

***Strophitus undulatus* (Creeper):  
A Technical Conservation Assessment**

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

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# SUMMARY OF KEY COMPONENTS FOR CONSERVATION OF *STROPHITUS UNDULATUS*

## *Status*

*Strophitus undulatus*, commonly called the creeper or the squawfoot mussel, was recently considered for, but not granted, sensitive species status in Region 2 of the USDA Forest Service (USFS). It is unknown where the species occurs within Region 2 lands, which are on the western edge of the overall range of this species. However, based on historical records and occurrences in nearby waterways, USFS administration units where *S. undulatus* is most likely to occur include Pike National Forest, Medicine Bow National Forest, Nebraska National Forest, Samuel R. McKelvie National Forest, Oglala National Grassland, Pawnee National Grassland, and Roosevelt National Forest. This species is declining in portions of Region 2, especially Colorado and Kansas.

## *Primary Threats*

Like all bivalves, *Strophitus undulatus* feeds by filtering particles from the water. In areas with large numbers of mussels, the filtering action removes organic matter from the water. Nutrients are then transferred to other parts of the food chain as the mussels are fed upon by fish or bottom scavengers (Negus 1966). In this way, mussels serve an important role in the ecosystem. In fact, mussels may be critical to the ecosystem even though they are rare in the region (as compared to the central and eastern United States).

Because they filter many particles from the water, mussels 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 negatively affect this species. The primary potential threats include diverting or impounding water away from streams or naturally hydrated areas, harvesting timber, grazing, road building and maintenance, fires, mining, and exotic species.

*Strophitus undulatus* also depends on several fish species as host species, so anything that might negatively affect the presence of healthy or robust host fish populations would also impact these mussels.

## *Primary Conservation Elements, Management Implications and Considerations*

Without information about locations of specific populations of *Strophitus undulatus*, it is difficult to manage the species. Additional surveys and analyses are necessary to understand its distribution and to make fine-scale management decisions. Because so little is known about the specific biology of this species, the conservative route of maintaining the integrity of aquatic ecosystems and natural processes that influence mussel habitat should be strongly considered when planning land management activities. Developing a general mussel management plan may be more realistic than a species-specific plan given the paucity of information on Region 2 species such as *S. undulatus*.

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## INTRODUCTION

This assessment is one of many being produced to support the Species Conservation Project for the Rocky Mountain Region (Region 2), USDA Forest Service (USFS). *Strophitus undulatus* is the focus of this assessment because it was considered for sensitive species status in Region 2, during the Regional Forester's Sensitive Species list revision process in 2001-2003, but it was not awarded such status ([www.fs.fed.us/r2/projects/scp/sensitivespecies](http://www.fs.fed.us/r2/projects/scp/sensitivespecies)). Within the National Forest System, a sensitive species is a plant or 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 may require special management, so knowledge of its biology and ecology is critical.

This assessment addresses the biology of *Strophitus undulatus*, but there is very little information available that specifically addresses the species. Therefore, this assessment draws on information on other mussel species in order to provide some perspective on mussel biology. 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 scientific knowledge accumulated prior to initiating the assessment. 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 or failure of those that have been implemented.

### **Scope**

This assessment examines the biology, ecology, conservation status, and management of *Strophitus undulatus* 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 Region 2. Similarly, this assessment is concerned with behavior, population dynamics, and other characteristics of *S. undulatus* 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 it is 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 *Strophitus undulatus* are referenced in the assessment. The assessment emphasizes refereed literature because this is the accepted standard in science. Non-refereed publications or reports were used, however, when information was unavailable elsewhere. These were regarded with greater skepticism than the refereed publications. 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 collection.

This assessment was designed as a summary of existing, readily available information and therefore does not attempt to revise taxonomy, analyze stream suitability, or conduct further field surveys for the species. Ideally information on each topic would be available that specifically addresses *Strophitus undulatus*. Unfortunately that is not the case because very few studies have focused on the species. Therefore, this assessment draws on information about other mussels in order to provide managers with some basic information, especially for those not familiar with mussel biology. As a result, this summary is a bit more general than one would prefer. Gaps in information do not mean management decisions stop, however, so this summary provides a valuable resource.

## ***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. Often, observations, inference, good thinking, and models must be relied on to guide our understanding of ecological relations. Confronting uncertainty then is not prescriptive. Experiments addressing the effects of many management activities on mollusks are not available, so these alternative approaches are utilized. In this assessment, the strength of evidence for particular ideas is noted, and alternative explanations are described when 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 data or support are not available from the written documents. In some cases, the scientists may be continuing their work, and the information may become available in the future.

The lack of species-specific information introduces additional uncertainty into the report. Other mussel species may have different life histories and/or sensitivities. General mussel information presented should be used as a guide, not a prescription for *Strophitus undulatus*.

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 because 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 this species. Most information should apply broadly throughout the range of the species, but certain life history parameters may vary along environmental gradients. Additionally, information provided on other mussel species is also limited in scope (see discussion above).

## ***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](http://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, it facilitates their revision, which 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, an independent scientific organization, 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***

*Strophitus undulatus* is assigned a Global Heritage Status Rank of G5, which indicates that the species is "demonstrably widespread, abundant, and secure" when considering its entire range (NatureServe 2003). In the United States it is also considered a G5 or "demonstrably widespread, abundant, and secure" (NatureServe 2003). The status varies among states from S1, "critically imperiled", in Alabama, Delaware, Rhode Island, and Texas to S5, secure, in Kentucky and Pennsylvania (NatureServe 2003). In Canada, the status ranges from S5, secure, in Ontario to S1, critically imperiled, in Nova Scotia (NatureServe 2003). The statuses of this species for states within USFS Region 2 are as follows: Colorado (S?, "unranked"), Kansas (S2, "imperiled"),

Nebraska (S?, “unranked”), and South Dakota (S3, “vulnerable to extirpation or extinction”). Wyoming is not listed as being within the species’ range.

The U.S. Fish and Wildlife Service does not include *Strophitus undulatus* on their lists of threatened, endangered, or candidate species (2003). USFS Region 2 has evaluated *S. undulatus* for sensitive species status but has not granted it such status. The state of Kansas considers the species to be a “species in need of conservation” (Obermeyer 1999).

### ***Existing Regulatory Mechanisms, Management Plans, and Conservation Strategies***

In Region 2, *Strophitus undulatus* is considered to be of conservation importance because it has declined in some watersheds (see Population trend section). Individual national forests within Region 2 do not have any official written policies aimed at managing *S. undulatus*. However, the Rocky Mountain Region does have a Watershed Conservation Practices Handbook (FSH2509.25) that sets standards and guidelines to (a) meet state water quality regulations, and (b) conserve both aquatic resources (watershed processes, streams, and wetlands) and the species that utilize those resources throughout Region 2-administered lands. The USFS is currently in the process of revising the standards, design criteria, and process to determine stream health. Determining stream health now includes considering the biological component of the aquatic fauna during the assessment process.

Apparently no management strategies have been developed specifically for *Strophitus undulatus* 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 (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 10 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 that 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 for achievement are outlined for each goal. Several of these goals do not apply to the national forests in Region 2 (e.g., no zebra mussels are documented in the area), but they could be tailored to benefit native freshwater mollusks in the area.

The Mussel Ad Hoc Committee 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 (Mussel Ad Hoc Committee 2003). 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 Region 2.

Kansas is the only state within Region 2 that has developed recovery plans for mussel species (Obermeyer 1999, 2002). The 1999 Kansas mussel recovery plan (Obermeyer 2002) is designed to address the needs of mussel species of concern, including *Strophitus undulatus*. These plans consider decreased quality of streams and rivers to be the major factor hindering healthy mussel populations in Kansas. To combat these problems, Obermeyer (1999) recommends several approaches:

- ❖ protect existing mussel habitat in various ways, including provision of monetary incentives to landowners to reduce pollution and to increase stream bank stabilization and restoration
- ❖ maintain a database of historic and current mussel populations
- ❖ increase knowledge of mussel genetics, life history, population dynamics, and ecological requirements through research
- ❖ study and monitor habitat and water quality and their effects on mussels in targeted areas
- ❖ re-introduce mussels to suitable areas
- ❖ monitor mussel populations through systematic surveys
- ❖ develop a plan to deal with exotic species introductions in Kansas
- ❖ educate the public about mussels and the recovery program
- ❖ review the recovery plan periodically and update/amend it as necessary
- ❖ utilize agency personnel with expertise in aquatic systems to evaluate specific recovery projects and to update the recovery plan.

These sorts of recommendations could be adapted for National Forest System lands in Region 2.

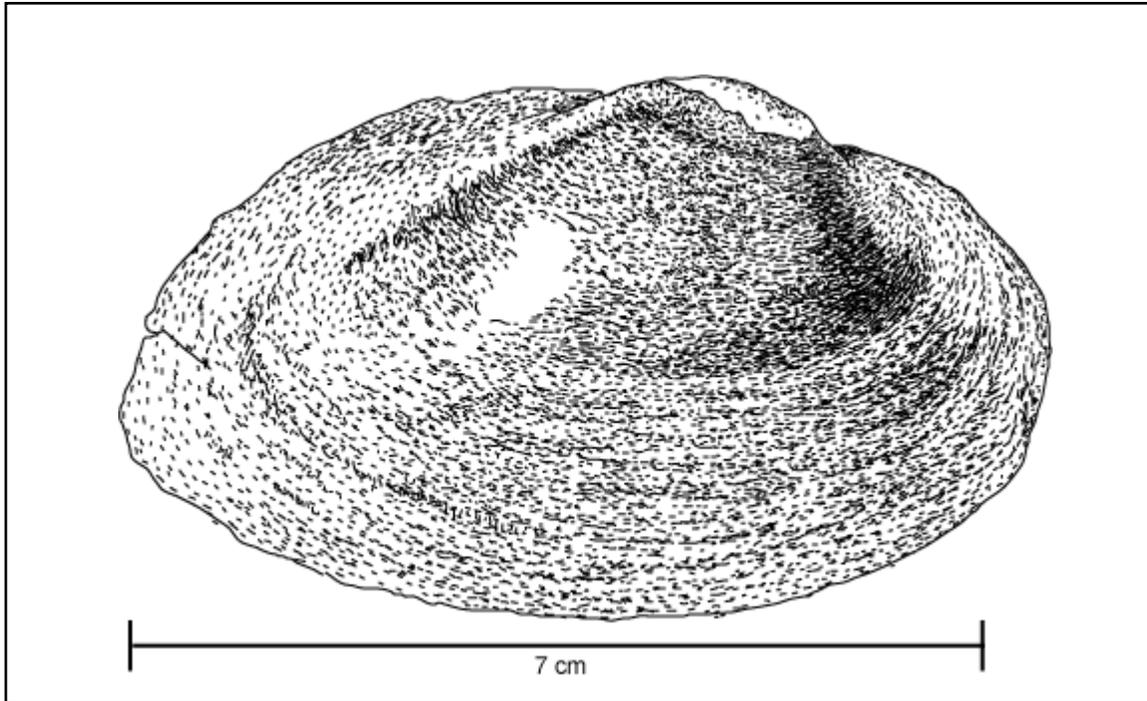
## ***Biology and Ecology***

### Systematics and general species description

*Strophitus undulatus* (Say 1817) is a mollusk in the Class Bivalvia, Order Unionoida, Family Unionidae (Turgeon et al. 1998). Other sources have used outdated scientific names including *Anodonta undulata*, *A. edentula*, and *S. rugosus* (see Parmalee and Bogan 1998 for a complete list of synonymous scientific names). The most frequently used common name for this species is creeper; other common names occasionally used include strange floater, sloughfoot, and squawfoot (Cummings and Mayer 1992). Bivalves are mussels with their shell divided into two halves (valves) joined at a hinge. (Anatomical and other scientific terms are explained in the Definitions section at the end of the report.) Family Unionidae represents a monophyletic group evolutionarily based on analyses by Giribet and Distel (2003). *Strophitus undulatus* belongs to the Subfamily Anodontinae. Two other North American species are recognized in the same genus, *S. connasaugaensis* and *S. subvexus* (Turgeon et al. 1998); these are both found in the southeastern United States (Burch 1973, Williams et al. 1993).

A diagram of *Strophitus undulatus* is shown in **Figure 1**. Shells of *S. undulatus* are described as:

“Shell elliptical, moderately compressed, and thin when young, becoming somewhat inflated and thicker in adults. Anterior end rounded, posterior end bluntly pointed, occasionally truncated. Ventral margin straight to slightly curved. Umbos slightly elevated above the hinge line and located at least one-third from the anterior end. Beak sculpture of two or three pronounced v-shaped ridges. Shell smooth and shiny. Periostracum green with rays in juveniles, becoming chestnut, dark brown, and black in older individuals. Length to 4 inches (10.2 cm). Pseudocardinal and lateral teeth weakly developed and present only as thickened ridges. Hinge line curved past the umbo. Beak cavity moderately shallow. Nacre salmon or cream-colored bluish white along the outer margin of the shell.” (Cummings and Mayer 1992, pg. 82).



**Figure 1.** *Strophitus undulatus* shell. Illustration by Leigh Anne McConnaughey.

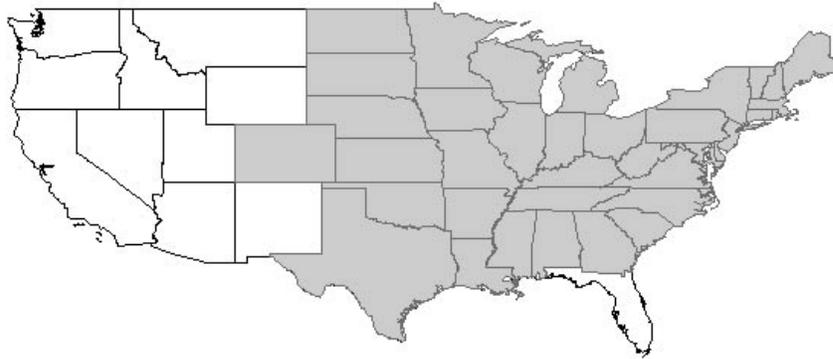
*Strophitus undulatus* can be distinguished from other similar mussels in Region 2 by close examination of shell color, shape, and sculpture. *Anodonta grandis* (giant floater) is generally larger (up to 10 inches [25.4 cm]) and has no teeth. *Anodontoides ferussacianus* (cylindrical papershell) has no teeth, and its shell is yellowish green and usually has greenish rays extending from the umbo to the posterior end. *Unio merus tetralasmus* (pondhorn) has two grooves on the posterior side of its shell and four to five circular ridges on the beak. (For more detailed descriptions of these other species, see Burch 1973, Cummings and Mayer 1992).

#### Distribution and abundance

The distribution of *Strophitus undulatus* is generally considered to be the Mississippi River drainage system (Parmalee and Bogan 1998). In the United States its range stretches from Colorado, North Dakota, and Texas in the west to Maine and Georgia in the east (**Figure 2**), and it extends northward into Saskatchewan, Manitoba, Ontario, Quebec, New Brunswick, and Nova Scotia (NatureServe 2003). Cummings and Mayer (1992) consider the species to be “widespread and common”, but they do not provide specific abundance or distribution information.

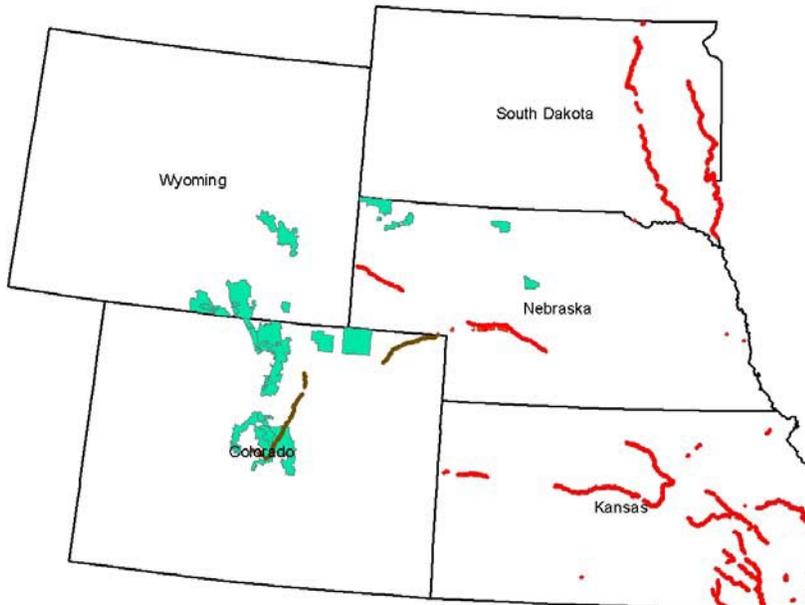
**Figure 3** shows the distribution *Strophitus undulatus* in Region 2. Based on museum records, the species may exist in the South Platte River in Colorado, but surveys in 1996 and 1997 did not find it anywhere in the state (Cordeiro 1999). In South Dakota, *S. undulatus* has been found in the following counties: Brookings, Deuel, Grant, Gregory, Hamlin, Lincoln, Minnehaha, Moody, Roberts, Turner, and Union (Backlund 2000, D. Backlund personal communication 2004). South Dakota waterways with this species include the James and the Big Sioux rivers and Lake Kampeska (Backlund 2000, D. Backlund personal communication 2004). *Strophitus undulatus* is not included among the species that are tracked by the Kansas Natural Heritage Program (C. Freeman personal communication 2004) although the species is reported from the state. Bergman et al. (2002) reported *S. undulatus* as present in Lyon Creek of the Smokey Hill River watershed system in northwest Kansas; earlier sampling by Hoke (1996) found only weathered shells from this watershed. Other locations in Kansas reported to contain this species include Cedar Creek, Solomon River, Neosho River, Cottonwood River, Verdigris River, Fall River, Elk River, Otter Creek, Upper Osage/Marais des Cygnes River, and Caney River (Couch 1995, Obermeyer et al. 1997, Dorsey 2000, Obermeyer 2002). The species is also reported from Nebraska (Hoke 2000), more specifically

## Known Distribution of *Strophitus undulatus* in the United States



**Figure 2.** Known distribution of *Strophitus undulatus* in the United States. Those states with reported occurrences of *S. undulatus* are shown in gray. These include historic and current records.

## Distribution of Creeper Mussels within USDA Forest Service Region 2



Watersheds in Region 2 with reports of creeper mussels are shown in red (extant) and brown (historical, possibly extinct). Several USFS lands (shown in green) may contain populations although no records are known for certain. If the Colorado population is not extinct, then Pike National Forest may also contain mussels. The Nebraska National Forest may be found to host creepers if searches on those watersheds are conducted. In addition, if populations reach the upper reaches of the North Platte in Wyoming (populations are known from the Platte in Nebraska), then Medicine Bow National Forest may also have potential habitat. If they reach the South Platte, then Roosevelt National Forest and Pawnee National Grasslands are potential habitat. Watersheds nearby the Nebraska National Forest, Samuel R. McKelvie National Forest, and the Oglala National Grasslands have reports of mussels, so it is possible these forests also support populations. Some reports (especially for eastern South Dakota) provide only county information, not watershed, so this map may not represent all watersheds with reports. See distribution section in this report for more information.

**Figure 3.** Distribution of creeper mussels within USDA Forest Service Region 2. Watersheds with reports of creepers are shown in red (extant) and brown (historical, possibly extinct). USDA Forest System lands are shaded in green.

in the Platte River, Niobrara River, and Missouri River (at Child's Point) (Roedel 1990, Peyton and Maher 1995, Myers and Perkins 2000). No records for this species are known from Wyoming (Beetle 1989).

Few efforts have been made to survey USFS Region 2 properties for mollusks. As a result, exact locations of *Strophitus undulatus* populations on National Forest System lands are unknown. Extrapolating from watersheds that are linked to reports of *S. undulatus*, additional USFS property should be surveyed. If the Colorado populations are not extinct, then Pike National Forest may contain *S. undulatus*. If the Upper Platte in Wyoming was thoroughly examined, low-elevation regions of the Medicine Bow National Forest might be found to support some mussels. Further surveys of north-central and northwestern Nebraska could potentially yield locations in the Nebraska National Forest, Samuel R. McKelvie National Forest, or the Oglala National Grasslands. The South Platte River stretches into Pawnee National Grasslands and Roosevelt National Forest, so these areas may need to be examined as well.

Abundances in Region 2 are generally unknown. Region 2 surveys that report abundances generally show rare occurrences. Myers and Perkins (2000) found only a single individual at Child's Point on the Missouri River in Nebraska. Obermeyer et al. (1997) found between one and 68 specimens at sites in the Verdigris, Neosho, and Spring River basins in southeastern Kansas and southwestern Missouri. One study in northeastern South Dakota (Perkins et al. 1995, as cited in Backlund 2000) found that *Strophitus undulatus* comprised 14 percent of the mussels in Minnesota River tributaries. Other data from South Dakota report between three and 34 individuals per site (D. Backlund personal communication 2004). Comparisons between these data are impossible because site size and methods of collection are not equivalent and, in some cases, not known.

#### *Potential habitat*

*Strophitus undulatus* should be able to exist in streams or rivers that have the proper host fish species and the proper temperature range, nutrients, stream gradient, and substrate. Unfortunately, the exact temperature, stream characteristics, and nutrient requirements for this species are unknown, so it is difficult to predict acceptable habitat *a priori*. Records

of occurrence in Region 2 are not common, but it is unknown whether this is due to 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. It may be useful to survey National Forest System lands that are near watersheds with extant or historical records, including: Nebraska National Forest, Samuel R. McKelvie National Forest, the Oglala National Grasslands, Pike National Forest, Medicine Bow National Forest, Pawnee National Grasslands, and Roosevelt National Forest. Such surveys would provide information on whether *S. undulatus* populations exist on USFS Region 2 lands.

#### *Degree of isolation of populations*

Because of the limited movement in adults, connectivity between mussel populations is mainly limited to areas among which host fish can move. Populations within watersheds may be isolated if there are barriers (e.g., dams, impoundments) that limit fish movements. However, some movement of fish between ponds has been noted during severe flood events (B. Obermeyer personal communication 2004), and this could result in mussel movement if the fish were carrying glochidia. Some evidence for long-distance dispersal by birds or wind exists for other freshwater mussels (summarized in Burky 1983), but this has not been observed for *Strophitus undulatus*. In Region 2, populations in different watersheds may be isolated from one another unless such passive dispersal has occurred.

#### *Population trend*

In the United States, freshwater mussels are one of the most threatened groups of organisms (Williams et al. 1993, Master et al. 2000, Watters 2000). Unionids have been declining since around 1900 (McMahon and Bogan 2001). Nationwide population trends for *Strophitus undulatus* are not available. In Region 2, no information on population trends exists although the species' range appears to be declining or even extirpated in some areas, such as Colorado where no specimens were found in 1996-1997 surveys (Cordeiro 1999). Scientists who have actively collected mussels in the region report that the species historically had a broader range than it currently has based on the presence of Pleistocene relic shells in western Kansas (B. Obermeyer personal communication 2004).

## Activity patterns

### *Seasonal*

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 mussel species in other families (e.g., *Pisidium walkeri*) are able to slowly acclimate to temperature changes so metabolic rates remain somewhat stable (reviewed in McMahon and Bogan 2001). Such acclimation most likely does not occur in *Strophitus undulatus* because other members of the Family Unionidae that have been studied do not have this ability. Due to the reproductive cycle whereby gonads develop and then glochidia are released, reproductive stage varies with the season. (See Breeding biology and Demography sections for more information). The development and release of glochidia are stimulated by water temperatures within an acceptable range (McMahon and Bogan 2001). What that range is for *S. undulatus* is unknown.

### *Movement patterns*

The main dispersal movement during the lifetime of mussels occurs while they are attached to their host fish as glochidia. When juveniles mature, they burrow into suitable substrate with their foot (Coker et al. 1921). Most mussels in the Family Unionidae move little once they reach adult age (McMahon and Bogan 2001). However, seasonal vertical movement in the substrate is known to occur in several unionid mussel species (Watters et al. 2001; *Strophitus undulatus* was not included in this study). Specific information on the movements of *S. undulatus* is not available.

### *Connectivity*

Because of the limited movement in adults, connectivity between 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 by Burky 1983), but this has not been observed for *Strophitus undulatus*. Therefore, it is unlikely that these 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

*Strophitus undulatus* occur in aquatic fluvial environments (van der Schalie 1938, Cummings and Mayer 1992). Habitats for *S. undulatus* in the Platte River system in Kansas included rivers and small irrigation canals (Peyton and Maher 1995). In Nebraska Hirst (2000) reported *S. undulatus* from large rivers to small creeks with substrates ranging from gravel to mud. Some lakes with outlets also provide habitat, at least in Michigan (van der Schalie 1938). The substrate is varied and can consist of mud, sand, or gravel (Cummings and Mayer 1992).

Scale is important when considering what environmental variables are associated with mussels. Factors that affect the overall presence or absence of a mussel in a watershed may not be the same variable(s) that explain the location of mussels within a given watershed. For example, if a mussel species is located only in streams with certain threshold levels of calcium, then their distribution within the stream may be based on some other variable because calcium levels are acceptable throughout. Unfortunately, few studies have investigated the presence of mussels at multiple spatial scales within the same watersheds. Within this section, studies that address conditions at the watershed level refer to ‘macrohabitats’ while conditions within a stream or river are referred to as ‘microhabitats’.

Studies of mussels in the Susquehanna, Delaware, and Hudson River drainages of Pennsylvania and New York provided some insight into macrohabitat requirements (Strayer 1993). Records from 1919 through 1991 were used to determine the presence of mussel species in different rivers of the region. Stream size was significantly related to the species richness of the reported mussel fauna. Discriminant analysis was able to determine variables that predicted the presence of individual species in a particular stream. *Strophitus undulatus* tended to occur in streams with no tide activity and with low hydrological variability. Stream size, stream gradient, calcium concentration, and physiography (i.e., coastal plain, high plateau, etc.) were not important to the presence of *S. undulatus* at the macrohabitat level in this study. In southeastern Michigan, Strayer (1983) found *S. undulatus* to be widespread and could not relate its presence to surface geology. How these factors would translate to Region 2 streams is unknown since hydrology and habitats differ from the northern Atlantic Slope region and Michigan.

Specific microhabitat requirements are unknown for *Strophitus undulatus*. Roedel (1990) found the species in shallow channel areas of the Platte River in Nebraska that had substrates of mixed gravel and sand. It has been found at water depths from 0 to 3.0 m (0 to 9.8 ft) and with water currents anywhere from swiftly flowing to not flowing at all (summarized by Hirst 2000). Data are not available to indicate statistically preferred depths. Coker et al. (1921) reported microhabitat characteristics for *S. undulatus* in midwestern waterways very similar to those described above with substrates including every combination of sand, mud, and gravel and with water flows from no current to fair current (no observations of *S. undulatus* were reported from strong current areas). Again, these data cannot statistically address a preference for a particular substrate type.

Further information on microhabitat preferences by *Strophitus undulatus* is unavailable. What follows is information from other mussel species. 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.]), but this varies somewhat among species and also with changes in the water level and whether preferred substrate types are available at that depth (Dillon 2000).

The importance to mussels of microhabitat substrate characteristics such as porosity, percentage 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 with sufficient sample size to analyze (*Elliptio complanata*, *E. ictarina*, *Toxolasma paulus*, *Villosa lienosa*, and *V. vibex*), only one, *V. lienosa*, showed a relationship to any substrate characteristics (i.e., well-sorted and with many fine particles).

Temperature is important because mussels must have the proper amount of dissolved oxygen, which varies with temperature (Burky 1983). Both minimum and maximum temperatures apparently limit the distributions of some bivalves (McMahon and Bogan 2001). If temperatures in streams and rivers are above or below these levels, this may be one factor excluding populations of *Strophitus undulatus* from inhabiting portions of Region 2. Temperature is also important in stimulating spawning (Mackie 1984).

Juvenile survival has also been shown to be linked to temperature. In a laboratory study, temperatures of 34 °C (93 °F) 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 mussel species *Villosa iris* and *Actinonaias pectorosa* were viable for significantly shorter time periods at 25 °C (77 °F) than at 0 °C (32 °F) and 10 °C (50 °F) in the laboratory (Zimmerman and Neves 2002).

Chemical components of the habitat also contribute to the habitat 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 with pH ranging from 5.6 to 8.3. However, low pH levels can affect shell thickness, tissue cholesterol, and hemolymph concentrations of several ions (summarized in McMahon and Bogan 2001) and could relate to individual unionid mortality.

The pH of the water is a limiting factor for some mussels. Okland and Kuiper (1982) demonstrated 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). Low pH may also have a greater effect 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 unionids (*Pyganodon cataracta* and *Utterbackia imbecillis*) had <50 percent survival when exposed to pH of 4.0 in the lab, but they were not affected when pH was 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 potassium chloride and reduced tolerances to other contaminants such as aluminum (Huebner and Pynnonen 1992). Specific pH requirements for *Strophitus undulatus* are not available.

Calcium (usually in the form of calcium carbonate) is an important component of mussel habitat

also. Mussels need calcium to build their shells. A study of zebra mussels demonstrated the importance of calcium on growth, with peak growth occurring at 32 mg/L and low levels of calcium (<8.5 mg/L) resulted in negative growth (Hincks and Mackie 1997). 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). Species richness of Norwegian mussels in Family Sphaeriidae dropped off in waters with low levels (<20 mg CaO/liter) of calcium (Okland and Kuiper 1982). This requirement 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 *Strophitus undulatus* are unknown.

Fuller (1974) summarizes evidence that many chemicals are detrimental, even fatal, to mussels. These chemicals 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 closure of glochidia by 50 percent were 5.3 ug/L of copper, 46.8 ug/L cadmium, and 69.1 ug/L zinc. Reduced shell closure would interfere with the ability of glochidia to latch onto fish hosts.

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 discharges of 0.03 m<sup>3</sup>/s (1.1 ft<sup>3</sup>/s), which was the base level flow. When the dam was discharging water at higher rates, most species preferred areas with water velocities from 71 to 150 cm/s (2.3 to 4.9 ft/s). Mussels tended to be rare at low flow areas with velocities <4 cm/s (<0.13 ft/s). *Strophitus undulatus* was found in this study, but the sample size was too low (n=3) to analyze the species individually.

Mussels in areas prone to flooding may be more common in “flow refuges”, which are sections of the river somewhat sheltered from large changes in water flow. Strayer (1999b) found that mussel communities (including *Strophitus undulatus*) in two New York rivers were significantly denser in flow refuges than outside these refuges. Strayer suggests that these refuges may have more stable substrates than other areas, which allow the persistence of the mussels and

also explains the patchiness that is common in mussel distributions. Also, these refuges were more useful in explaining the distribution of the mussels than many other microhabitat variables measured, including water depth, bottom roughness, distance to shore, presence of macrophytes, presence of canopy, and the amount and size of sediment (Strayer and Ralley 1993). Current speed and spatial variation in current speed were important in determining where mussels were found, and current speed was able to differentiate preferences among the mussel species (Strayer and Ralley 1993). *Strophitus undulatus* was found at a mean current speed of 8.5 cm/s (+/- 0.5, n = 27).

### Food habits

Like all freshwater mussels, *Strophitus undulatus* 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 and organic material suspended in the water (Pennak 1989, McMahon and Bogan 2001). Mussels do not constantly feed but have periods of feeding, when valves are open, and periods of rest, when valves are closed (Dillon 2000). The periodicity in feeding periods varies among species and may be affected by environmental conditions such as light, temperature, and food availability (Dillon 2000). Specific information on *S. undulatus* feeding cycles is not available, but *Anodonta* species in the same subfamily as *S. undulatus* show cycles ranging from a few long closures per day to many per hour (Dillon 2000). The North American species, *A. grandis*, usually showed 24-hour cycles from one valve opening to the next (Salbenblatt and Edgar 1964). Salbenblatt and Edgar (1964) also demonstrated that valve activity for *A. grandis* decreased in lower light conditions in the lab and increased at high temperatures (29 °C [84.2 °F]).

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 filter feeders and relatively long-lived makes them susceptible to environmental pollutants (see Habitat section; Burky 1983, McMahon and Bogan 2001). Due to their feeding mechanisms, mussels are often used as bioindicators to monitor everything from arsenic to mercury to pesticides in the water (McMahon and Bogan 2001). Specific effects of pollutants on *Strophitus undulatus* are unknown.

### Breeding biology

Most Uniodeans have separate sexes (Dillon 2000, McMahon and Bogan 2001), and this is also the

case in *Strophitus undulatus* (Utterback 1916). Most mussel species have an approximately 50/50 ratio of males to females (Dillon 2000). The method of sex-determination in mussels (i.e., genetic or environmental) is unknown.

The breeding biology specific to *Strophitus undulatus* has not been well 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”. Eggs are carried directly to the gills via ducts. Sperm are released externally to the shell and are brought in through the incurrent siphon of another individual to the gills. After fertilization, the embryo matures in the marsupia. After developing to the larval stage, the embryo is now called a glochidium, and it is released to the outside world. Glochidia attach to fish hosts to mature, then become free-living juveniles and continue to mature.

Watters (2002) closely examined the process of glochidia release in *Strophitus undulatus*, and the details are presented here. *Strophitus undulatus* glochidia are released from the marsupia within white, spongy, rod-shaped structures about 3 to 7 mm (0.12 to 0.28 inches) long; these structures are called conglutinates. Each conglutinate contains several glochidia that then pass through pores to the outside of the conglutinate but remain attached via threads. Once outside the conglutinate, the glochidia open their valves so that they are prepared to attach to any host fish that is attracted to the area. An additional bonus to this setup is that when one glochidia of a conglutinate attaches to a host, the rest of the conglutinate is brought along, increasing the chances for attachment of the remaining glochidia.

Although it can utilize fish hosts (see Community ecology section below), *Strophitus undulatus* is one of only a few mussel species that is able to mature without a fish host on some occasions (Lefevre and Curtis 1911). When not utilizing a fish host, the glochidia receive nutrition from the parent mussel, and after developing into juveniles they are expelled with conglutinate cords (Lefevre and Curtis 1911). The cords subsequently disintegrate, releasing the juveniles. Mackie (1984) reports most bivalve species’ glochidia are only viable without a host for less than two weeks, and most likely only a small proportion of glochidia reach a suitable host (Howard and Anson 1922). Within the fish host, a cyst forms around the glochidia in 2 to 36 hours (Kat 1984). Without proper physiological chemistry

cues between the glochidia and fish, 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 utilizing fish hosts is also believed to be an evolutionarily advantageous adaptation for dispersal (Kat 1984). The length of time that *S. undulatus* remains attached to its host in the wild is unknown. In lab experiments on various fish hosts, metamorphosis ranged from 12 to 41 days (van Snik Gray et al. 2002).

After releasing from the host fish, juveniles drift briefly until settling to the bottom (Coker et al. 1921). They then 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 many species are not reproductively mature until at least a year because further development is needed (Coker et al. 1921).

Temperature stimulates the maturation of gametes and the release of the sperm in many mussels (Mackie 1984). Apparently this threshold temperature varies by species and may vary within a species depending on the latitude (reviewed by Mackie 1984). The threshold temperature for *Strophitus undulatus* 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 *S. undulatus* are unknown.

Unionids have only one breeding season per year (McMahon and Bogan 2001). Unionids differ among species by when they release their glochidia, generally fitting one of two patterns. They either release glochidia over a short time span in the summer months or retain the glochidia within the adult over the winter and release them the following spring (Howard and Anson 1922). Anodontinae species have breeding activity (ovulation, fertilization, embryo development, and glochidia release) over much of the year with a short interim period (van der Schalie 1938). Coker et al. (1921) reported finding *Strophitus undulatus* adult females with glochidia from March through November (except for July), which indicates an over-wintering situation. Lefevre and Curtis (1911) determined that fertilization of *S. undulatus* occurred in late July in Wisconsin. The interim period between breeding for *S. undulatus* in the Huron River is June and July (van der Schalie 1938).

Unionids reproduce multiple times during their lifetime (McMahon and Bogan 2001). Specific information on brood size in *Strophitus undulatus* is not available.

Demography

Genetic characteristics

Bivalves show a range of patterns of genetic structure. 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 are both the case in much of Region 2, it is possible that the genetic diversity of *Strophitus undulatus* is low within populations. If larger populations exist, higher levels of diversity may exist within populations. Different populations may be genetically different from one another, resulting in high diversity among populations. No information is available on the genetic diversity within or among *S. undulatus* populations anywhere across its range, so it is unknown whether the patterns exhibited in Region 2 are similar to those elsewhere.

Life history

Specific information on the life history of *Strophitus undulatus* is unknown. Data from other mussel species is compiled by McMahon and Bogan (2001), the following discussion draws from this source 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 *S. undulatus* in his summary of life spans of mollusks but lists other members of Unionidae that have life spans ranging from five to 116 years. Unionids mature somewhere before reaching 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 *Strophitus undulatus* is shown in **Figure 4**. This is a general model using information for mussels and is limited in its utility because so much information is unknown for *S. undulatus*. The life cycle diagram shown is a

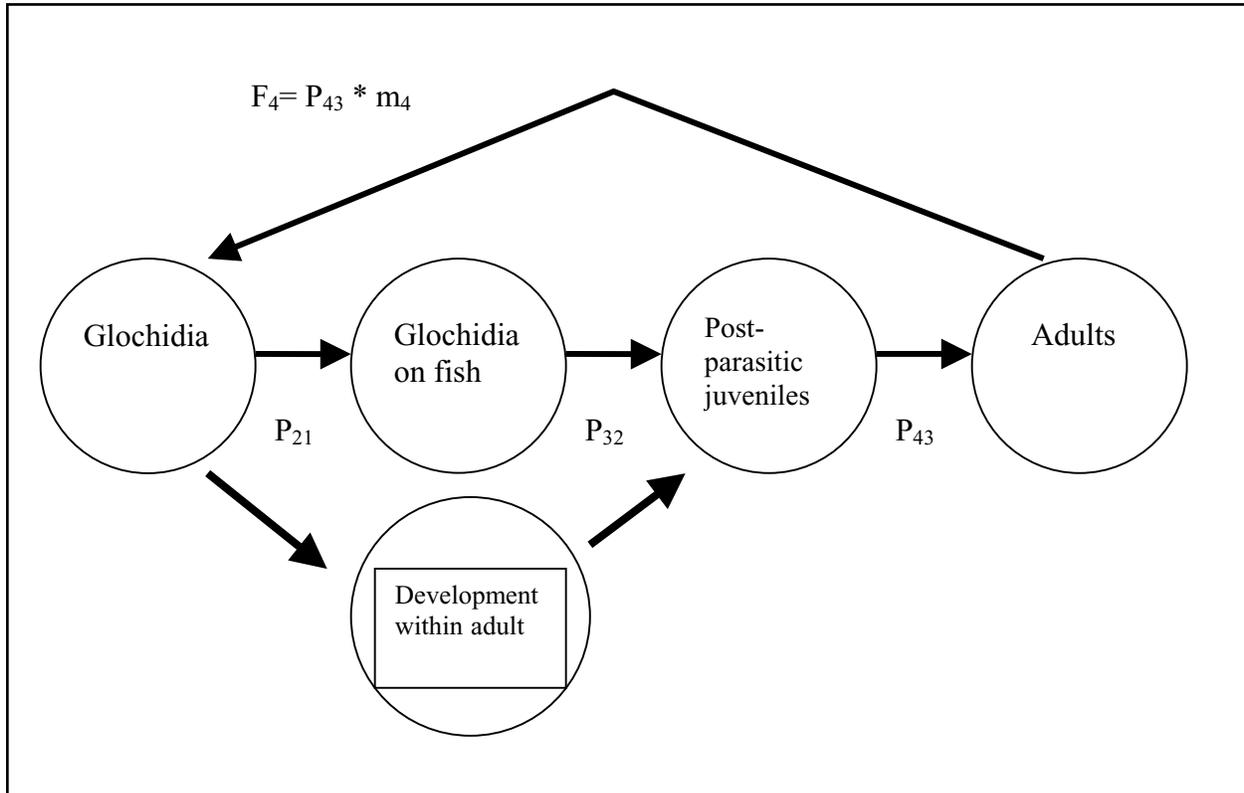


Figure 4. Life cycle diagram for *Strophitus undulatus*.

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. No information is available 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 of reaching each successive stage are listed in a similar fashion. The fertility, 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 *S. undulatus* at these stages, this diagram could be used to construct a demographic model (after McDonald and Caswell 1993, Caswell 2001).

No life history models or population viability models are available in the literature for this species. A demographic matrix is not provided because of the lack of data available on the life history of the species.

#### *Patterns of dispersal*

Dispersal occurs almost exclusively during the glochidia and juvenile stages. Fish hosts transport attached glochidia to wherever fish go, whether that is ideal habitat or not. However, since fish move more than sedentary adult mussels, this does allow for wider dispersal. See the Connectivity and Life history sections for more details.

#### *Social spacing*

Densities of *Strophitus undulatus* are unknown. Downing and Downing (1992) studied aggregation in 76 North American mussel populations in homogeneous environments and found that 45 percent of the populations were significantly clustered in space. Small populations were not likely to be significantly clumped. *Strophitus undulatus* was not included in the study, but four of nine *Anodonta grandis* populations were significantly clumped. In their study, densities of *A. grandis* in lakes ranged from 0.2 to 3.4 per  $m^2$ .

#### *Limiting factors*

No information is available on limiting factors specific to *Strophitus undulatus*. 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). Obermeyer (1999) also points out that population density may be a limiting factor because populations must be dense enough for sperm to reach other mussels. Beetle (1989) surmises that the number of mollusks is limited (at least in Wyoming) by high elevation, harsh climate, low amounts of moisture, and the temporary 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.

#### *Community ecology*

##### *Predation*

A wide variety of predators feed on one or more stages of mussels: oligochaetes, crayfish, salamanders, frogs, turtles, fish, waterfowl, otters, minks, muskrats, and raccoons (summarized in McMahan and Bogan 2001). Juvenile bivalves are an important part of many freshwater food chains (McMahan and Bogan 2001). Specific studies on the predators of *Strophitus undulatus* are not available.

However, the effects of predation on other mussel species showed impacts from muskrat predation. Adult mussels are widely consumed by muskrats in rivers in Virginia (Neves and Odom 1989). Muskrat predation resulted in selection for larger individuals of *Anodonta grandis simpsoniana* (northern floater) in an Alberta lake; mussels preyed upon had a median length of 64.3 mm vs. random mussels with a median length of 49.1 mm (Convey et al. 1989). Muskrats there also showed a preference for *Fusconaia cor* (shiny pigtoe) and *Pleurobema oviforme* (Tennessee clubshell) and against the small species *Medionidus conradicus* (Cumberland moccasin) (Neves and Odom 1989). In an Alberta lake, 21 percent of *A. grandis* glochidia from individuals >70 mm were consumed by muskrats (Hanson et al. 1989). The effects such predators have on *Strophitus undulatus* in Region 2 are unknown.

## Competition

Competition between *Strophitus undulatus* and other mussel species in the region is unknown. Zebra mussels (*Dreissena polymorpha*), an invasive species common in the eastern and midwestern United States, are known to negatively affect native mussel populations, but *D. polymorpha* is not known to occur within Region 2 (McMahon and Bogan 2001). Another invasive species, the Asian clam (*Corbicula fluminea*), may also negatively impact native mussels (Bogan 1993). It is unknown if *C. fluminea* occurs within Region 2 (NatureServe 2003).

## Parasites and disease

No information is available on the parasites or diseases of *Strophitus undulatus*. Studies of other Unionidae have shown them to be susceptible to water mites (*Unionicola* spp. and *Najadicola* spp.), which attach to gills, mantle, or internal organs (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, such as heavy siltation or disturbance (Fuller 1974).

## Symbiotic and mutualistic interactions

Glochidia usually require host fish species for development. The glochidia are released from adult mussels, and then attach to and obtain nutrients from the host fish until they reach the free-living juvenile stage (McMahon and Bogan 2001). Whether this has any significant negative effect on the fish under normal infestation levels is unclear. Studies of young rainbow trout (*Oncorhynchus mykiss*) infected with glochidia showed that artificially high numbers of glochidia (600 to 1200 per fish) resulted in 52 percent mortality (Murphy 1942). In separate experiments rainbow and brown trout (*Salmo trutta*) suffered death by secondary fungal and bacterial infections in high numbers. Murphy was unable to determine if this was due to glochidial attachment making infection easier or to the crowded conditions in the tanks. A subsequent study with fewer fish and lower numbers of glochidia per fish (30 to 50) showed no fish mortality.

Many fish species and one amphibian have been suggested as hosts for *Strophitus undulatus* (**Table 1**). Apparently there are some differences among geographical areas and laboratory conditions in suitable hosts. Van Snik Gray (2002) found a high metamorphosis rate for central stonerollers (*Campostoma anomalus*)

from the Susquehanna River drainage in Pennsylvania, but Watters et al. (1998) found that central stonerollers did not act as hosts for *S. undulatus* from the Ohio River drainage or from the Susquehanna River drainage. Likewise, banded darter (*Ethostoma zonale*) and bluntnose minnows (*Pimephales notatus*) allowed metamorphosis in Watters' experiments, but not in van Snik Gray's. The exact species serving as hosts in Region 2 has not been examined, but presumably *S. undulatus* is a generalist using a variety of fish species for hosts.

Amphibians and exotic fish species have also been shown to be compatible host species for some other freshwater mussels (Watters 1997, Watters and O'Dee 1998). The red-spotted newt (*Notophthalmus viridescens*) also provided a high (20 percent) rate of successful metamorphosis for *Strophitus undulatus* glochidia (van Snik Gray 2002). Whether this is the case for *S. undulatus* in Region 2 is unknown.

Hypotheses for how the important ecological relationships affect *Strophitus undulatus* are diagrammed in the envirogram shown in **Figure 5**. Envirograms (after Andrewartha and Birch 1984) are graphical representations of the 'ecological web' of complex pathways that influence an animal's survival. The center (centrum) of the web is the focal animal, in this case *S. undulatus*. 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 *S. undulatus*.

## CONSERVATION

### Threats

No studies address effects specifically on *Strophitus undulatus*; therefore, this section is based on information from other mussel species. Malacologists consider the main causes of mussel decline to be as follows: habitat destruction (mainly due to sedimentation, damming, dredging, water diversion, etc.), pollution (especially acidic runoffs from mines, pesticides, and heavy metals), commercial use (i.e., in-stream mining, harvesting of mussels), decline or loss of important host fish, and invasion of exotic species (i.e., zebra mussels

**Table 1.** Potential fish and amphibian hosts for *Strophitus undulatus*.

**FISHES**

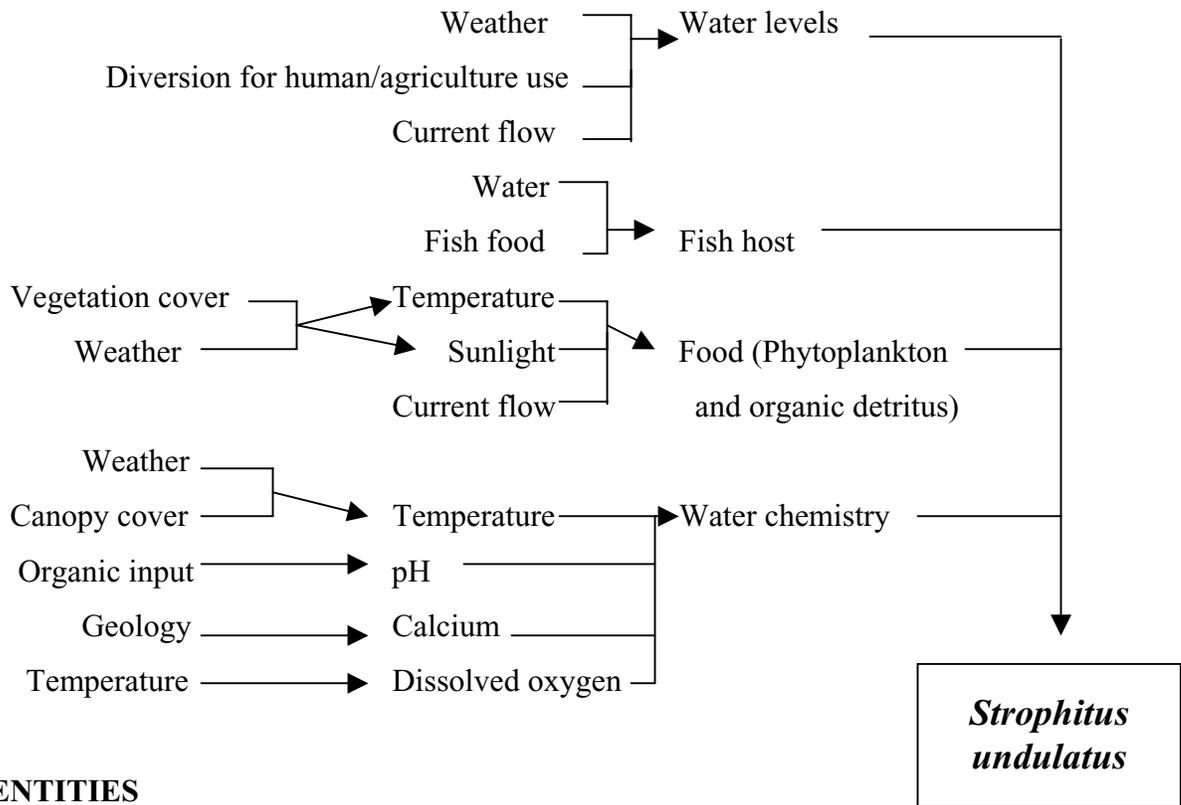
<b>Scientific Name</b>	<b>Common Name</b>	<b>Type of Evidence</b>	<b>Reference</b>	<b>Known distribution in Region 2<sup>1</sup></b>
<i>Acipenser oxyrinchus</i>	Atlantic sturgeon	Lab metamorphosis	Van Snik Gray 2002	None
<i>Ambloplites rupestris</i>	Rock bass	Lab metamorphosis	Van Snik Gray 2002	KS, SD; Introduced to CO, Wyoming
<i>Ameiurus melas</i>	Black bullhead	Lab metamorphosis	Hillegass and Hove 1997	CO, KS, NE, SD, WY
<i>Ameiurus natalis</i>	Yellow bullhead	Lab metamorphosis and hypothesis	Van Snik Gray 2002, Obermeyer 1999	KS, NE, SD
<i>Camptostoma anomalum</i>	Central stoneroller	Lab metamorphosis	Van Snik Gray 2002	CO, KS, NE, SD, WY
<i>Cottus cognatus</i>	Slimy sculpin	Lab metamorphosis	Van Snik Gray 2002	None
<i>Cyprinella spilopterus</i>	Spottfin shiner	Hypothesis	Obermeyer 1999	KS, NE
<i>Etheostoma flabellare</i>	Fantail darter	Lab metamorphosis	Watters et al. 1998	KS
<i>Etheostoma olmstedi</i>	Tessellated darter	Lab metamorphosis	Van Snik Gray 2002	None
<i>Etheostoma zonale</i>	Banded darter	Lab metamorphosis	Watters et al. 1998	KS
<i>Lepomis cyanellus</i>	Green sunfish	Lab metamorphosis	Hillegass and Hove 1997	CO, KS, NE, SD; introduced to WY
<i>Lepomis macrochirus</i>	Bluegill	Lab metamorphosis	Hillegass and Hove 1997	KS, NE, SD; introduced to CO, WY
<i>Luxilus cornutus</i>	Common shiner	Lab metamorphosis	Van Snik Gray 2002	CO, KS, NE, SD, WY
<i>Micropterus salmoides</i>	Largemouth bass	Lab metamorphosis and hypothesis	Hillegass and Hove 1997, Obermeyer 1999, Van Snik Gray 2002	KS, NE, SD; introduced to CO, WY
<i>Nocomis micropogon</i>	River chub	Lab metamorphosis	Van Snik Gray 2002	None
<i>Notemigonus crysoleurus</i>	Golden shiner	Hypothesis	Obermeyer 1999	KS, NE, SD; introduced to CO, WY
<i>Notropis stramineus</i>	Sand shiner	Lab metamorphosis	Watters et al. 1998	CO, KS, NE, SD, WY
<i>Oncorhynchus mykiss</i>	Rainbow trout	Lab metamorphosis	Van Snik Gray 2002	Introduced to CO, KS, NE, SD, WY
<i>Perca flavescens</i>	Yellow perch	Lab metamorphosis	Hillegass and Hove 1997, Van Snik Gray 2002	NE, SD; introduced to CO, KS, WY
<i>Pimephales notatus</i>	Bluntnose minnow	Lab metamorphosis	Watters et al. 1998	KS, NE, SD
<i>Pimephales promelas</i>	Fathead minnow	Hypothesis	Obermeyer 1999	CO, KS, NE, SD, WY
<i>Pomoxis annularis</i>	White crappie	Lab metamorphosis	Watters et al. 1998	KS, NE, SD; introduced to CO, WY
<i>Rhinichthys atratulus</i>	Blacknose dace	Lab metamorphosis	Van Snik Gray 2002	KS, NE, SD
<i>Rhinichthys cataractae</i>	Longnose dace	Lab metamorphosis	Watters et al. 1998, Van Snik Gray 2002	CO, NE, SD, WY
<i>Salvelinus fontinalis</i>	Brook charr	Lab metamorphosis	Van Snik Gray 2002	Introduced to CO, NE, SD, WY
<i>Semotilus atromaculatus</i>	Creek chub	Hypothesis	Obermeyer 1999	CO, KS, NE, SD, WY
<i>Stizostedion vitreum</i>	Walleye	Hypothesis	Obermeyer 1999	KS, NE, SD; introduced to CO, WY
<b>AMPHIBIANS</b>				
<b>Scientific Name</b>	<b>Common Name</b>	<b>Type of Evidence</b>	<b>Reference</b>	<b>Known distribution in Region 2<sup>1</sup></b>
<i>Notophthalmus viridescens</i>	Red-spotted newt	Lab metamorphosis	Van Snik Gray 2002	None <sup>2</sup>

<sup>1</sup>All distribution information is from NatureServe (2003).

<sup>2</sup>NatureServe lists the red-spotted newt as *Notophthalmus viridescens viridescens*. The eastern newt (*Notophthalmus viridescens*) is known from Kansas.

<b>WEB</b>			<b>CENTRUM</b>
3	2	1	

**RESOURCES**



**MALENTITIES**

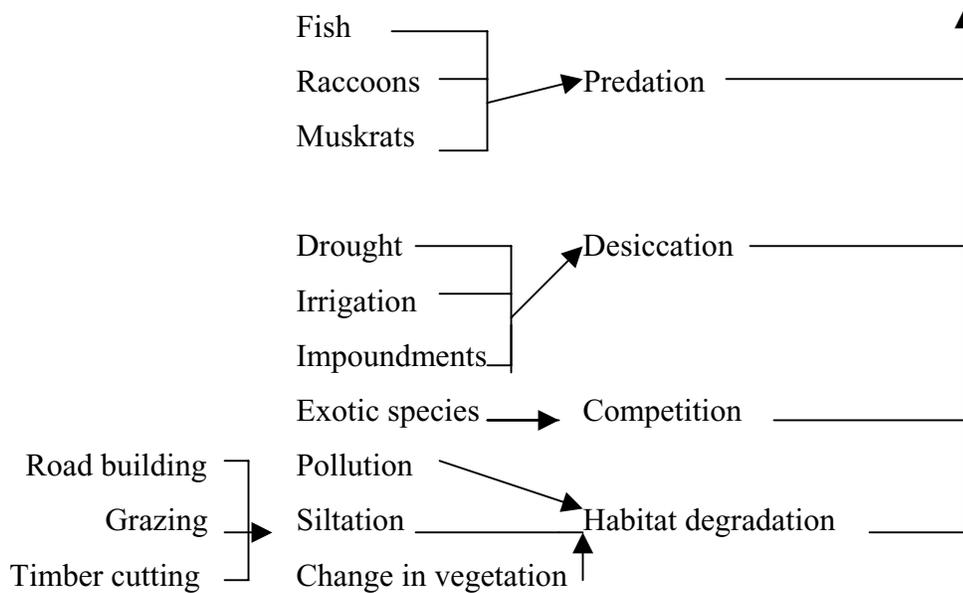


Figure 5. Envirogram for *Strophitus undulatus*.

and Asian clams) (Bogan 1993, 1996, Lydeard et al. 2004). Changes in water velocity are also detrimental to mussels (Vaughn and Taylor 1999). In southeastern Kansas, mussel declines have been attributed to decreased water quality of streams (Obermeyer 1999). More details on how specific management activities may affect mussels are outlined below.

Besides specific activities at the local scale, the activities across an entire landscape may need to be considered. 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 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 than in Iowa, this study does indicate that in some cases mussels may be affected by landscape activities at a larger scale than just what is occurring immediately adjacent to the point where mussels are living. Activities throughout an entire watershed may need to be considered when managing for stream health and mussel populations.

#### Changes in water flow

Extended low water levels interfere with mussel 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. For example, *Leptodea fragilis* and *Potamilus alatus* are currently limited to areas downstream of dams in five midwestern rivers, presumably because important fish hosts can not move upstream (Watters 1996). The dams present in Region 2 have not been investigated for their effect on mussels, but they could similarly restrict fish movement.

In addition to low water levels, changes in water velocity or 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; however, 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 (*Elliptio dilatata*, *Lampsilis radiata*, and *Lasmigona costata*) were identified as stable-site species, and three others (*Amblema plicata*, *Pygandon grandis*, and *Fusconaia flava*) as flooding-event site species. *Strophitus undulatus* was not included, so it is unknown how this species responds after discharge from dams or natural flooding events. Some studies in New England indicate that the distribution of *S. undulatus* is negatively affected by variability in water flow (Strayer 1993, 1999b), which would indicate that the species is probably susceptible to flooding events.

#### Timber harvest

No information is available on the effect of timber harvest on *Strophitus undulatus*. When harvesting near waterways with mussels, care should be taken so that removal of vegetation does not increase runoff into the water or increase the water temperature. 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 for stream health may include not just trees being removed, but also understory and ground vegetation as well.

In addition to the impacts from the absence of vegetation and organic matter after the harvest, 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 fluvial systems is important in maintaining natural water flow regimes (see Changes in water flow section above).

## Exotic species

Unlike unionids that burrow into substrate, zebra mussels attach to the substrate with strong, stringy byssal threads. Rapid reproduction can result in up to 1000 zebra mussels colonizing a mussel shell (Neves et al. 1996). The increased weight on a mussel shell decreases 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 otherwise be available for other species (Strayer et al. 1999). At this time, however, zebra mussels are not known to occur within Region 2 (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 1999a). It is unknown if this species occurs within Region 2 (NatureServe 2003).

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

## Livestock grazing

No information is available on the effect of livestock grazing on *Strophitus undulatus*. Grazing in areas with mussels could be detrimental if mussel beds are trampled, water levels are reduced, nitrates are increased, pH of water is altered, or runoff and/or sedimentation is increased due to trampled stream banks. For example, livestock concentrated in riparian areas may compact soil, decrease bank stability leading to increased sediment or pollution entering the stream, or change water flow regime. 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).

## Roads

Impacts of road building on *Strophitus undulatus* have not been studied specifically, but roads may cause problems if the building or maintenance process increases the amount of fine sediment deposited in streams. 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 meters (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, road salts, or spills (e.g., oil, antifreeze). Because this work includes many mussel species and has been conducted in areas with mostly paved roads, it is unknown whether these results are applicable to *Strophitus undulatus* habitat in Region 2.

## 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 malathion, a chemical commonly used for mosquito control; concentrations in the water were as low as 28 mg/L (Keller and Ruessler 1996). Other pesticides (DDT, aldrin, methoxychlor, diazinon, parathion, dieldrin, etc.) 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). Areas where chemical weed control is a priority would be more likely to exhibit these effects than other locations.

## Mining

Specific effects of mining on *Strophitus undulatus* 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 the decline to increased sedimentation 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. In their study, the exotic mollusk, *Corbicula* spp., increased with the increased fine sediment.

Chlorine pollution, 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.

#### Fire

No information is available on the effect of fire on mussels. A study following macroinvertebrates in Cache Creek in northern Yellowstone National Park for 10 years after fires found richness, density, and dominant taxa differed between burned and unburned creeks (Minshall et al. 2001). They determined that these changes were due to 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 water may increase the temperature of the mussel habitat and thereby have a negative effect on mussels. Excessive sediment may choke mussels in the affected areas. Large increases in waterflow due to runoff after large fires could potentially displace or choke mussels. For more details, see Habitat section and Changes in water flow section.

#### Off-road motorized recreation

Off-road motorized recreation near water containing mussels could be detrimental if erosion is increased or if mussel beds are directly damaged by vehicles. Stream banks could be destabilized, leading to increased sediment entering streams.

#### Non-motorized recreation

No information is available on the impacts of non-motorized recreation on mussels. As long as recreational trail stream crossings are located away from mussel beds and stream banks are not damaged, it is unlikely that non-motorized uses would impact mussels. Camping along stream banks could result in waste entering the water. Elevated bridges may allow for crossings near mussel beds with presumably minimal impacts. Fisheries management activity could affect mussels through trampling or poisoning for fish reclamation, so this should be conducted with care.

#### Blowdown

No studies have investigated the effects of blowdown on mussels. If a large blowdown event occurred near enough to water containing mussels that runoff or temperature at the mussel bed increased,

it could have an impact. As discussed above with the effects of timber harvest, removal of vegetation near waterways 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).

Commercial, scientific, and educational purposes

Historically, many freshwater mussels were harvested for pearls and the button industry (Pennak 1989). Moderating harvest pressure can help mussel populations recover (Hubbs 2001). No evidence exists that commercial uses are currently affecting *Strophitus undulatus* in Region 2. No evidence exists that scientific or educational collecting has caused the decline in *S. undulatus*. However, with the low population numbers currently found in many areas of Region 2, close regulation of collecting with permitting processes would probably be prudent.

### **Conservation Status of *Strophitus undulatus* in Region 2**

More study is needed before the conservation status of *Strophitus undulatus* can be fully understood in Region 2. Priority areas should include those areas where historical records exist and adjacent areas with similar habitats. In general, mussels are somewhat rare and traditionally are overlooked in much of the region, so it is unclear if historical records accurately represent the range of *S. undulatus*.

The abundance of *Strophitus undulatus* is apparently declining in portions of Region 2. The habitats in different parts of Region 2 vary in their capacity to support this species, depending on how 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 Colorado may already be extinct (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 *S. undulatus* 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 of the decline in mussel populations in Region 2.

### ***Potential Management of Strophitus undulatus in Region 2***

Implications and potential conservation elements

In order to best combat the potential decline in 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 flow patterns and maintain chemical concentrations at levels equal to those found in a relatively pristine stream in the area of concern. Dams are detrimental to aquatic health, unless natural 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 are needed for aquatic species, but excessive erosion can choke off the normal flow of nutrients. Logging and construction activities, such as road management, can interfere with the natural particle distribution. Maintaining natural temperature and light in the aquatic ecosystem allows for natural nutrient flows, provides proper amounts of dissolved oxygen, and therefore promotes the survival of native aquatic species. Grazing can affect sediment levels as well as unnatural amounts of organic matter input to the streams.

Mussels are affected by inadequate flow from groundwater sources, chemicals in the water and/or sediment, fish availability, predation, exotic species, and stability of the stream bed (U.S. Geological Survey 2000). Suitable fish hosts must be available to complete the life cycle of *Strophitus undulatus*. Predation by some exotic fish species may negatively impact survival of juvenile mussels. Exotic mollusk species, such as zebra mussels and Asian clams, can outcompete native mussels. 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.

Tools and practices

#### *Inventory and monitoring populations and habitat*

Surveying and monitoring protocols used for other freshwater mussels should be sufficient to evaluate *Strophitus undulatus*. 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 tend to be overlooked in the snorkel searches; however, more effort was required for the quadrat searches because the substrate within the quadrat was moved and searched by hand.

One alternative to the above methods is to sample muskrat middens because it is an efficient way to sample large numbers of mussels. Muskrats cache their food, and therefore many mussel shells are often found in these middens. The drawback to this method is that the middens represent a biased sample that does not reflect the diversity or abundance of the actual mussel beds (Watters 1993).

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 mussels then incorporate 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 (i.e., 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 the 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 annual survival was greater than 85 percent after relocation.

Mussel populations can recover over lengthy time periods after pollution events, assuming refuge populations and the necessary fish hosts remain, as demonstrated by Sietman et al. (2001). In the early 1900s, sewage from Chicago was diverted into the Illinois River, and 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. (**Note:** *Strophitus undulatus* 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 *Strophitus undulatus*, were harvested. Of these 20 species, three species (*Truncilla donaciformis*, *Obliquaria reflexa*, and *T. truncata*) did not survive captivity. Two species were supplemented with specimens from elsewhere upon reintroduction. Sixteen species still had live representatives in 2000-2002. However, numbers were about one-third of those that had been returned. It remains to be seen if these species will successfully reproduce and recruit new generations of mussels. The three *S. undulatus* returned to the site were not found living in the surveys.

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 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. Extreme caution would be needed, taking into account fish population structure and using only native fish species. Water flow might need to be restored in some situations. No studies are available of attempts to restore mussel populations after damage due to timber harvesting, fire, road management, or grazing. Eliminating the negative activity 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 *Strophitus undulatus* fall into four main areas: 1) surveying for the species and monitoring known populations, 2) evaluating the health of the aquatic systems in which these mussels are located, 3) studying the basic biology of the species, and 4) evaluating whether restoration of waterways can restore healthy populations in areas with evidence of historic populations.

The current distribution of *Strophitus undulatus* 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. Suitable rivers might be determined by utilizing databases of river type and water quality in comparison to rivers in other regions that have large *S. undulatus* populations.

Monitoring of 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 quickly identified and remediated.

Increased knowledge of the basic biology of the species would greatly enhance management. For example, required habitat characteristics in Region 2 would allow better predictions of where the species may reside. Also, information on survival and life history would allow for more effective population monitoring and management.

Reintroduction of historic populations may be an option if habitats are healthy. However, an evaluation of the quality of the aquatic habitats (e.g., water and sediment chemistry, flow levels) is necessary to determine if populations could potentially survive. Extreme caution would be necessary with any reintroduction program to take into account fish population structure and to use only native fish species.

## DEFINITIONS

See **Figure 6** for a diagram of morphological characteristics.

**Anterior** – the side of the shell closest to the beak

**Beak** – the peak at the top of the shell; also called the umbo

**Bivalve** – the category of mollusks characterized by individuals with shells with two identical halves

**Desiccation** – drying out

**Foot** – muscular organ that is extended from the shell and allows for movement

**Glochidia** – the larval stage of mussels; require a fish host

**Grab sampling** – sediment 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; holds the two valves together

**Juvenile stage** – the developmental stage that occurs after glochidia release from the fish host

**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

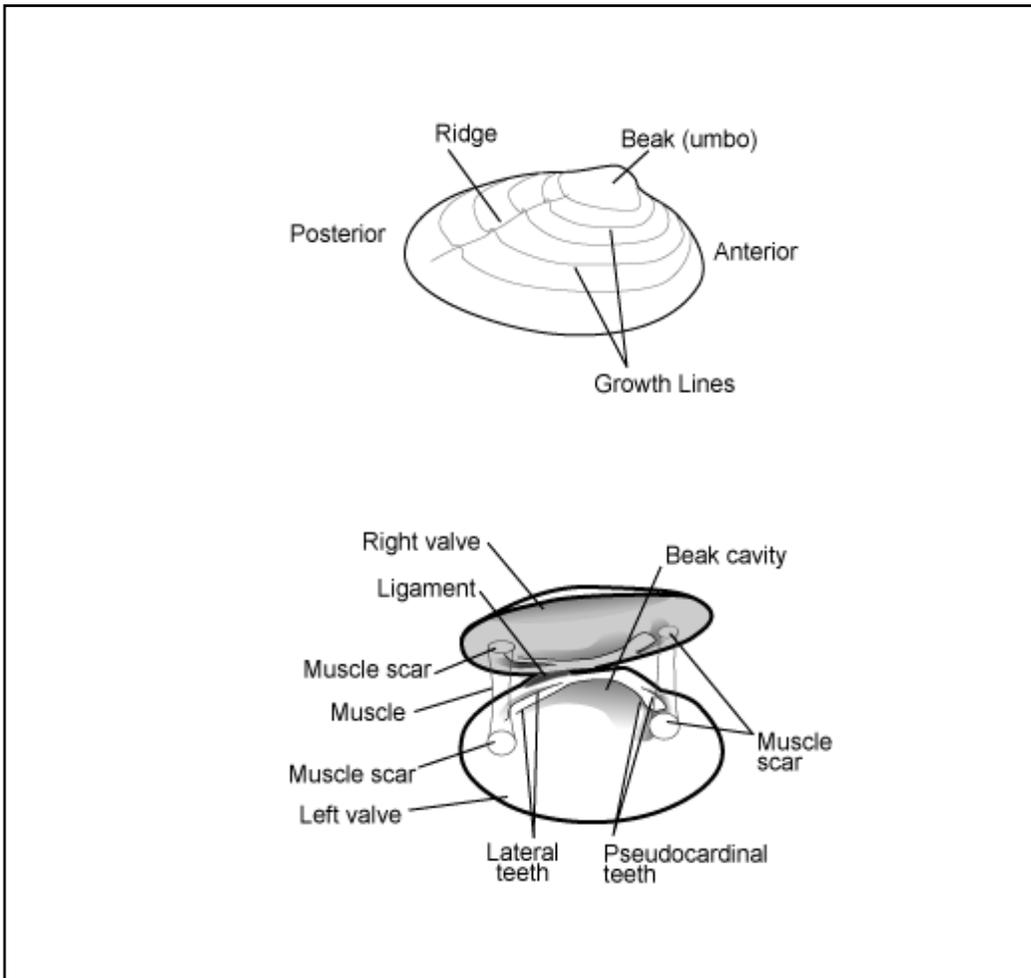
**Pseudocardinal teeth** – ridges at the anterior side of the beak that form part of the hinge

**Shear stress** – physical forces exerted by flowing water

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

**Umbo** – see **Beak**

**Valves** – identical halves of the bivalve shell that are held together at the hinge



**Figure 6.** Diagram of morphological characteristics used to describe mussels. Illustration by Leigh Anne McConnaughey.

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