Uniomerus tetralasmus (Pondhorn): A Technical Conservation Assessment

Prepared for the USDA Forest Service, Rocky Mountain Region, Species Conservation Project

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AUTHOR'S BIOGRAPHY

Tamara Anderson has studied mollusks for more than 10 years and has spent several years surveying mollusks in the Black Hills region of South Dakota and Wyoming. She received her Ph.D. in Ecology and Evolutionary Biology from Iowa State University where she studied *Discus macclintocki*, a federally endangered land snail. She has also conducted research on *Dreissena polymorpha*. She is currently an adjunct curator at the University of Colorado Museum.

Summary of Key Components for Conservation of *Uniomerus tetralasmus*

Status

Uniomerus tetralasmus (pondhorn mussel) is not currently included on the sensitive species list of the USDA Forest Service (USFS) Rocky Mountain Region (Region 2). Based on current and historic records of occurrences, this species most likely occurs on the Cimarron and Comanche national grasslands of Region 2, which is on the western edge of its overall range. It has been documented as declining in portions of Region 2, especially in southeastern Colorado.

Primary Threats

Because mussels filter many particles from the water, they are especially sensitive to water quality issues. Management activities that affect the water level, the amounts of sediment and pollutants in the water, or the temperature of the water are likely to affect this species. Such activities include timber harvest, grazing, road building or maintenance, fires, mining, exotic species introduction, and damming or impounding water away from natural areas.

Uniomerus tetralasmus also depends on the golden shiner (*Notemigonus crysoleucas*) as the only known intermediate host species. Therefore, negative impacts to golden shiner populations would affect *U. tetralasmus* populations as well.

Primary Conservation Elements, Management Implications and Considerations

Without information on the status of more of the known populations of *Uniomerus tetralasmus*, it is difficult to manage the species. Additional surveys and monitoring are necessary to better understand the species' distribution and to make fine-scale management decisions. Like all bivalves, *U. tetralasmus* feeds by filtering particles from the water. In areas with large numbers of mussels, the filtering action serves to remove phytoplankton from the water and to transfer these nutrients to other parts of the food chain, thereby serving an important role in the ecosystem. Because mussels are rare in Region 2 (as compared to the central and eastern United States), it cannot be assumed that any native mussel species is unimportant to the ecosystem.

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INTRODUCTION

This assessment is one of many being produced to support the Species Conservation Project for the USDA Forest Service (USFS) Rocky Mountain Region (Region 2). *Uniomerus tetralasmus*, the pondhorn mussel, is the focus of an assessment because it was considered for Region 2 sensitive species status during the Regional Forester's Sensitive Species list revision process from 2001 to 2003, but it is not currently included on that list (www.fs.fed.us/r2/projects/scp/sensitivespecies). Instead, the evaluation process suggested that it be "considered for other species emphasis lists". Within the National Forest System, a sensitive species is a plant or and animal whose population viability is identified as a concern by a Regional Forester because of significant current or predicted downward trends in abundance and/or habitat capability that would reduce its distribution (FSM 2670.5 (19)). A sensitive species requires special management, so knowledge of its biology and ecology is critical. This assessment will facilitate further evaluation of *U. tetralasmus*, leading to future decisions by the USFS regarding the management and conservation status of this species.

This assessment addresses the biology of *Uniomerus tetralasmus* throughout its range in Region 2. The Cimarron and Comanche national grasslands are the most likely USFS properties to contain or to be adjacent to *U. tetralasmus* populations. This introduction defines the goal of the assessment, outlines its scope, and describes the process used in its production.

Goal

Species conservation assessments produced as part of the Species Conservation Project are designed to provide forest managers, research biologists, and the public with a thorough discussion of the biology, ecology, conservation status, and management of certain species based on available scientific knowledge. The assessment goals limit the scope of the work to critical summaries of scientific knowledge, discussion of broad implications of that knowledge, and outlines of information needs. The assessment does not seek to develop specific management recommendations. Rather it provides the ecological background upon which management must be based and focuses on the consequences of changes in the environment that result from management (i.e., management implications). Furthermore, it cites management recommendations proposed elsewhere and examines the success of those recommendations that have been implemented.

Scope

This assessment examines the biology, ecology, conservation status, and management of *Uniomerus tetralasmus* with specific reference to the geographical and ecological characteristics of the USFS Rocky Mountain Region. Although some of the literature on the species originates from field investigations outside the region, this document places that literature in the ecological and social context of the central Rocky Mountains. Similarly, this assessment is concerned with the behavior, population dynamics, and other characteristics of *U. tetralasmus* in the context of the current environment rather than under historical conditions. The evolutionary environment of the species is considered in conducting the synthesis, but placed in a current context.

Producing the assessment involved reviewing refereed literature, non-refereed publications, research reports, and data accumulated by resource management agencies. Not all publications on *Uniomerus tetralasmus* are referenced in the assessment, nor were all published materials considered equally reliable. The assessment emphasizes refereed literature, where possible, because this is the accepted standard in science. Some non-refereed publications and reports were used in the assessment when information was unavailable elsewhere. Such literature should be regarded with greater skepticism. Unpublished data (e.g., Natural Heritage Program records, museum records) were especially important in estimating the geographic distribution of this species. These data require special attention because of the diversity of persons and methods used in their collection.

Treatment of Uncertainty

Science represents a rigorous, systematic approach to obtaining knowledge. Competing ideas regarding how the world works are measured against observations. However, because our descriptions of the world are always incomplete and our observations are limited, science focuses on approaches for dealing with uncertainty. A commonly accepted approach to science is based on a progression of critical experiments to develop strong inference (Platt 1964). However, it is difficult to conduct experiments that produce clean results in the ecological sciences. In the case of mollusks, experiments addressing the effects of many management activities are not available. Often, we must rely on observations, inference, good thinking, and models to guide our understanding of ecological relations. In this assessment, we note the strength of evidence for particular ideas, and we describe alternative explanations where appropriate.

In cases where articles or reports make statements without supplying the supporting data, the lack of support for the authors' statements is indicated. Discussions of uncertainty of particular references described in this report are not meant as indictments of individual scientists or their work. Rather, this report points out situations where particular evidence or data are not available from the written documents. In some cases, the scientists may be continuing the work, and the information may become available in the future.

Uncertainty also comes into play when life cycle models are discussed. Due to a lack of basic biological information on this species, developing an accurate population model is extremely difficult. Since the basic demographic parameters are unknown, mathematic simulations are not particularly useful as the error becomes larger than potential effects found.

Application and Interpretation Limits of this Assessment

Information used to complete this assessment includes studies from across the geographical range of the species. Although it would be desirable to have information on life history and ecology specific to Region 2, in most cases that is not available for *Uniomerus tetralasmus*. Most information should apply broadly throughout the range of the species, but certain life history parameters may vary along environmental gradients. Inferences made from this information regarding threats to the species are understood to be limited in scope (see Treatment of Uncertainty section) and take into account the particular conditions present in Region 2. Therefore, information regarding the conservation status of this species pertains specifically to Region 2 and does not necessarily apply to other portions of the species' range.

Publication of Assessment on the World Wide Web

To facilitate the use of species assessments in the Species Conservation Project, they are being published on the Region 2 World Wide Web site (www.fs.fed.us/r2/ projects/scp/assessments). Placing the documents on the Web makes them available to agency biologists and the public more rapidly than publishing them as reports. In addition, Web-based publications can be easily revised. Revision will be accomplished based on guidelines established by Region 2.

Peer Review

Assessments developed for the Species Conservation Project have been peer reviewed prior to their release on the Web. This report was reviewed through a process administered by the Society for Conservation Biology, which chose two recognized experts to provide critical input on the manuscript. Peer review was designed to improve the quality of communication and to increase the rigor of the assessment.

MANAGEMENT STATUS AND NATURAL HISTORY

Management Status

Uniomerus tetralasmus is assigned a Global Heritage Status Rank of G4, which indicates that the species is "apparently secure" across its entire range (NatureServe 2003). In the United States it is also considered "apparently secure" (NatureServe 2003). Its status varies among states from presumed extirpated (in New York) to abundant (in Georgia, Kentucky, and Mississippi) (NatureServe 2003). Within the states of Region 2, NatureServe (2003) ranks this species as follows: Colorado (S1, "critically imperiled"), Kansas (S3S4, "vulnerable to apparently secure"), Nebraska (S?, "unranked"), and South Dakota (S1, "critically imperiled"). Wyoming is not listed as within the species' range.

The U.S. Fish and Wildlife Service (2003) does not include *Uniomerus tetralasmus* on their lists of threatened, endangered, or candidate species. In Region 2, *U. tetralasmus* was considered for sensitive species status, but it is not currently recognized as such.

Existing Regulatory Mechanisms, Management Plans, and Conservation Strategies

In Region 2, *Uniomerus tetralasmus* is considered of conservation importance because of its decline in some watersheds (see Population trend section). Forests in Region 2 do not have any official written policies specifically aimed at managing *U. tetralasmus*. However, Region 2 does have a Watershed Conservation Practices Handbook (FSH2509.25) that attempts to set standards and guidelines to meet state water quality regulations. The USFS is currently in the process of updating the standards, design criteria, and process used to determine stream health.

Apparently no management strategies have been developed specifically for *Uniomerus tetralasmus* in other regions either. However, some conservation strategies are available for freshwater mussel species in general in the Upper Mississippi River System (National Native Mussel Conservation Committee 1998, Mussel Ad Hoc Committee 2003), and recovery plans are available for some mussel species that are on the endangered species list (e.g., U.S. Fish and Wildlife Service 1982, Mignogno 1996). These strategies and plans could help to guide the development of mussel management in Region 2 as outlined below.

The National Native Mussel Conservation Committee's (1998) strategy includes ten goals:

- encourage information exchange among agencies and groups regarding mussel conservation
- conserve and recover quality mussel habitat
- research basic biology and habitat needs of mussels
- organize recent and historical survey data so populations can be monitored and trends can be assessed
- research impacts of habitat change on mussel populations
- organize response to zebra mussels
- increase public outreach to promote the role of freshwater mussels in the environment
- explore artificial propagation methods for mussels
- successfully transport adult individuals to other areas
- develop funding sources.

Associated strategies are outlined to help reach each goal. Several of these goals do not apply to national forests in Region 2. For example, no zebra mussels are documented in Region 2. However, these goals could be tailored to benefit native freshwater mollusk communities in the region.

The Mussel Ad Hoc Committee (2003) of the Upper Mississippi River Conservation Committee (UMRCC) used the goals listed above to develop a mussel conservation plan for the Upper Mississippi River region. The main objectives in the UMRCC plan are to:

- establish a program to survey and monitor mussels
- study the biology of the mussels
- determine the effects of habitat changes on mussels through new research and literature searches
- restore and maintain mussel populations in the Upper Mississippi River basin
- promote public education about the importance of and conservation of mussels.

Similar objectives could be applied to mussel conservation in any USFS region, including Region 2. In addition, more specific guidelines are needed for adequate management of *Uniomerus tetralasmus* in Region 2 to address the threats from management activities that mussels are facing and/or may face in the future.

Biology and Ecology

Systematics and general species description

Uniomerus tetralasmus is a mollusk in the Class Bivalvia, Order Unionoida, Family Unionidae (Turgeon et al. 1998). Bivalves are mollusks with their shell divided into two halves (valves) joined at a hinge (see Definitions section for an explanation of terms). The closest relatives to *U. tetralasmus* are unknown but presumably are other members of the Family Unionidae, which represents a monophyletic group based on analyses by Giribet and Distel (2003).

A diagram of *Uniomerus tetralasmus* is shown in **Figure 1**. Shells of *U. tetralasmus* are described as:

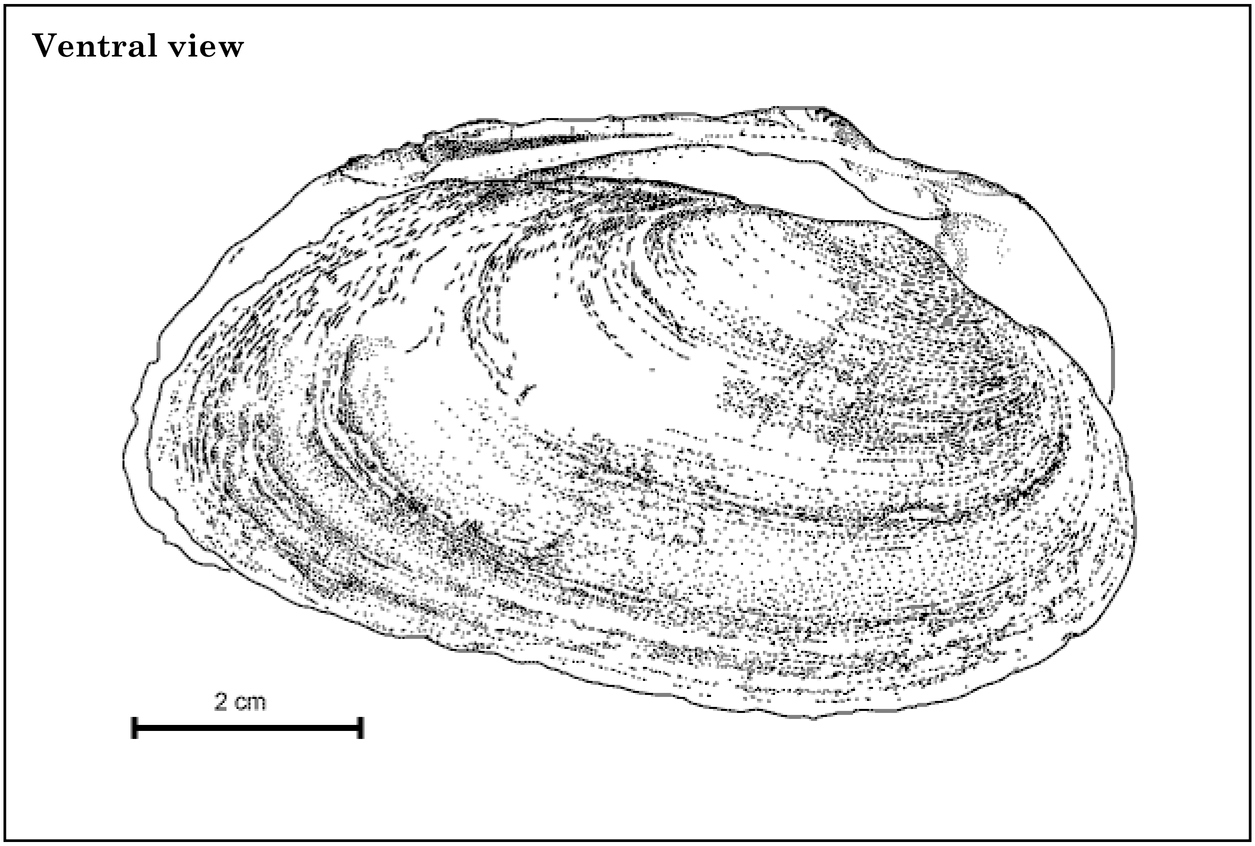


Figure 1. Diagram of *Uniomerus tetralasmus*. Illustration by Leigh Anne McConnaughey.

> "elongate, light to dark brown [in color], …[with the] anterior end rounded, posterior end bluntly or sharply pointed. Dorsal margin straight, ventral margin straight, rarely curved. Umbos low, approximately even with the hinge line. Beak sculpture of four or five concentric ridges. Two shallow grooves present on the posterior slope, giving rise to a short ridge. Surface smooth and shiny in small shells, becoming rougher and dull in older individuals. Periostracum greenish or yellowish brown in young individuals, adults dark brown to black and rayless." (Cummings and Mayer 1992, pg 72).

Brandauer and Wu (1978, pg 56) further describe the internal part of the shells as follows:

> "The hinge is long (about 2/3 the shell length) and has two strong triangular pseudocardinal teeth on the left valve and one on the right valve. An anterior pseudocardinal tooth on the right valve is small or inconspicuous. Two posterior lateral teeth in the left valve and one posterior lateral tooth in the right valve are sharply edged, slightly curved and extend along roughly 1/3 of the shell length. The ligament is long, approximately ½ of the shell length. The interior of the shell is white… The beak cavity is shallow and usually contains several small round, or oval pits, The anterior muscle scars are much more strongly impressed than the posterior muscle scars."

Uniomerus tetralasmus range from 88 to 100 mm (3.5 to 3.9 inches) in length in Colorado (Wu 1989). Elsewhere, shells have been known to reach 149 mm (5.9 inches; Taylor 1984). Brandauer and Wu (1978) describe Colorado specimens as averaging 92.1 mm (3.6 inches) in length, 46.6 mm (1.8 inches) in height, and 30.2 mm (1.2 inches) in width.

Other mussels in the region can be distinguished from *Uniomerus tetralasmus* by close examination of the shell color, shape, and sculpture. Similar bivalves that might be confused with *U. tetralasmus* are differentiated by the characteristics described here (based on the descriptions in Cummings and Mayer 1992). *Lampsilis teres* (yellow sandshell) has a similarly shaped shell, but it is much more yellow in color. *Anodonta grandis* (giant floater) also has similar coloration, but it is larger (up to 25.4 cm [10 inches]) and has no teeth. *Anodontoides ferussacianus* (cylindrical papershell) has no teeth, and the shells usually have greenish rays extending from the umbo to the posterior end. *Strophitus undulatus* (creeper) has very small teeth and usually a pink to orange nacre. *Ligumia subrostrata* (pondmussel) is similar in size and coloration, but it has green rays on its shell. Several resources provide detailed descriptions of these other species, including Burch 1973, Cummings and Mayer 1992, and Parmalee and Bogan 1998.

Distribution and abundance

The overall range of *Uniomerus tetralasmus* stretches from Colorado, South Dakota, and Texas in the west to Florida and New York in the east (**Figure 2**; NatureServe 2003). Cummings and Mayer (1992) consider the species to be "widespread but generally uncommon" in the Midwest, but they do not provide specific abundance information.

The distribution of this species within Region 2 is shown in **Figure 3**. National Forest System lands where the species is most likely to occur include the Cimarron National Grasslands and the Comanche National Grasslands. However, it is unknown if healthy populations still exist at those locations. In Colorado, the species may currently exist at the Queen's State Wildlife Area (Cordeiro 1999), but this has not been confirmed. Historical populations from the Cimarron River, Carrizo Creek, and Lake Henry are believed to be extinct (Cordeiro 1999). Although the species is reported from the western part of Kansas (Hoke 1996), *Uniomerus tetralasmus* is not included among the species that are tracked by the Kansas Natural Heritage Program (C. Freeman personal communication 2004). Bergman et al. (2000) report *U. tetralasmus* as present but rare in surveys of Republican and Smokey Hill River systems in northwestern Kansas. They indicate that the rarity of this species in their study may be due to the fact that ponds were not included in their surveys. Other locations reported in Kansas include Middle Creek, Neosho River, Labette Creek, Shoal Creek, Verdigris River, Elk River, and Caney River (Couch 1995, Obermeyer et al. 1997). Native peoples living along the Solomon River in Kansas apparently utilized mussels, including *U. tetralasmus*, for food (Dorsey 2000); the current presence of the species in this area could not be confirmed. The species is reported from Nebraska (Hoke 2000) in the Platte River (Freeman and Perkins 1992, as reported in Myers and Perkins 2000). In South Dakota, *U. tetralasmus* has been found in Ponca Creek in Gregory County (D. Backlund personal communication 2004). No records of *U. tetralasmus* are known from Wyoming (Beetle 1989).

The reported distribution of *Uniomerus tetralasmus* is somewhat surprising given our current understanding of the biology of the species. Only one host species is known, the golden shiner (*Notemigonus crysoleucas*). While not a native to western Kansas or eastern Colorado, it has been introduced there (**Figure 4**; NatureServe 2003, U.S. Geological Survey 2003, 2004). This indicates that at least one of the following is true: (1) additional host species exist, at least in these areas, (2) the native range of golden shiners extends further west than reported, or (3) these mussel populations are not native populations, but were established when golden shiners with mussel glochidia already attached were introduced to these areas. Because fish introductions are not always rigorously recorded (especially when done by private individuals), it may not be possible to determine which of these three hypotheses is correct without extensive genetic testing. At least by the 1970s, golden shiners had established populations in Wyoming (Baxter and Simon 1970), so it may be useful to survey areas with known golden shiner populations in Wyoming for the presence of *U. tetralasmus*. Amphibians and exotic fish species have been shown to be compatible host species for some freshwater mussels (Watters 1997, Watters and O'Dee 1998), but this has not been studied in *U. tetralasmus*.

Potential habitat

Uniomerus tetralasmus should be able to exist in muddy or sandy, slow-moving creeks or lakes that have suitable host species (golden shiner) and suitable temperature range and nutrients. Records of occurrence of this species in Region 2 are not common, but it is not known whether this is due to a lack of mussel surveys or to unsuitable habitat parameters. Region 2 is towards the western edge of the range of the species, so it may not be common in the area naturally.

Unfortunately, the exact temperature and nutrient requirements for *Uniomerus tetralasmus* are unknown, so it is difficult to predict acceptable habitat *a priori*. It may be useful to survey areas with known golden shiner populations (**Figure 4**) to determine if any additional *U. tetralasmus* populations exist in the region.

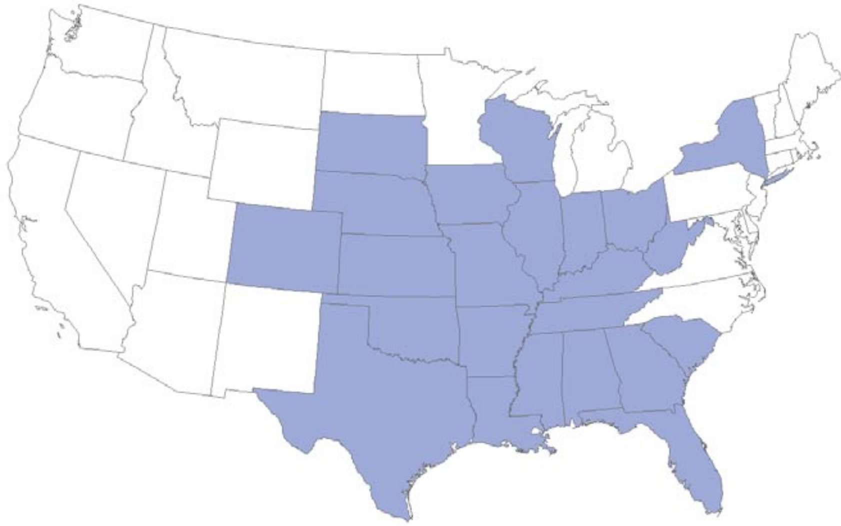
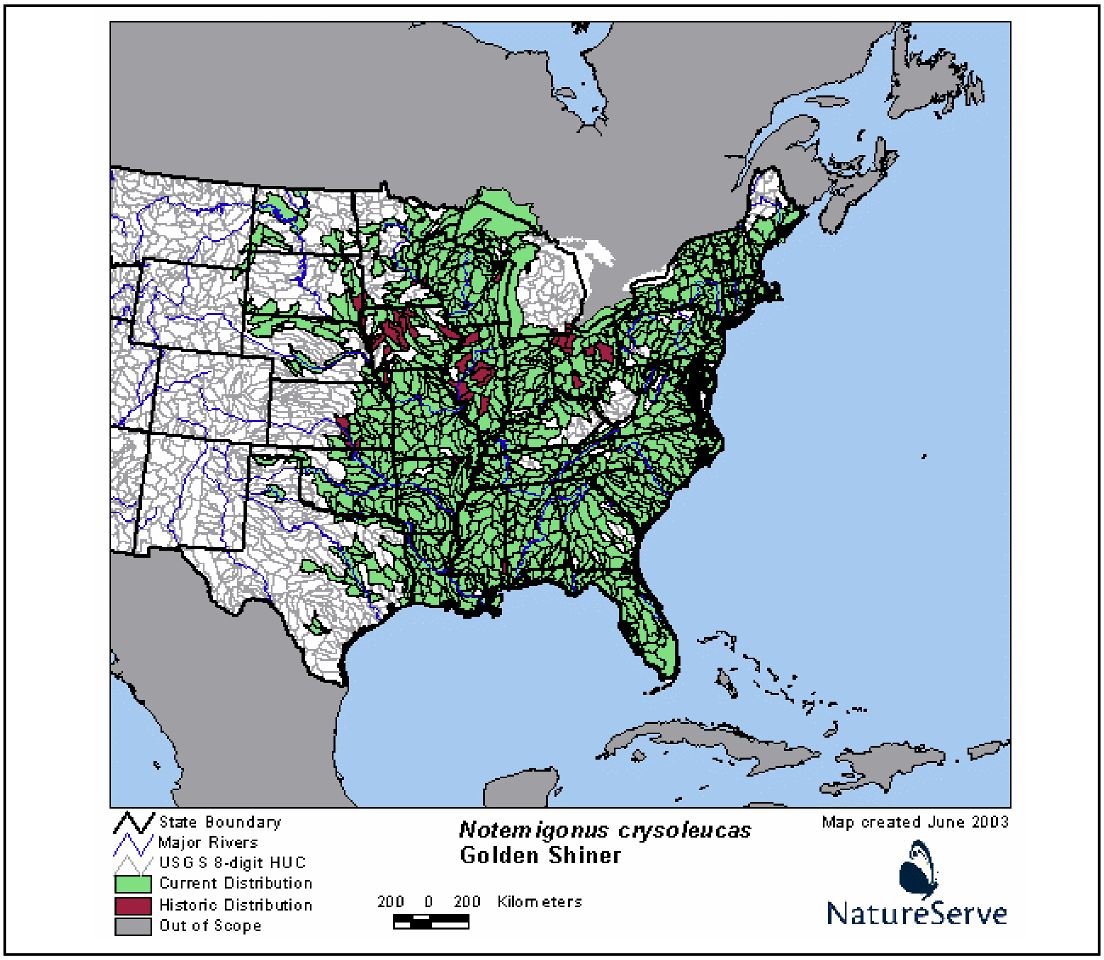


Figure 2. Known distribution of *Uniomerus tetralasmus* in the United States. Purple states are those with reported occurrences. These include historic and current records.

Figure 3. Pondhorn distribution in USDA Forest Service Region 2. Waterways where mussels are reported are shown in blue and include both extant and historical population records. For specific waterway names, see Distribution section in the text of this report. The shaded areas in Colorado and Kansas represent federal lands that overlap the mussel distribution. The federal lands shown are the Cimarron and Comanche national grasslands.

(A)



(B)

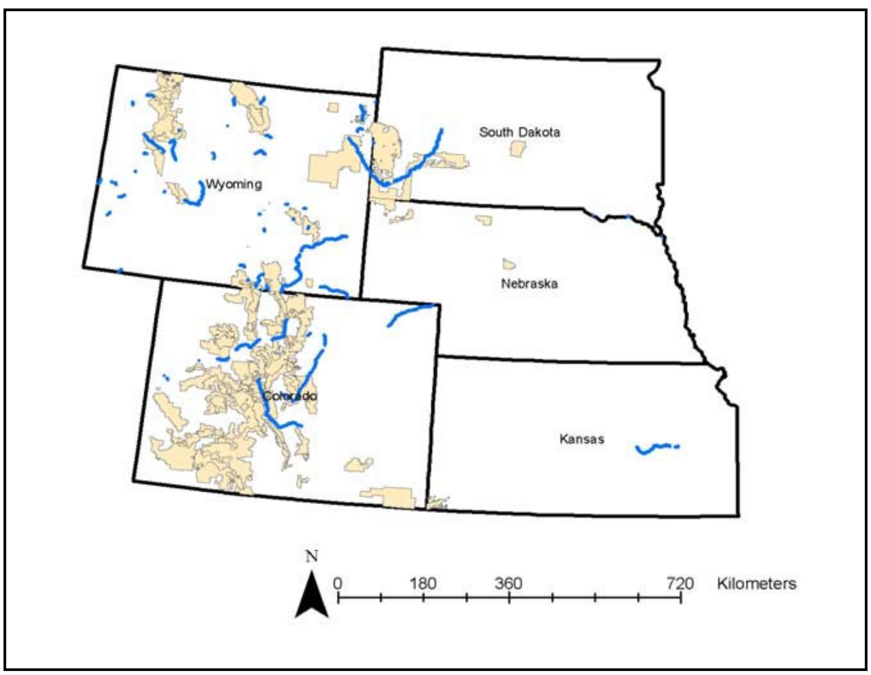


Figure 4. Distribution of golden shiner (*Notemigonus crysoleucas*), the host for *Uniomerus tetralasmus*. **(A)** Native distribution of the golden shiner (NatureServe 2005). Copyright 2005 NatureServe, 1101 Wilson Boulevard, 15th Floor, Arlington, Virginia 22209. Used with permission. **(B)** Additional distribution of golden shiners in Region 2. Rivers highlighted in blue show drainages where golden shiners have been reported. (Note: data exists by drainage, so the species may not be known along the entire river shown.) These are believed to be introduced populations. Data are from assorted references: Baxter and Simon 1970, Deromedi personal communication 2004, U.S. Geological Survey 2004. Shaded areas represent national forest and national grassland boundaries. Because golden shiners are not tracked in all areas, additional locations may exist.

Degree of isolation of populations

Because of the limited movement in adults, connectivity among mussel populations is mainly limited to areas among which host fish can move. Some evidence for long-distance dispersal by birds or wind exists for other freshwater mussels (summarized in Burky 1983) but not for *Uniomerus tetralasmus*. Mussel populations within watersheds are most likely isolated if there are barriers that limit host fish movements. Therefore, in Region 2, populations in different watersheds are most likely isolated from one another unless golden shiners infected with *U. tetralasmus* glochidia are moved among watersheds by humans (i.e., during fish stocking) or unless passive dispersal occurs.

Population trend

Freshwater mussels are one of the most threatened groups of organisms in the United States (Master et al. 2000, Watters 2000, Lydeard et al. 2004). Unionids have been declining since around 1900 (McMahon and Bogan 2001). Nationwide population trends for *Uniomerus tetralasmus* are not available. In Region 2, the only information on population trends is from Colorado, where some areas with historical populations of *U. tetralasmus* no longer support any individuals (Cordeiro 1999). In fact, Cordeiro (1999) indicated that one watershed where historical populations were recorded (the Cimarron River) did not even hold water during his survey. The populations in Kansas may also be declining; only dead specimens were found in mussel surveys of southeastern Kansas waterways in the Neosho and Verdigris River basins (Obermeyer et al. 1997).

Activity patterns

Seasonal

The growth and metabolic rates of mussels vary with the seasons due to temperature changes (reviewed in McMahon and Bogan 2001). Generally, lower temperatures result in lower metabolic rates. However, some species are able to slowly adjust to temperature changes so that their metabolic rates remain somewhat stable (reviewed in McMahon and Bogan 2001). Due to the reproductive cycle whereby gonads develop and then glochidia are released, reproductive stage varies with the season (see Breeding biology and Life history sections for more information). The development and release of glochidia is stimulated by water temperatures within an acceptable range (McMahon and Bogan 2001). What that range is for *Uniomerus tetralasmus* is unknown. In addition, *U. tetralasmus* is able to survive periods of dry conditions (McMahon and Bogan 1991), but it presumably is not active during such times.

Movement patterns

The main movement during the lifetime of mussels occurs while they are attached to their host fish as glochidia. When juveniles mature, they locate a suitable substrate and burrow in with their foot (Coker et al. 1921). Most mussels in the Family Unionidae move little once reaching adult age (McMahon and Bogan 2001), but in some species horizontal movement (i.e., to deeper or shallower waters) and vertical movement (i.e., burrowing deeper into the sediment and/or moving to the surface of the sediment) are known to occur (Watters et al. 2001). Specific information on the movement of *Uniomerus tetralasmus* is not available; vertical movement is probably less than in other species because of its adaptations to dry conditions (McMahon and Bogan 1991) as discussed under the Limiting factors section below.

Connectivity

Because of the limited movement in adults, connectivity among mussel populations is mainly limited to areas among which host fish can move. Some evidence for long-distance dispersal by birds or wind exist for other freshwater mussels (summarized by Burky 1983), but this has not been observed for *Uniomerus tetralasmus*. Therefore, it is unlikely that mussels are able to move to separate watersheds without human intervention (through either transport of fish with glochidia attached or transport of the mussels themselves.

Habitat

Uniomerus tetralasmus occur in ponds, creeks, and the upper reaches of larger streams (Cummings and Mayer 1992). The substrate usually consists of mud or sand (Cummings and Mayer 1992). Specific habitat characteristics for *U. tetralasmus* in a West Virginia pond site included sand and gravel substrate with some silty places and "cool" temperatures (actual water temperatures were not given) (Taylor 1984). They appeared on a range of substrates and at a range of water depths in this pond from 10 cm (3.9 inches) to 3 m (9.8 ft.).

While Coker et al. (1921) reported microhabitat characteristics for many mussel species, *U. tetralasmus* was not one of them, and specific microhabitat requirements for this species remain unknown.. In general, freshwater mussels prefer water depths of around 1 m (3.3 ft.), potentially ranging from 0.5 to 2.0 m (1.6 to 6.6 ft.). However, this varies somewhat among species and changes in water levels, as well as whether preferred substrate types are available at that depth (Dillon 2000).

The importance to mussels of substrate characteristics such as porosity, percent of fine sediments, and particle size is unclear. Brim Box et al. (2002) studied mussels in three river basins in the southeastern United States. Of the five species (*Elliptio complanata*, *E. icterina*, *Toxolasma paulus*, *Villosa lienosa*, and *V. vibex*) with sufficient sample size to analyze, only *V. lienosa* showed a relationship to any substrate characteristics (i.e., well-sorted and with many fine particles).

Temperature is important in determining where mussels can live because they must have the proper amount of dissolved oxygen, which varies with temperature (Burky 1983). In a laboratory study, temperatures of 34 ºC (93 ºF) for as little as 48 hours resulted in 50 percent or more mortality for juveniles of two unionid species, *Pyganodon cataracta* and *Utterbackia imbecillis* (Dimock and Wright 1993). Glochidia extracted from *Villosa iris* and *Actinonaias pectorosa* mussels were viable for significantly shorter time periods at 25 ºC (77 ºF) than at 0 ºC (32 ºF) and 10 ºC (50 ºF) in the laboratory (Zimmerman and Neves 2002). Both minimum and maximum temperatures apparently limit the distributions of some bivalves (McMahon and Bogan 2001). If temperatures in streams and lakes are above or below these limits, this may be one factor excluding populations of *Uniomerus tetralasmus* from inhabiting portions of Region 2. Temperature is also important in stimulating spawning (Mackie 1984).

Chemical components of the habitat also contribute to the microhabitat characteristics of a site. The pH has been shown to be important for freshwater snails (Hunter 1990, as cited in Dillon 2000). Dillon (2000) suggests that pH may be affecting the overall metabolic regulation of the organisms. However, McMahon and Bogan (2001) consider pH to be less important in determining the distribution of bivalves, so long as the pH remains above 7.0. The acidity of the water depends on the natural content of the water, but it can be lowered by point-source pollution or sulphur transport by air (acid rain). McMahon and Bogan (2001) summarize studies where unionids have been found to successfully inhabit habitats where pH ranges from 5.6 to 8.3.

However, low pH levels can affect shell thickness, tissue cholesterol, and hemolymph concentrations of several ions; this in turn may negatively affect survival and/or population distributions (summarized in McMahon and Bogan 2001). For example, Okland and Kuiper (1982) demonstrated that several Norwegian mussel species of Family Sphaeridae were absent from areas with pH under 6. Impacts of low pH may be species-specific in mussels (Okland and Kuiper 1982), and because the Okland and Kuiper study was of distantly related mussels, it is unknown if these results would be similar for *Uniomerus tetralasmus*.

Low pH may also have greater effects on glochidia and juveniles than on adults. For example, Huebner and Pynnonen (1992) found that *Anodonta cygnea* and *A. anatina* showed decreased glochidia viability at pH as high as 5. Juvenile specimens of the unionids (*Pyganodon cataracta* and *Utterbackia imbecellis*) had less than 50 percent survival when exposed to pH of 4.0 in the lab, but they were not affected by pH of at least 5.0 (Dimock and Wright 1993). Juvenile zebra mussels (*Dreissena polymorpha*), a bivalve in a different family, grew only at pH higher than 8.3 (Hincks and Mackie 1997).

Low pH may also compound other pollution problems. Decreased pH slowed the closure responses of the glochidia to lethal exposures of KCl and reduced tolerances to other contaminants such as aluminum (Huebner and Pynnonen 1992). Specific pH requirements for *Uniomerus tetralasmus* are not available.

Calcium (usually in the form of calcium carbonate) is an important component of the habitat also. Mussels need calcium to build their shells. A study in Britain found that most mollusks occurred where there were at least 20 ppm calcium ions (Boycott 1936, as cited in Burky 1983). This may be species-dependent, as mussels in New York were located in areas with concentrations as low as 8.4 ppm (Harman 1969, as cited in Burky 1983). Green (1971) also found calcium to be one of the most important factors in discriminating between species found in different Canadian lakes. Calcium requirements for *Uniomerus tetralasmus* are unknown.

Calcium can also affect mussel growth rates. A study of zebra mussels demonstrated the importance of calcium on growth: peak growth occurred at 32 mg/

L, and low levels of calcium (<8.5 mg/L) resulted in negative growth (Hincks and Mackie 1997).

Fuller (1974) summarizes evidence that many chemicals are detrimental, even fatal, to mussels. These include arsenic, cadmium, chlorine, copper, iron, mercury, nitrogen, phosphorus, potassium, and zinc. Toxicities of metals on glochidia of *Anodonta* species were investigated by Huebner and Pynnonen (1992). Metal ion concentrations that reduced shell closure of glochidia by 50 percent were 5.3 ug per L of copper, 46.8 ug per L cadmium, and 69.1 ug per L zinc. Reduced shell closure would interfere with the ability of glochidia to latch onto fish hosts.

The trophic status of the habitat may be just as important as water chemistry for mussels (Green 1971). Green used discriminate analysis to determine important factors influencing the presence of ten mussel species in 32 Canadian lakes. The first three discriminate functions (accounting for 80 percent of the among-species variance) were interpreted as 1) "concentration of calcium relative to total alkalinity", 2) "depth and depth-related sediment mean particle size", and 3) "organic content of sediment, related to sediment particle size". Water depth and water velocity influenced the distribution of mussels in Horse Lick Creek in Kentucky during normal flows (Layzer and Madison 1995). Different species had slightly different distributions, but most species preferred depths between 7 and 30 cm (2.8 and 11.8 inches) at water velocities of 0.03 m^3 per s (1.1 ft^3 per s), which was the base level flow. When the dam was discharging water at higher rates, most species preferred areas with water flows from 71 to 150 cm per s (2.3 to 4.9 ft. per s). Mussels tended to be rare at low flow areas with velocities less than 4 cm per s (0.13 ft. per s). *Uniomerus tetralasmus* was not included in either of these studies.

Food habits

Uniomerus tetralasmus, like all freshwater mussels are filter feeders, which means that as water passes across their gills, they remove suspended particles from the water (McMahon and Bogan 2001). They consume large amounts of phytoplankton (McMahon and Bogan 2001). Mussels do not constantly feed, but they have periods of feeding (when valves are open) and periods of rest (Dillon 2000). The periodicity in feeding periods varies among species and may be affected by environmental conditions such as light, temperature, and food availability (summarized in Dillon 2000). Specific information on *U. tetralasmus* feeding cycles is not available.

Although not every particle that passes through the siphons ends up in the gut of mussels to be used for food, the fact that they are relatively long-lived filter feeders makes them susceptible to other pollutants in the environment (Burky 1983, McMahon and Bogan 2001; see Habitat discussion above). Due to their feeding mechanisms, mussels are often used as bioindicators to monitor everything from arsenic to mercury to pesticides in the water (summarized in McMahon and Bogan 2001). Specific effects of pollutants on *Uniomerus tetralasmus* are unknown.

Breeding biology

Uniomerus tetralasmus is believed to have separate sexes, like most unionids (McMahon and Bogan 2001, Dillon 2000). The breeding biology specific to *U. tetralasmus* has seldom been studied. Reproduction in unionid mussels is summarized in McMahon and Bogan (2001) as follows. During the reproductive season, the gills are transformed into marsupia that function as "brood chambers". Sperm are released externally to the shell and are brought in through the siphon of another individual to the gills. Eggs are carried directly to the gills via ducts. After fertilization, the embryo matures in the marsupia. After developing to the larval stage, the embryo is now called a glochidia, and it is released to the water column. Glochidia attach to fish hosts to mature, and then become free-living juveniles once mature.

Mackie (1984) reports that the glochidia of most bivalve species are only viable without a host for less than two weeks. Most likely only a small proportion reach a suitable host (Howard and Anson 1922). Glochidia and the fish host have a complex chemical interaction that results in a cyst forming around the glochidia within two to 36 hours (Kat 1984). Without proper physiological chemistry cues between the fish and mussels, fish can slough off glochidia, as happens in non-host species. During this time when the glochidia are parasitizing the fish, the mussel gets some nutrition, but it is believed to be mainly an adaptation for dispersal (Kat 1984). The length of time *Uniomerus tetralasmus* remains attached to its host is unknown.

After releasing from the host fish, juveniles drift briefly until they reach the bottom (Coker et al. 1921). Then they use their foot to stick to surfaces and to move across the substrate, until they find a place to settle. The end of the juvenile stage in mussels is usually about one month, but they may not be sexually mature for years (Coker et al. 1921).

Temperature stimulates the maturation of the gametes and the release of the sperm in many mussels (Mackie 1984). Apparently this threshold temperature varies by species and may also interact with latitude. The threshold temperature for *Uniomerus tetralasmus* is unknown. The length of the larval stage can also be influenced by temperature (Mackie 1984). Presumably effects of temperature on developmental rate are due to metabolic reactions that occur faster or slower at particular temperatures. Ideal temperature ranges for larval development in *U. tetralasmus* are unknown.

Unionids have only one breeding season per year (McMahon and Bogan 2001), but the timing of glochidia release differs among unionid species. Either the glochidia are released in the summer or they overwinter within adult mussels (Howard and Anson 1922). Coker et al. (1921) reported only finding *Uniomerus tetralasmus* females with glochidia in May. Utterback (1916) also observed glochidia in May and August, leading him to suggest that the species may be longer term breeders. Unionids reproduce multiple times during their lifetime (McMahon and Bogan 2001).

Specific information on brood size in *Uniomerus tetralasmus* is unknown. The mechanism of sex-determination (i.e., genetic or environmental) in mussels is unknown. Most studies have indicated an approximately 50:50 ratio of males to females in mussel populations (Dillon 2000).

Demography

Genetic characteristics

Bivalves show a range of genetic patterns. Berg et al. (1996) found genetically distinct "management units" of *Quadrula quadrula* within one river basin in the eastern United States, but another river basin showed a unified population. With limited dispersal and small populations (which may be the case in much of Region 2), it is possible that the genetic diversity of *Uniomerus tetralasmus* is low *within* populations. However, if populations are the result of multiple introductions, or if larger populations exist, then higher levels of genetic diversity may exist within populations. No information is available on the genetic diversity within or among *U. tetralasmus* populations anywhere in its range.

Life history

Specific information on the life history of *Uniomerus tetralasmus* is unknown. Data from other mussel species is compiled by McMahon and Bogan (2001). The following discussion draws from this data, unless otherwise stated. In general, mussels in the family Unionidae live from less than six to more than 100 years. Heller (1990) does not include *U. tetralasmus* in his summary of life spans of mollusks but lists other members of Unionidae that have life spans ranging from five to 116 years. Therefore, it is likely that *U. tetralasmus* live for several years. Unionids mature somewhere between six and 12 years old and produce between 200,000 and 17 million young per female each season, with one reproductive effort per year. Quantitative survival rates are not listed but are described as extremely low for juveniles and high for adults. The proportion of the population that is breeding likely depends on the conditions at that particular site.

A diagram of the life cycle of *Uniomerus tetralasmus* is shown in **Figure 5**. The life cycle diagram shown is a stage-based diagram rather than an age-based diagram because the intervals between stages are not necessarily constant. The four stages shown in the life cycle are: 1) the glochidia development stage before they are released by the mussels, 2) the glochidia while they are parasitizing the fish, 3) the post-parasitic juvenile stage, and 4) the adult mussel stage. The only stage that produces offspring (glochidia) is the adult stage. There is no available information that indicates that there are post-reproductive adult stages. In the diagram, variables are shown for the probability of successfully reaching each stage from the stage before (P), fertility (F), and the productivity of an individual (m). The probability of glochidia that are released (stage 1) surviving and successfully parasitizing a fish host (stage 2) is given as P_{21}. Probabilities (P) of reaching each successive stage are listed in a similar fashion. The fertility (F), or number of glochidia produced, is a function of both the number of glochidia produced by an adult (m) and the probability of an individual reaching the adult stage (P_{43}). Should numerical data become available in the future for survival and productivity of *U. tetralasmus* at these stages, this diagram could be used to construct a demographic model (after McDonald and Caswell 1993, Caswell 2001).

Patterns of dispersal

Dispersal occurs almost exclusively during the glochidia and juvenile stages. See discussions in Connectivity and Life history sections for more details.

Social spacing

In some locations, such as a pond in West Virginia reported by Taylor (1984), populations of *Uniomerus*

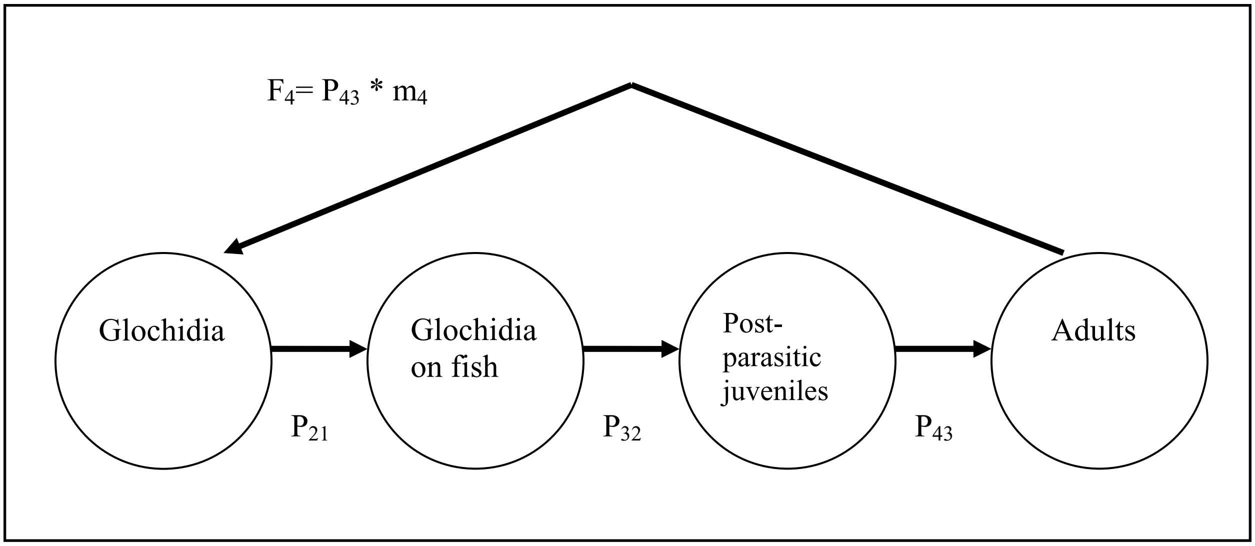


Figure 5. Life cycle diagram for *Uniomerus tetralasmus*.

tetralasmus reach hundreds of individuals. Taylor (1984) estimated that the West Virginia specimens ranged in age from eight to 14 years old.

Limiting factors

No information is available on limiting factors specific to *Uniomerus tetralasmus*. Obviously, the species is limited to aquatic areas where the host fish is present. In general, aquatic mollusks are limited by the water chemistry (pH, dissolved oxygen, and dissolved salts such as calcium carbonate) and water temperature (Turgeon et al. 1998). Beetle (1989) surmises that at least in Wyoming, the number of mollusks is limited due to high elevation, harsh climate, low amounts of moisture, and the temporal nature of many of the bodies of water. These factors would also affect much of the rest of Region 2. Pennak (1989) attributes the lack of mussels in high mountain lakes of the Rocky Mountains to the lack of host fish species and low calcium levels.

Uniomerus tetralasmus is able to survive emersion (exposure to air when water levels have dropped) up to 578 days at 15 ºC (59 ºF) and 95 percent humidity; this is much longer than other mussel species (Holland 1991, as cited in Byrne and McMahon 1994). This tolerance drops considerably as temperature increases or humidity decreases, but it is still longer than for other species. At 25 ºC (77 ºF), *U. tetralasmus* survived emersion of just over 200 days at 95 percent and 53 percent relative humidity. At 15 ºC (59 ºF) and relative humidities of 53 percent and less than 5 percent, emersion tolerance was between 100 and 200 days. *Uniomerus tetralasmus* survives these conditions by reducing mantle tissue exposure to the air in dry conditions and by plugging its siphons with mucous that allows for a greatly reduced rate of water loss (Byrne and McMahon 1994).

Community ecology

Predation

A wide variety of predators feed on one or more stages of mussels: water fowl, fish, crayfish, fire ants, turtles, frogs, salamanders, oligochaetes, otters, minks, muskrats, and raccoons (summarized in McMahon and Bogan 2001). Juvenile bivalves are an important part of many freshwater food chains (McMahon and Bogan 2001). Specific studies on the predators of *Uniomerus tetralasmus* within and outside of Region 2 are not available.

Competition

Competition between *Uniomerus tetralasmus* and other mussel species in the region is unknown. Zebra mussels, an invasive species common in the eastern and midwestern United States, are known to negatively affect native mussel populations, but they are not known to occur within Region 2 (McMahon and Bogan 2001). Asian clams (*Corbicula fluminea*), another invasive species, may also negatively impact native mussels (Bogan 1993). It is unknown if Asian clams occur within Region 2 (NatureServe 2003).

Parasites and disease

No information is available on the parasites or diseases of *Uniomerus tetralasmus*. Studies of other Unionidae have shown them to be susceptible to water mites (*Unionicola* spp. and *Najadicola* spp.), which attach to gills, the mantle, or internal organs (summarized in McMahon and Bogan 2001). Trematodes, nematodes, and chironomids (*Ablabesmyia janta*) are also known to parasitize unionids (McMahon and Bogan 2001). Bacteria can also negatively affect mussels under certain circumstances when they are already stressed such as during times of heavy siltation or disturbance (Fuller 1974).

Symbiotic and mutualistic interactions

Glochidia require specific fish species for development. The only known fish species that hosts glochidia from *Uniomerus tetralasmus* is the golden shiner (Stern and Felder 1978). Golden shiners utilize slow-moving waterways and prefer areas with plentiful vegetation (Baxter and Simon 1970). **Figure 4** shows the watersheds where golden shiners are reported to reside in Region 2. The mussel glochidia obtain nutrients from the host fish until they reach the free-living stage (McMahon and Bogan 2001). Whether this has any significant negative effect on the fish under normal infestation levels is unknown.

Hypotheses for how the important ecological relationships affect *Uniomerus tetralasmus* are diagrammed in the envirogram shown in **Figure 6**. An envirogram (after Andrewartha and Birch 1984) is a graphical representation of the 'ecological web' of complex pathways that influence an animal's survival. The center of the web is the focal animal, in this case *U. tetralasmus*. Each step out from the center is influenced by the factors in other steps of the web. For example, factors listed in level 2 of the web affect those factors in level 1 of the web and are themselves affected by the factors in level 3 of the web. Both positive (resources) and negative (malentities) influences are shown on the envirogram. In this case, water, food, the presence of the host fish, and healthy aquatic habitats are essential for the mussels to survive. Predation, desiccation, and habitat degradation are shown as having negative impacts on *U. tetralasmus*.

CONSERVATION

Threats

No studies specifically address threats to *Uniomerus tetralasmus*. Therefore, this section is based on information from other mussel species. Bogan (1993, 1996) considers the main causes of mussel decline as follows:

- habitat destruction, mainly due to sedimentation, damming, dredging, etc.
- pollution, especially acidic runoffs from mines, pesticides, and heavy metals
- commercial uses such as in-stream mining and harvesting of mussels
- declining host fish populations
- invasion of exotic species such as zebra mussels and Asian clams.

Changes in the water flow are also detrimental to mussels (Vaughn and Taylor 1999). More details on how specific management activities may affect mussels are outlined below.

Besides specific activities at the local scale, managers may need to consider the activities across an entire landscape. Large-scale landscape changes that alter the type of vegetation cover alongside streams have been linked to the disappearance of rare mussel species in Iowa (Poole and Downing 2004). The landscape changes in Iowa were due mostly to the removal of riparian woodlands and agricultural uses that changed the landscape from historical vegetation covers. Although the land uses in much of Region 2 are different from those in Iowa, this study does indicate that in some cases mussels may be affected by landscape activities at a scale larger than just what is occurring immediately adjacent to the point where mussels are living. Activities on the entire watershed may need to be considered when managing for stream health and mussel populations.

Changes in water flow

Even though *Uniomerus tetralasmus* can survive emergence longer than some mussel species, extended low water levels interfere with reproduction by killing fish hosts or by keeping them away from the areas where there are mussels with glochidia needing a host. Low water levels caused by weather-related drought conditions are difficult to alleviate. However, diversion or impounding of natural water flows can also contribute to low water levels in some areas.

Dams have been shown to restrict unionid distributions. *Leptodea fragilis* and *Potamilus alatus* are currently limited to areas downstream of dams in five Midwestern rivers, presumably because fish hosts cannot move upstream (Watters 1996).

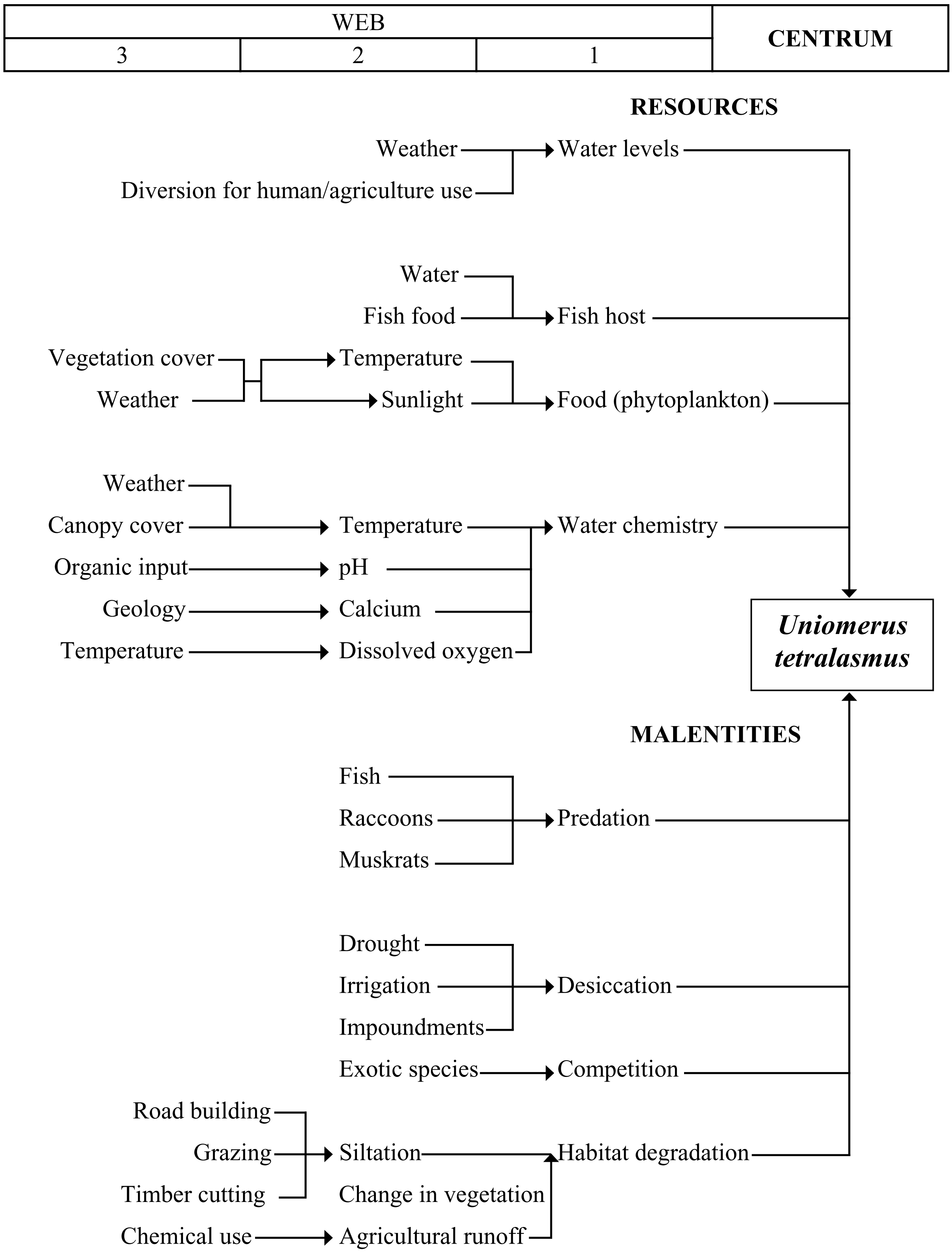


Figure 6. Envirogram for *Uniomerus tetralasmus*.

In addition to low water levels, changes in water velocity, water temperature, or extreme fluctuations of water flows due to human water management can also be detrimental to mussel populations. A study of reservoirs along the Little River in Oklahoma found that areas closest to the dams (less than 20 km downstream) were devoid of most live mussels, although dead shells from many species were present (Vaughn and Taylor 1999). More mussel species were present as the distance from the reservoir increased. In streams with flows regulated by hydraulic discharges, high shear stress may reduce mussel recruitment by interfering with the ability of juveniles to settle (Layzer and Madison 1995)

Individual mussel species may be adapted to particular patterns of water flow. In a study of 15 mussel species found in Ontario and Michigan, the mussel communities differed between river basins that experienced flooding or discharge events versus those with more stable water flows (DiMaio and Corkum 1995). Three species were identified as stable-site species and three others as flooding-event site species. *Uniomerus tetralasmus* was not included, so it is unknown how this species responds to discharge or flooding events.

Mining

Specific effects of mining on *Uniomerus tetralasmus* have not been investigated, but the effects are likely to be similar to those shown for other mussel species. Surface mining was the most probable cause for the significant decline in mussel populations observed from 1981 to 1987 in Little South Fork Cumberland River, Kentucky (Anderson et al. 1991). Researchers attributed this decline to increased fine sediment downstream, which may or may not have also contained toxic wastes from the surface coal mining activity. After strip mining was permitted there in 1984, most mussel species declined or were eliminated downstream. The exotic *Corbicula* species increased with the increased fine sediment.

Chlorine pollution and tar and oil waste associated with gas and oil fields also negatively affect mussels when the runoff reaches waterways (Fuller 1974). Whether this is due to chemical toxicity or to physical interference with filter-feeding was not reported.

Roads

Impacts of road building on *Uniomerus tetralasmus* have not been studied specifically, but such activity may cause problems if the building process increases the amount of fine sediment deposited in the waterways. Large amounts of fine sediment can suffocate mussels, as evidenced by large numbers of dead mussels following heavy sedimentation in a river in Kentucky (Anderson et al. 1991).

Road runoff could potentially impact mussels and is currently being studied for its impacts on freshwater mussels in North Carolina (Eads et al. 2001). Preliminary information suggests that there may be some effects from bridges and culverts within 50 m (164 ft.) immediately downstream of the road crossing (C. Eads personal communication 2004). It is not clear if this is due to runoff that increases fine sediment, or chemical pollutants from exhaust. Because this work includes many mussel species and has been conducted in areas with mostly paved roads, it is unknown whether these results apply to *Uniomerus tetralasmus* habitat in Region 2.

Livestock grazing

No information is available on the effects of livestock grazing on *Uniomerus tetralasmus*. Grazing in areas with mussels could be detrimental if mussel beds are trampled, water levels are reduced, pH of water is altered, or runoff and fine sediment are increased due to trampled streambanks. For example, livestock concentrated in riparian areas may compact soil or decrease bank stability, leading to increased sediment or pollution entering the stream or changes in waterflow. Increased organic material from livestock waste entering streams or lakes may alter the pH of the system. Low pH can negatively affect mussels (see Habitat section). Water diverted for livestock may result in decreased water levels in the mussel habitat areas, which can have a negative effect (see Changes in water flow section).

Fire

No information is available on the effect of fire on mussels. A ten-year, post-fire study of macroinvertebrates in Cache Creek in northern Yellowstone National Park found that richness, density, and dominant taxa differed between burned and unburned creeks (Minshall et al. 2001). Researchers determined that these changes were due to the loss of streamside and/or canopy vegetation as well as increased amounts of sediment entering the stream. These factors could also negatively affect mussel populations. Decreased shading of the stream may increase the temperature of the mussel habitat and thereby have negatively affect mussels if the acceptable temperature range is exceeded. Excessive sediment may choke mussels in the affected areas. Large increases in waterflows due to runoff after large fires could potentially displace or choke mussels. For more details, see Habitat and Changes in water flow sections.

Timber harvest

No information is available on the effects of timber harvest on *Uniomerus tetralasmus*. When harvesting near streams or lakes with mussels, care should be taken that removal of vegetation does not result in increased sediment or pollution entering the water, decreased amount of water flow, or increased temperature of the water. The Watershed Conservation Practices Handbook recognizes that "vegetation next to water bodies plays a major role in sustaining the long-term integrity of aquatic systems. Values provided include shade, bank stability, …storage and release of sediment, … and plant-and-animal habitats" (USDA Forest Service 2001, p.4). Important riparian vegetation contributing to stream health may include not just the trees being removed, but the understory and ground vegetation as well.

In addition to the impacts from the absence of vegetation and organic matter after timber harvest activities, the physical act of timber harvest can affect stream health. The Watershed Conservation Practices Handbook recognizes that soil compaction may occur from skid trails and log decks used during logging. "[Soil compaction] increases soil density and reduces large pores so that water absorption and root growth are impaired" (USDA Forest Service 2001, p. 19). Maintaining the natural soil structure along watersheds is important in maintaining natural water flow regimes (see Changes in water flow section).

Motorized recreation

Preliminary information from a North Carolina study suggests that there may be some negative effects on mussels within 50 meters immediately downstream of a road crossing (C. Eads personal communication 2004). It is not clear if this is due to runoff that increases fine sediment, or to chemical pollutants from exhaust. Because this work includes many mussel species and has been conducted in areas with mostly paved roads, it is unknown whether these results would apply to *Uniomerus tetralasmus* habitat in Region 2.

Off-road motorized recreation near or in water containing mussels could be detrimental if erosion is increased or if mussel beds are directly damaged by vehicles.

Non-motorized recreation

No information is available on the impacts of non-motorized recreation on mussels. As long as stream crossings are located away from mussel beds and stream banks are not damaged, it is unlikely that non-motorized uses would impact mussels. Elevated bridges may allow for crossings near mussel beds with presumably minimal impacts.

Blowdown

No studies have investigated the effects of blowdown on mussels. If a large blowdown event occurred near enough to water containing mussels that it increased runoff or temperature at the mussel bed, it could potentially have an impact. As discussed above with the effects of timber harvest, removal of vegetation near streams can increase water temperature (by removing shade), increase sedimentation (by reducing bank stability or increasing runoff), and change waterflow regimes (either by re-routing runoff or causing peak waterflow runoff events).

Pesticide application

A large number of chemicals are used to control plants and/or insects in the environment. Most of these chemicals have not been tested for effects on mussels. A few chemicals that have been tested indicate that mussels may be sensitive to at least some of these substances. In laboratory tests, glochidia and juveniles of *Utterbackia imbecilis* and *Villosa lienosa* were negatively affected by concentrations of malathion as low as 28 mg/L (Keller and Ruessler 1996). Malathion is a chemical commonly used for mosquito control. Other pesticides (e.g., DDT, aldrin, methoxychlor, diazinon, parathion, dieldrin) are absorbed by mussels, making them good bioindicators. However, the actual effects of these substances on the mussels themselves have not been demonstrated (Fuller 1974).

Exotic species

Unlike unionids that burrow into substrate, zebra mussels attach themselves to substrates with strong, stringy byssal threads. Rapid reproduction can result in up to 1000 zebra mussels colonizing a mussel shell (Neves et al. 1996). The resulting increased weight on a mussel shell decreases its feeding and respiration (Neves et al. 1996). Zebra mussels are also extremely efficient at filtering particles, which can affect the entire aquatic ecosystem by eliminating nutrients that might be available for other species (Strayer et al. 1999).

Zebra mussels are not known to occur within Region 2 at this time (McMahon and Bogan 2001).

Asian clams may also negatively impact native mussels (Bogan 1993). Although not well-documented, negative effects could be due to competition for resources (Strayer 1999). It is unknown if Asian clams occur within Region 2 (NatureServe 2003).

Strayer (1999) also suggests that exotic fish, such as redear sunfish (*Lepomis microlophus*) and pumpkinseed (*L. microlophus*), may be detrimental to mollusk populations. These species feed on mussels, and their distribution has expanded to reach at least portions of Region 2.

Commercial, scientific, and educational purposes

Historically, freshwater mussels in the United States were harvested for pearls and the button industry in the late 1800s and early 1900s (Pennak 1989). Moderating harvest pressure can help mussel populations to recover (Hubbs 2001). No evidence exists that commercial uses are currently affecting *Uniomerus tetralasmus* in Region 2. Nor is there evidence that scientific or educational collecting has contributed to the decline in *U. tetralasmus*. However, with the low population numbers currently found in many areas of the Region, closely regulating collection through issuance of permits would probably be prudent.

Conservation Status of Uniomerus tetralasmus in Region 2

More study is needed before the conservation status of *Uniomerus tetralasmus* can be fully understood in Region 2. Priority areas for surveying and conservation should include those areas where historical records exist and adjacent areas with similar habitats (i.e., Cimarron and Comanche national grasslands) in southeastern Colorado and western Kansas. In general, mussels are somewhat rare and traditionally overlooked in much of the region, so it is unclear if historical records accurately represent the range of *U. tetralasmus*. Additional surveys of areas with golden shiner populations in western Nebraska, South Dakota, and eastern Wyoming may also produce additional sites where *U. tetralasmus* resides.

The abundance of *Uniomerus tetralasmus* is apparently declining in portions of Region 2, especially southeastern Colorado. The habitats in different parts of Region 2 vary in their capacity to support this species depending on how their water levels and water quality are affected by drought, impoundments, and pollution. When populations reach very low levels, they are vulnerable to extinction. Populations from some areas in southeastern Colorado may already be extinct, at least in part due to the absence of water in their historical habitats (Cordeiro 1999). Investigation of locations with historical records should be conducted to determine if water levels can be restored to those areas and if populations can be restored. Additional information is needed to determine if healthy populations of *U. tetralasmus* still reside elsewhere within Region 2.

Water quality in some areas may also be limiting or reducing populations. Unfortunately, the specific requirements and/or tolerances of this species for many important habitat parameters (e.g., pH, water flow, calcium, temperature, sediment levels) are unknown. Without further investigation, it is impossible to determine the precise cause(s) of the decline in mussel populations in Region 2.

Populations of suitable fish hosts, in this case golden shiners, must also be available to maintain populations of *Uniomerus tetralasmus*. The presence of fish is obviously a concern for areas with extremely depressed water levels. However, it is unknown whether golden shiner populations have declined in the region as a whole, and this should be investigated.

Potential Management of Uniomerus tetralasmus in Region 2

Implications and potential conservation elements

In order to best combat the potential decline of mussels in Region 2, care must be taken to provide healthy aquatic systems. Baron et al. (2003, p. 12) clearly state the important factors in this process: “The sustainability of aquatic ecosystems can best be ensured by maintaining naturally variable flows, adequate sediment and organic matter inputs, natural fluctuations in heat and light, clean water, and a naturally diverse plant and animal community”. The points stressed by Baron et al. (2003) are further developed and summarized below. They suggest trying to match natural water flow patterns and to maintain chemical levels equal to those found in a relatively pristine stream in the area of concern. Dams are detrimental to aquatic health, unless natural water flow conditions are maintained. In the case of mussels, dams may also negatively impact populations by interfering with natural movements of fish hosts. Some sediment and organic matter is needed for aquatic species, but excessive sedimentation can choke off the normal flow of nutrients. Logging and construction, such as road management activities, can interfere with the natural particle distribution. Maintaining natural temperature and light in the aquatic ecosystem allows for natural nutrient flows, proper amounts of dissolved oxygen, and therefore survival of aquatic species. Grazing can affect sediment levels as well as contribute unnatural amounts of organic matter to the streams.

Mussels are affected by inadequate flow from groundwater sources, chemical pollutants and/or sediment in the water, fish availability, predation, exotic species, and stability of the stream bed (U.S. Geological Survey 2000). Suitable fish hosts, in this case golden shiners, must be available to complete the life cycle of *Uniomerus tetralasmus*. Predation by some exotic fish species may negatively impact survival of juveniles. Exotic mollusk species, such as zebra mussels and Asian clams, can outcompete mussels; however, the presence of these exotics is still in question in Region 2.

All of the above factors must be taken into account when maintaining habitat for mussel populations. If attempts are made to restore populations to historical areas, the habitat should be maintained at the highest quality possible to maximize the potential for success. Unfortunately specific environmental parameters are unknown for *Uniomerus tetralasmus*.

Tools and practices

Inventory and monitoring populations and habitat

Surveying and monitoring protocols used for other freshwater mussels should be sufficient to evaluate *Uniomerus tetralasmus*. Sampling methods for freshwater mussels are thoroughly discussed by Strayer and Smith (2003) and are briefly summarized here.

The most common sampling methods involve visual or tactile (when water clarity makes visual searches impossible) searches and sediment collection (usually with grab samplers). When the objective is to inventory areas for the presence of a mussel species, Strayer and Smith emphasize the importance of designing the survey so that it is possible to calculate the error (in this case the relevant error is the probability of not detecting a species when it is actually there). They recommend a quantitative or semi-quantitative method such as visually searching along transects, supplemented with sediment collection in a few quadrats so that error, due to buried mussels not seen, can be estimated.

If the objective is to estimate population size, Strayer and Smith recommend a random sampling design for a uniform population and a stratified, systematic, or double-sampling method for patchy populations. The scale to conduct sampling would depend on how widespread mussel populations were in a particular watershed.

Studies of the impact of a particular disturbance are more effective if multiple impact and control sites are available and can be surveyed multiple times before and after the disturbance. Changes in populations over time should of course use the same sampling methods. Strayer and Smith recommend quantitative sampling of some sort for the most statistically accurate data, but often only presence/absence data or possibly timed-search data are available from historical surveys. For additional information on statistical analysis of surveys, see Strayer and Smith (2003).

Obermeyer (1998) compared quantitative quadrat methods to qualitative timed snorkel searches. Similar total numbers of mussels (896 vs. 786) were found by the two methods. Species richness per sample was significantly higher using quadrat searches although overall richness (20 vs. 18) differed only by two species. Some small species may have been overlooked in the snorkel searches; however, more effort was required for the quadrat searches because the substrate within the quadrate was moved and searched by hand.

One alternative to the above methods is to sample muskrat middens (Watters 1995). Muskrats cache their food, and therefore many mussel shells are often found in these middens. The drawback to this method is that the natural distributions of the mussel species are then not known.

Marking mussels for tracking survival or other study objectives is tricky, but possible with tags or chemical fluorescence (see Eads and Layzer 2002 for discussion). In brief, chemically marking mussels is done by submerging juveniles in a chemical such as calcein for several hours. The mussel then incorporates the chemical into their shell material where it can be viewed over the course of the study.

Habitats can be monitored with standard water quality practices. Water can be tested for temperature, pH, calcium, etc. Regular water testing at mussel beds would identify any changes in water quality (e.g., increased sediment or chemical pollution).

Population and habitat management approaches

U.S. Geological Survey (2000) suggests that an understanding of the environmental factors of the particular watershed is essential to maintaining mussel populations. Specifically, information on the amount of water flow in dry weather, the stability of stream channels, and availability of host fish in the areas with mussels is essential. In addition, they recommend inventorying an area for mussel species and population sizes and analyzing environmental quality (i.e., water and sediment chemistry).

Relocation programs have been successful for some mussel species. A study in the St. Croix River in Minnesota and Wisconsin followed four mussel species (*Quadrula pustulosa*, *Elliptio dilatata*, *Lampsilis higginsii*, and *L. cardium*) for two to three years after relocation (Cope et al. 2003). Researchers found that annual survival was greater than 85 percent after relocation.

Sietman et al. (2001) demonstrated that mussel populations can recover over lengthy time periods after pollution events, assuming refuge populations and the necessary fish hosts remain. Beginning in the early 1900s, sewage from Chicago was diverted into the Illinois River. This continued until the Clean Water Act began regulating water pollution in the 1970s. Mussels were mostly extinct in the upper portion of the river and remained rare even in the 1980s. Surveys in the 1990s found 332 individuals of 18 mussel species. Presumably these mussels are recolonizing the Illinois River from several tributaries. Nine species known from before the extirpation have not yet recolonized the area.*Uniomerus tetralasmus* was not one of the species included in this study.

In Metzger Marsh, at the southwest end of Lake Erie, a program successfully harvested unionids prior to the marsh being drained in 1996, housed the mussels at aquaculture facilities, and re-established them in the marsh in 1999 (Nichols and Wilcox 2002). Twenty species (including *Uniomerus tetralasmus*) were harvested. Of these 20 mussel species, three (*Obliquaria reflexa*, *Truncilla donaciformis*, and *T. truncata*) did not survive captivity. Two species (*T. donaciformis* and *T. truncata*) were supplemented with specimens from elsewhere upon reintroduction. Sixteen species (including *U. tetralasmus*) still had live representatives between 2000 and 2002; however, numbers were about one-quarter to one-third of those that had been returned (i.e., 22 *U. tetralasmus* were returned to the marsh in 1999, and six were found alive between 2000 and 2002). It remains to be seen if these species will successfully reproduce and recruit new generations of mussels.

Layzer (1996) cautions that restoring populations is unlikely to be successful if water flow is not adequate or if peak discharge flows are too strong. How natural recolonization might occur in Region 2 areas is unknown because recorded locations are apparently isolated on separate watersheds. Restoration attempts in Region 2 would probably require reintroduction of host fish infected with juvenile mussels. Water flow might need to be restored in some situations. No studies of attempts to restore mussel populations after damage due to timber harvesting, fire, road management, or grazing are available. Eliminating the negative activity(s) and restoring water quality could provide habitat that would support reintroduced mussels in many cases, but the time scale needed to restore the habitat may be many years, even decades in cases where large amounts of riparian vegetation have been eliminated.

Information Needs

Information needs for *Uniomerus tetralasmus* fall into three main areas. In order of importance, these are 1) surveying for the species/monitoring known populations, 2) evaluating the health of the aquatic systems in which these mussels are located, and 3) evaluating whether restoration of waterways can restore healthy populations in some areas. The current distribution of *U. tetralasmus* in relation to its historical distribution is not well understood and is of primary importance. For example, it is unclear if populations still exist in Colorado or if conditions exist where they could be successfully reintroduced. It may also be necessary to survey for golden shiners in order to ensure that host fish are available where mussels are present to avoid future mussel extinctions.

Monitoring known populations could provide information on population trends. Combined with information on the water chemistry in those areas, should population decreases arise, potential causes could be identified and remediated.

In areas where historical populations existed, an evaluation of the quality of the aquatic habitats (water and sediment chemistry, flow levels, etc.) is necessary to determine if populations could potentially survive. Reintroduction of historic populations may be an option if habitats are healthy.

Genetic study of the populations would benefit management by answering several questions. Studying the genetic relationships among western populations and their relationship with eastern populations would confirm that they are the same taxa. In addition, patterns of relationships might indicate some populations were introduced, especially if paired with genetic structure information on the host species, golden shiner. Genetic work also would determine the amount of genetic diversity within populations. Conversely, if western populations are a unique taxa then fish host species may differ, and more study would be needed.

DEFINITIONS

See **Figure 7** for a diagram of morphological characteristics.

Anterior — the side of the shell closest to the beak, right side.

Beak — also called the umbo, this is the peak at the top of the shell.

Bivalve — the category of mollusks characterized by individuals with shells with two identical halves.

Desiccation — drying out.

Double sampling — the process of sampling using two different methods; a lower-cost method is used over most of the area and a subset of the area is sampled using a more intense method.

Emersion — exposure to air; in mussels this is usually due to water levels dropping.

Foot — muscle that can be extended outside the shell and used for movement or burrowing.

Glochidia — the larval stage of mussels that require a fish host.

Grab sampling — sampling procedure where substrate is removed and passed through sieves.

Hemolymph — the liquid found in the open circulatory system of mollusks that serves functions of blood and lymph fluid.

Hinge — made up of teeth that interlock, it holds the two valves together.

Juvenile stage — the developmental stage that occurs after glochidia release from the fish host.

Mantle — tissue layer that excretes the shell material.

Marsupia — portions of the gills that function as brood chambers for the developing larvae.

Muscle scars — marks on the shell where the muscles attach.

Nacre — the interior shell covering.

Periostracum — the outer shell covering.

Posterior — the side of the shell away from the beak, opposite the anterior end, left side.

Pseudocardinal teeth — ridges at the anterior side of the beak that form part of the hinge.

Siphons — structures through which water and dissolved particles are brought into the mussel's body (incurrent siphon) and wastes are released (excurrent siphon).

Stratified sampling — sampling strategy where habitat is divided into areas, such as substrate more and less likely to find mussels, and the areas are surveyed separately.

Umbo — see Beak.

Valves — identical halves of the bivalve shell that are held together at the hinge.

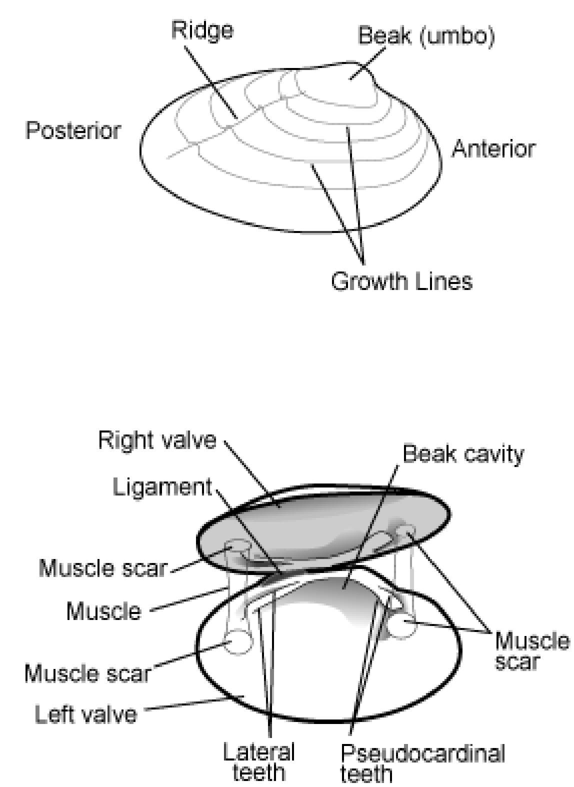


Figure 7. Diagram of morphological characteristics used to describe mussels. (Illustration by Leigh Anne McConnaughey.)

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