel, or cobble. May become abundant in oxygen-rich riffles and runs (Stansberry 1965). Often found resting on the substrate surface.

Reproduction: Identified host fishes include the Brown Bullhead, Yellow Bullhead, and Flathead Catfish (Howells 1997; Pepi and Hove 1997; Hove and Kurth 1998). During the glochidia release period, Pepi and Hove (1997) observed an inflated mantle dorsal to the excurrent siphon, crenulated with a blue-gray edge (top right).

Rainbow

Villosa iris (I. Lea, 1829)

Identification tips: General: Shell elliptical and elongate, somewhat thin to moderately thick, and compressed to moderately inflated. Sexually dimorphic: Females (A) inflated and obliquely flared or rounded posteriorly, males (B) pointed posteriorly. Sexual dimorphism may be cryptic in some specimens. General: Periostracum yellowish-tan to light brown with broken or solid bright green rays. Beak relatively even to slightly raised above hinge-line; sculpture of erratic double-loops (C). Teeth well developed, although somewhat small and delicate. Nacre white. Shell up to 4 inches in length.

Indicator use: Although fairly widespread and abundant (Williams et al. 1993), the Rainbow is reportedly declining in some portions of its range (Metcalfe-Smith et al. 2003; COSEWIC 2006). It generally inhabits clean, well oxygenated stream reaches (Watters 1995; Parmalee and Bogan 1998).

The Rainbow has been used extensively as a surrogate to evaluate the effects of various toxic contaminants to freshwater mussels (e.g. Goudreau et al. 1993; Jacobson et al. 1993; Jacobson et al. 1997; Cherry et al. 2002; Mummert et al. 2003; Valenti et al. 2005; Valenti et al. 2006b; Wang et al. 2007a; 2007b). GMAVs compiled and ranked by Augspurger et al. (2003), Augspurger (2006), and March et al. (2007) placed *V. iris* among the 15 most sensitive aquatic taxa to copper and ammonia.

Habitat: Widespread in the upper Mississippi River basin and Great Lakes basin. Occurs in creeks to small rivers where the water is shallow and current sluggish to moderately strong. May also be found in lakes (Gordon and Layzer 1989; Watters 1995). Most abundant in mixtures of sand, gravel, and cobble.

Reproduction: Confirmed host fishes include the Western Mosquitofish, Rock Bass, Largemouth Bass, Smallmouth Bass, Suwanee Bass, and Spotted Bass (Zale and Neves 1982; Neves et al. 1985).

The Rainbow is bradytictic, with the reproductive period extending from July to May (Ortmann 1919).

Conservation Status

Common Name	Scientific Name	Federal (1)	Indiana (2)	Ohio (3)	Michigan (4)	N. Carolina (5)	Virginia (6)	Natureserve (7)	Williams et al. 1993
Mucket	*Actinonaias ligamentina*	-	-	-	-	-	-	G5	CS
Pheasantshell	*Actinonaias pectorosa*	-	-	-	-	-	-	G4	SC
Dwarf Wedgemussel	*Alasmidonta heterodon*	E	-	-	-	-	E	G1G2	E
Elktoe	*Alasmidonta marginata*	SC	-	SC	SC	-	-	G4	SC
Threeridge	*Amblema plicata*	-	-	-	-	-	-	G5	CS
Purple Wartyback	*Cyclonaias tuberculata*	-	-			E	-	G5	SC
Dromedary Pearlymussel	*Dromus dromas*	E	-			-	E	G1	E
Eastern Elliptio	*Elliptio complanata*	-	-			-	-	G5	CS
Spike	*Elliptio dilatata*	-	-	-	-	SC	-	G5	CS
Oyster Mussel	*Epioblasma capsaeformis*	E	-	-	-	-	E	G1	E
Northern Riffleshell	*Epioblasma torulosa rangiana*	E	E	E	E	-	-	G2T2	E
Tubercled Blossom	*Epioblasma torulosa torulosa*	E	-	-	-	-	-	G2TX	E*
Wabash Pigtoe	*Fusconaia flava*	-	-	-	-	-	-	G5	CS
Pink Mucket	*Lampsilis abrupta*	E	E	E	-	-	E	G2	E
Plain Pocketbook	*Lampsilis cardium*	-	-	-	-	-	-	G5	SC
Wavyrayed lampmussel	*Lampsilis fasciola*	-	SC	SC	T	SC	-	G5	CS
Fatmucket	*Lampsilis siliquoidea*	-	-	-	-	-	-	G5	CS
White Heelsplitter	*Lasmigona complanata complanata*	-	-	-	-	-	-	G5T5	CS
Flutedshell	*Lasmigona costata*	-	-	-	-	-	-	G5	CS
Black Sandshell	*Ligumia recta*	-	-	T	-	-	T	G5	SC
Cumberland Moccasinshell	*Medionidus conradicus*	-	-	-	-	-	-	G3G4	SC
Threehorn Wartyback	*Obliquaria reflexa*	-	-	T	-	-	-	G5	CS
Sheepnose	*Plethobasus cyphyus*	C	E	E	-	-	T	G3	T
Clubshell	*Pleurobema clava*	E	E	E	E	-	-	G2	E
Ohio Pigtoe	*Pleurobema cordatum*	SC	SC	E	-	-	E	G4	SC
Round Pigtoe	*Pleurobema sintoxia*	-	-	SC	SC	-	-	G4G5	CS
Kidneyshell	*Ptychobranchus fasciolaris*	-	SC	SC	-	-	-	G4G5	CS
Fluted Kidneyshell	*Ptychobranchus subtentum*	C	-	-	-	-	-	G2	SC
Giant Floater	*Pyganodon grandis*	-	-	-	-	-	-	G5	CS
Rabbitsfoot	*Quadrula cylindrica cylindrica*	SC	E	E	-	-	-	G3G4T3	T
Pimpleback	*Quadrula pustulosa pustulosa*	-	-	-	-	-	T	G5	CS
Mapleleaf	*Quadrula quadrula*	-	-	-	-	-	-	G5	CS
Creeper	*Strophitus undulatus*	-	-	-	-	T	-	G5	CS
Pistolgrip	*Tritogonia verrucosa*	-	-	-	-	-	-	G4G5	CS
Rainbow	*Villosa iris*	-	-	-	SC	SC	-	G5Q	CS

CS = Currently stable SC = Special concern C = Candidate species T = Threatened E = Endangered
G5 = Secure G4 = Apparently secure G3 = Vulnerable G2 = Imperiled G1 = Critically imperiled
T = Infraspecific taxon X = Presumed extinct Q = Questionable taxonomy

(1) U.S. Fish and Wildlife Service, report generated 12/04/2007
(2) Indiana Department of Natural Resources, last updated 9/2004
(3) Ohio Department of Natural Resources, last updated 9/2007
(4) Michigan Natural Features Inventory, last updated 7/2002
(5) North Carolina Wildlife Resources Commission
(6) Virginia Department of Inland Game and Fishes, last updated 7/24/06
(7) Natureserve, Accessed 12/04/2007

Glossary

Adductor muscles: Muscles anterior and posterior that close the mussel shell.

Anterior: Forward portion of the shell.

Beak: Raised area on the dorsal margin near hinge.

Beak sculpture: Small, textured patterns on the beak.

Chevron: A V-shaped marking on the periostracum.

Cumberlandian: An ecoregion that encompasses the Cumberland River and Tennessee River basins. This guide follows the interpretation of Parmalee and Bogan (1998) that extends the region down to the mouth of both the Cumberland and Tennessee rivers.

Dorsal wing: An extension of a shell from the dorsal margin, posterior of the beak.

Extirpation: The elimination of a population from a certain geographic area.

Lateral teeth: The narrow, thin teeth located near the hinge-line.

Muscle scar: Impressions in the nacre where a muscle was previously attached.

Nacre: The inside of the shell, often pearly white, salmon, or purple.

Pallial line: A line present on the inner nacre where muscles previously attached the mantle to the shell.

Periostracum: The outside layer of the shell or epidermis.

Posterior: Rear portion of the shell.

Posterior ridge: A ridge extending from the beak to the posterior margin.

Pseudocardinal teeth: Located anterior of the lateral teeth near the hinge, often raised and triangular.

Unionid: A freshwater mussel belonging to the family Unionidae.

Unionoid: A freshwater mussel belonging to the order Unionoida.

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November 2008