Rocky Mountain Capshell Snail (*Acroloxus coloradensis*): A Technical Conservation Assessment

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Tamara Anderson, Ph.D.
1075 S. 2nd
Lander, WY 82520

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AUTHOR'S BIOGRAPHY

Tamara Anderson has studied mollusks for more than 10 years and has spent several years surveying mollusks in South Dakota and Wyoming. She received her Ph.D. in Ecology and Evolutionary Biology from Iowa State University where she studied a federally endangered land snail. She is currently an adjunct curator at the University of Colorado Museum.

SUMMARY OF KEY COMPONENTS FOR CONSERVATION OF *ACROLOXUS COLORADENSIS*

Status

Acroloxus coloradensis (Rocky Mountain capshell snail) is considered a sensitive species in the USDA Forest Service Rocky Mountain Region (Region 2). This species is the only representative of Family Acroloxidae that resides in North America. Across its range, *A. coloradensis* is rare and has widely disjunct populations with some clusters of populations in Quebec, Colorado, and British Columbia. Only six locations are known in Region 2, including populations on the Routt and Roosevelt national forests.

Primary Threats

Acroloxus coloradensis resides in clean boreal lakes with rocky substrate. Because these lakes are critical habitat, some management activities have the potential to impact these populations. Primary threats include timber harvesting, pesticide application, fisheries management, and some recreational activities. Lowered water levels are a possible cause of the decline in one population.

Primary Conservation Elements, Management Implications and Considerations

Without information on the status of more of the known populations, it is difficult to manage the species. Additional surveys and monitoring are necessary to better understand the distribution and make fine-scale management decisions. However, it is known that this species evolved under a much narrower range of water quality conditions, less influenced by anthropogenic factors. Therefore, taking conservative routes of maintaining the integrity of aquatic ecosystems and natural processes that influence *Acroloxus coloradensis* habitat should be strongly considered when planning land management activities.

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INTRODUCTION

This assessment is one of many being produced to support the Species Conservation Project for the USDA Forest Service (USFS) Rocky Mountain Region (Region 2). *Acroloxus coloradensis* (Rocky Mountain capshell snail) is the focus of an assessment because it is considered a sensitive species in Region 2. 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 requires special management, so knowledge of its biology and ecology is critical. This assessment addresses the biology of *A. coloradensis* throughout its range in Region 2. This introduction defines the goals of the assessment, outlines its scope, and describes the process used in its production.

Goal

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

Scope

This assessment examines the biology, ecology, conservation status, and management of *Acroloxus coloradensis* with specific reference to the geographical and ecological characteristics of the USFS Rocky Mountain Region. Although some of the literature on the species originates from field investigations outside the region, this document places that literature in the ecological and social context of the central Rocky Mountains. Similarly, this assessment is concerned with behavior, population dynamics, and other characteristics of *A. coloradensis* 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 *Acroloxus coloradensis* are referenced in the assessment, nor were all published materials considered equally reliable. The assessment emphasizes refereed literature, where possible, because this is the accepted standard in science. Non-refereed publications or reports were used when information was unavailable elsewhere, but these were regarded with greater skepticism. Unpublished data (e.g. Natural Heritage Program records, museum records, etc.) were especially important in estimating the geographic distribution. These data required special attention because of the diversity of persons and methods used in collection.

Treatment of Uncertainty

Science represents a rigorous, systematic approach to obtaining knowledge. Competing ideas regarding how the world works are measured against observations. However, because our descriptions of the world are always incomplete and our observations are limited, science focuses on approaches for dealing with uncertainty. A commonly accepted approach to science is based on a progression of critical experiments to develop strong inference (Platt 1964). However, it is difficult to conduct experiments that produce clean results in the ecological sciences. Often, we must rely on observations, inference, good thinking, and models to guide our understanding of ecological relations. In this assessment, we note the strength of evidence for particular ideas, and we describe alternative explanations where appropriate.

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

Uncertainty also comes into play when lifecycle 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; 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. Inferences made from this information regarding threats to the species are understood to be limited in scope (see section above) and take into account the particular conditions present in Region 2. Therefore, information regarding the conservation status of this species pertains specifically to Region 2 and does not necessarily apply to other portions of the species' range.

Publication of Assessment on the World Wide Web

To facilitate the use of species assessments in the Species Conservation Project, they are being published on the Region 2 World Wide Web site (www.fs.fed.us/r2/projects/scp/assessments). Placing the documents on the Web makes them available to agency biologists and the public more rapidly than publishing them as reports. Furthermore, 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

The U.S. Fish and Wildlife Service does not currently include *Acroloxus coloradensis* on its list of endangered species (U.S. Fish and Wildlife Service 2003). USFS Region 2 considers it a sensitive species; it is not considered a Management Indicator Species on any national forest within Region 2 (N. Warren personal communication 2004).

The global heritage status rank for *Acroloxus coloradensis* is G1G2, which means the species is "imperiled" to "critically imperiled" across its global range (NatureServe 2003). In Canada, this species' conservation status ranks vary from S1 ("critically imperiled") in Alberta and Quebec, to S2S3 ("vulnerable" to "imperiled") in British Colombia, and SU ("status unknown") in Ontario (NatureServe 2003). Within the United States, the conservation status ranks vary from S1 ("critically imperiled") in Montana to S2 ("imperiled") in Colorado (NatureServe 2003). No occurrences are known for other states in Region 2 (South Dakota, Wyoming, Kansas, or Nebraska).

Existing Regulatory Mechanisms, Management Plans, and Conservation Elements

No management plans or conservation strategies exist that address *Acroloxus coloradensis* specifically. No guidelines that address *A. coloradensis* are present within Forest Plans for the national forests in Region 2. Riebesell (1993) suggested some actions to reduce potential impacts within Rocky Mountain National Park. These actions included rerouting a hiking trail that comes very close to *A. coloradensis* habitat, posting keep-off signs, keeping campsites away from habitat, and refraining from using poison for fish management.

Conservation plans and management guidelines for any aquatic gastropod species are extremely rare in the United States. In the northwestern United States, the USFS has developed some guidelines for surveying and managing mollusks. The Northwest Forest Plan requires surveys for aquatic mollusk species of concern when any sort of disturbance in riparian habitats is planned (Furnish et al. 1997).

Recovery plans are available for a few federally endangered gastropod species, such as *Athearnia anthonyi* (Anthony's riversnail) (U.S. Fish and Wildlife Service 1997). The main aspects of this plan are to:

1) protect the species and its habitat using available regulations, working with local governments and businesses, and educating the public about actions that may help the snail

2) research the biology and life history of the species

3) research the impacts of habitat degradation, water quality, and invasive species on population viability of the species and determine appropriate management strategies

4) continue searching for additional populations that may exist

5) investigate the possibility of augmenting existing populations and/or reintroducing individuals to additional sites within the historic range

6) monitor populations and habitat (U.S. Fish and Wildlife Service 1997).

Athearnia anthonyi resides in Tennessee and is primarily a river-dwelling species, unlike *Acroloxus coloradensis*, so some habitat requirements are different. However, *Athearnia anthonyi* is also known from only two locations, so guidelines similar to these may apply to conserving *Acroloxus coloradensis* in Region 2. Because *A. coloradensis* is not considered endangered, no legal guidelines are implied, so establishing general mollusk conservation strategies may be helpful.

Biology and Ecology

Systematics and general species description

Acroloxus coloradensis is a species of limpet, which is related to snails. Limpets are classified in the same class as snails, Gastropoda, within Phylum Mollusca. *Acroloxus coloradensis* is contained within Family Acroloxidae, within the Order Basommatophora. It is the only member of Family Acroloxidae recognized in North America (Turgeon et al. 1998). Older references include *A. coloradensis* within other families and by other species names, so in the past it has been referred to as *Ancylus coloradensis*, *A. hendersoni*, and *Ferrissia hendersoni*, but these names are incorrect with current taxonomy (Henderson 1925).

Acroloxus coloradensis, like other limpets, has a flat shell, not coiled like most gastropods, and is characterized by the angle of its apex. (See Definitions section at the end of the report for a description of morphological structures and other technical words.) The apex of *A. coloradensis* is pointed to the back and to the left, and this dextral organization is what differentiates the species from limpets included in Family Ancylidae (Burch 1982). Clarke (1993) describes a brown periostracum and a shell sculpture including both radial striae and growth lines. Clarke's samples measured up to 4.6 mm (0.18 in) long, 2.9 mm (0.11 in) wide, and 1.2 mm (0.05 in) high. According to figures shown in Paul and Clifford (1991), the shells measure about 5 mm (0.2 in) long and 2.7 mm (0.11 in) wide. Although *A. coloradensis* is an aquatic snail, it is still a pulmonate. Unlike some other pulmonates, limpets have developed some gill-like tissues (McMahon 1983), so they do not depend on breathing air to obtain oxygen. A diagram of *A. coloradensis* is shown in **Figure 1**.

Distribution and abundance

The range of *Acroloxus coloradensis* includes isolated populations in Canada and the United States (**Figure 2**). In Canada, the species' range is divided into an eastern population (Ontario and Quebec) and a western population (British Columbia and Alberta) (Lee and Ackerman 2001). Some speculation exists as to whether the eastern specimens are actually a different species (see Clarke 1993 and Lee and Ackerman 2001 for discussion). Two independent genetic studies currently underway in Germany and Montana may help to determine how the eastern and western populations are related, but that information is not yet available (C. Albrecht personal communication 2003, B. Ellis personal communication 2004).

In the United States, *Acroloxus coloradensis* is currently known only from one site in Montana and six sites in Colorado (Riebesell et al. 2001). The Colorado locations occur on the Routt and Roosevelt national forests, in Rocky Mountain National Park, and in a privately-owned location in Boulder County. A map of the Region 2 locations and names are shown in **Figure 3**. Because of the difficulty in viewing these animals and because the species is apparently rare even where it is known, it is likely that additional locations exist, perhaps even a more continuous range from Canada south to Colorado (Lee and Ackerman 2001), but this is unknown. However, other sources suggest that

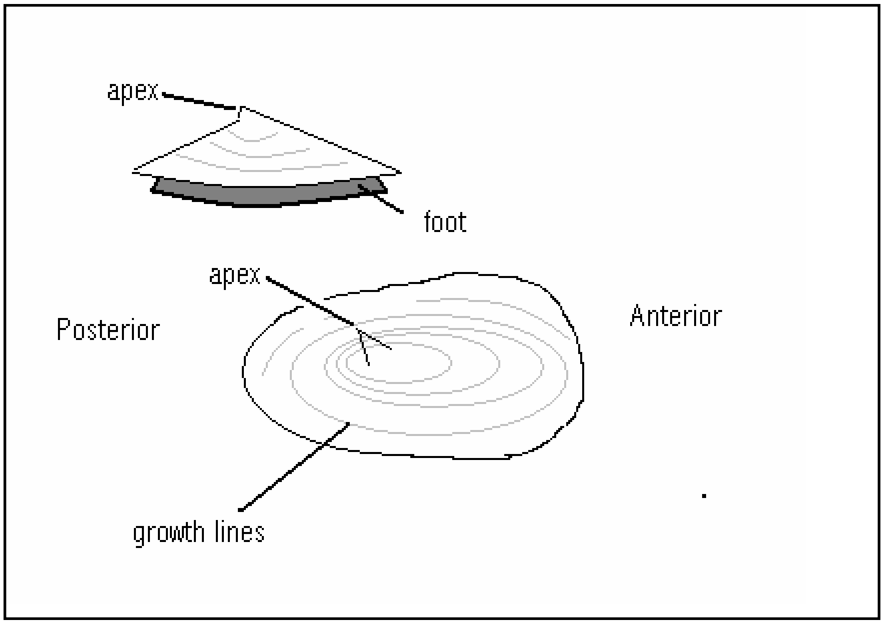
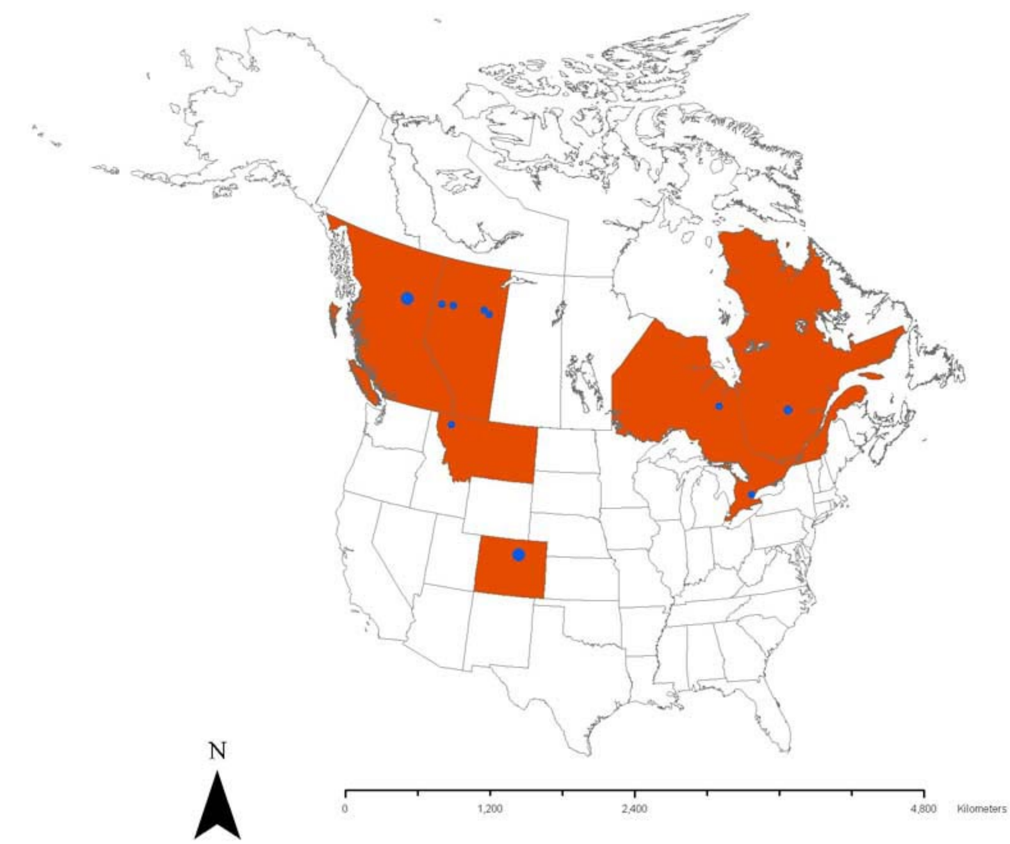


Figure 1. Diagram of *Acroloxus coloradensis*. Modified from Burch (1982). See **Definitions** section for an explanation of terms.



States and provinces marked in red contain known extant populations of *Acroloxus coloradensis*. Circles represent populations or clusters of populations. Canadian locations are from Lee and Ackerman (2001.)

Figure 2. Known modern range of *Acroloxus coloradensis*.

Points show known locations in Region 2. Locations are from Riebesell et al. 2001. 1 = a national park lake, 2 = Lost Lake, 3 = Peterson Lake, 4 = Teal Lake, 5 = an unnamed pond, and 6 = Upper Big Creek Lake. Shaded areas represent Routt and Roosevelt national forests and Rocky Mountain National Park, where these lakes are located.

Figure 3. Known extant populations of *Acroloxus coloradensis* in USFS Region 2.

the species exists only in relict populations (Burch 1982), so more populations would not be expected. Fossil locations are known from Nebraska, Kansas, and Oklahoma (Taylor 1954, 1960 as cited in Clarke 1993), but no known extant populations have been identified there.

Reported population density varies tremendously both within and among locations. For example, Lee and Ackerman (2001) found that the density in Purden Lake in British Columbia, Canada varied from 27 individuals per m^2 (27 individuals per 10 square feet) in one area of the lake to one individual along 80 m (262 ft) of the lake's perimeter. In Gataiga Lake, also in British Columbia, they found only one individual on the entire perimeter of a 34 ha lake. In Lost Lake, Montana, the density was 20 individuals per m^2 (20 individuals per 10 square feet) (Clarke 1993). Population density in Quebec reached only 0.2 individuals per m^2 (0.2 individuals per 10 square feet) (Clarke 1993).

Although limpets do move while grazing for food, populations are likely isolated from one another because the aquatic species would need to traverse miles of dry land to reach other suitable water bodies. Outlet streams between lakes provide potential migration pathways between some populations where lakes are in the same watershed (e.g., Peterson and Last lakes, two lakes within Jasper National Park in Canada) or in adjacent watersheds (an undisclosed national park lake and unnamed pond).

Population trend

Accurate information on trends in populations is not available for *Acroloxus coloradensis*. Most of the literature notes only how many specimens were collected at a site, which may or may not reflect the population size. Reports of repeat visits to historical locations are difficult to interpret due to possible differences in collecting methods and/or natural fluctuations in population sizes.

One population does appear to be declining. Wu (1989) reported finding only one live specimen in 1989 in Peterson Lake, Colorado, where population densities of 72 individuals per m^2 were previously known (Bryce 1970). Clarke (1993) also found only three individuals in 1992 surveys. Because the survey methods were not specifically reported, it is impossible to make accurate comparisons from these data.

Population trends in Canadian populations are also unknown. The historical locations of Purden Lake (known from 1972) in Canada still contained *Acroloxus coloradensis* when revisited in 1997 (as reported in Lee and Ackerman 2001). Population numbers are not supplied, so no statements about trends in those locations can be made.

The *Acroloxus coloradensis* density on artificial tiles in an undisclosed national park lake in Colorado steadily increased after monitoring began in 1994 (Riebesell et al. 2001, J. Riebesell personal communication 2004), presumably because individuals were colonizing the tiles. One year after placing tiles on the bottom of the lake, 3.3 individuals per m^2 (3.3 individuals per 10 ft^2) were observed. The density increased to 27 individuals per m^2 (27 individuals per 10 ft^2) in 1999 and 111 individuals per m^2 (111 individuals per 10 ft^2) in 2003. It is unknown at what density the population will level off, or whether it will crash.

Activity patterns and movements

No information is available about the daily or seasonal activity patterns of *Acroloxus coloradensis*. Limpets can move by utilizing their muscular foot. *Acroloxus coloradensis* may be slower than other limpets, based on comparisons with *Ferrissia parallela* in captivity (Clarke 1993), but the relevance to their movements in the natural environments is unknown. Individuals may move in search of food or in response to environmental conditions. Other freshwater gastropods appear to migrate vertically as temperatures change from season to season (summarized in Dillon 2000). Although some aquatic pulmonates must move to the surface for air, others may obtain oxygen from submerged vegetation or by adjusting their metabolism for anoxic environments (see discussion in McMahon 1983). It is unknown what pattern *A. coloradensis* follows.

It is unlikely that *Acroloxus coloradensis* commonly moves to other lakes. Boag (1986) reports that freshwater gastropods can attach to the feathers of waterfowl and survive simulated flight conditions, but actual dispersal by this method has not been observed for *A. coloradensis*. Boag found that individual gastropods could survive flight conditions of up to 10 km (6.2 mi), but only individuals less than 3 mm (0.1 in) could remain attached for long. Perhaps juvenile *A. coloradensis* could be transported in this way. If such passive dispersal occurs among *A. coloradensis* locations, it is likely to be a rare occurrence.

Observations of the first individuals colonizing tiles in an undisclosed national park lake showed that they were larger (>1 mm, 0.039 in) individuals (Riebesell personal communication 2004), suggesting larger individuals do move within a lake.

Habitat

Originally, it was thought that *Acroloxus coloradensis* occurred only in cold mountain lakes (Bryce 1970). Most known populations occur in lakes, but a recent discovery occurred in a very slowly-moving portion of Beaver River in Alberta, Canada (Paul and Clifford 1991).

An excellent study by Riebesell et al. (2001) provides much insight into the types of lakes where *Acroloxus coloradensis* occurs. They surveyed lakes in northern Colorado and compared characteristics of six lakes with *A. coloradensis* present to 28 lakes without *A. coloradensis*. Lakes with *A. coloradensis* were significantly lower in elevation (2864 m [9394 ft] versus 3074 m [10,083 ft], $p<0.05$), higher in calcium content (104 mg per L [0.00364 oz per 0.27 gal] versus 49 mg per L [0.0017 oz per 0.27 gal], $p<0.01$), and higher in conductivity (39 μmhos per cm versus 24 μmhos per cm, $p<0.01$) than lakes without *A. coloradensis*. No significant differences were observed in lake surface area or flushing rates (determined from the ratio of drainage basin area to surface area as a measure of the amount of inflow). Lakes containing *A. coloradensis* have glacial till nearby, but this was not a significant factor in determining their presence because area lakes without *A. coloradensis* also were near glacial till soils. Riebesell et al. (2001) conclude that in Colorado, *A.*

coloradensis may be limited to lakes in an elevation band low enough to have enough calcium and other ions, but high enough to have rocky substrate that is not too muddy (as is common in highly productive lakes and lakes with large amounts of runoff, such as is seen commonly at lower elevations).

This species apparently has a wide temperature tolerance. During the winter, ice covers at least some of the lakes (Bryce 1970). Summer temperatures ranged from 17 to 25 °C (63 to 77 °F) in Beaver River, Canada (Paul and Clifford 1991) and from 1.6 to 23.7 °C (35 to 67 °F) in an undisclosed national park lake, Colorado with *Acroloxus coloradensis* (Riebesell et al. 2001, unpublished data). Year-round temperatures in an unnamed pond in Colorado ranged from -7.4 to 25.4 °C (19 to 78 °F) (Riebesell unpublished data). Four other area lakes whose temperatures Riebesell has monitored rarely fall much below 0 °C (32 °F) with the low in an undisclosed national park lake of -0.2 °C (31.6 °F). Riebesell hypothesizes that during the coldest part of the winter, the *A. coloradensis* populations are encased in ice so that their temperatures are constantly near freezing, reducing the stress of being exposed to even colder temperatures or continuous temperature fluctuations.

Within a site, individuals are usually attached to rocks, wood, or vegetation (Lee and Ackerman 2001). Riebesell et al. (2001) describe finding most individuals on artificial substrates placed in rocky areas, especially those with piles of rocks. Fewer individuals are present if the rocks are covered by silt. However, neither Riebesell nor apparently anyone else has surveyed non-rock substrate areas to determine if these areas are part of the natural habitat for *Acroloxus coloradensis*. Individuals are usually found at depths less than 1 m (3.3 ft) (Riebesell et al. 2001). However, when water levels fluctuate greatly at a site, they may be found at greater depths (Clarke 1993).

No information is available on differences between microhabitats used in different seasons or for different functions. No information is available on the total available and/or occupied habitat because the exact parameters required are unknown.

Food habits

Specific information on the food habits of *Acoloxus coloradensis* is sparse. Based on reported behavioral observations, it is likely that grazing on algae is common (Clarke 1970, as cited in Lee and Ackerman 2001). In addition, the density of *A. coloradensis* increased as algae increased on artificial substrates in a Colorado lake (Riebesell et al. 2001), but this may be a coincidence. Whether certain species of algae are preferred or avoided is unknown.

In a study of freshwater gastropods in Sweden, the diversity of macrophytes showed a positive relationship to the number of gastropods at a particular site (Bronmark 1985). Bronmark suggests that an increase in macrophytes causes an increase in the number of microhabitats and refuges from predators. In the case of *Acroloxus coloradensis*, however, macrophyte vegetation may not be required, since some sites lack vegetation (Riebesell et al. 2001) and include other features such as boulders. More information is needed on the dietary requirements of this species in order to be able to evaluate what factors influence food availability.

Breeding biology

The breeding biology of *Acroloxus coloradensis* is not well understood, so information in this section draws mostly from information on other species. Like all snails in the Basommatophora, *A. coloradensis* are hermaphrodites (Geraerts and Joosse 1984). Freshwater pulmonates can self-fertilize or reproduce sexually (Dillon 2000). Among some, but not all, Basommatophora species, mating is reciprocal, that is gametes are exchanged between mates (Geraerts and Joosse 1984). Some species display elaborate courtship behaviors prior to copulation (Geraerts and Joosse 1984).

In mollusks, maturation of eggs, sperm, and the act of copulation can be stimulated by temperature, photoperiod, food availability for the female, and lunar cues (Geraerts and Joosse 1984). Reproduction in Basommatophora may be inhibited by lack of food, high density conditions, and parasitic infections (Geraerts and Joosse 1984). Presumably, if conditions are not favorable, mating may be delayed or the number of offspring may be reduced.

Acroloxus coloradensis lays yellowish egg masses of two to three eggs (Clarke 1970). Individual eggs measure approximately 1 mm (0.039 in) long and 0.5 mm (0.02 in) wide (Clarke 1970). The number of egg masses laid per season is unknown.

Demography

Genetic issues

Genetic information is not available to describe either the relationship among populations or the genetic diversity within populations of *Acroloxus coloradensis*. Because many populations are small and could be the result of self-fertilization, the diversity within populations may be low. Inbreeding in populations of other species has been demonstrated to result in decreased genetic diversity and possibly reduced fitness and even extinction in the long run (Saccheri et al. 1998).

Life history

Almost nothing is known about the life history of *Acroloxus coloradensis*. Generally, gastropods are known to have between one and three generations per year (Dillon 2000). Different species require anywhere from one to three years to mature (Dillon 2000). Some species reproduce more than once, while others die after reproduction (Dillon 2000). Heller (1990) classifies five species of limpets in the family Ancylidae (which does not include *A. coloradensis*) as short-lived, which he defines as living less than two years and reproducing only once.

A generalized lifecycle diagram is shown in **Figure 4**. The diagram is tentative because several aspects of the life history of *Acroloxus coloradensis* are unknown. The life cycle is stage-based (Caswell 2001) because it is unknown whether the rate of maturity fits a standard time frame or if it varies with environmental conditions. The three stages of the life cycle shown are: 1) sub-adult or juvenile stage, 2) mature, reproductive adult stage, and 3) post-first reproductive adults. 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 juveniles (stage 1) surviving and successfully maturing to adulthood (stage 2) is given as P_{21}. Probabilities (P) of reaching each successive stage are listed in a similar fashion. The fertility (F) or number of juveniles produced is a function of both the number of eggs produced by an adult (m) and the probability of an individual reaching the adult stage (P_{21}). Should numerical data become available in the future for survival and productivity of *A. coloradensis* at these stages, this diagram could be used to construct a demographic model could be constructed (after Caswell 2001, McDonald and Caswell 1993).

Dillon (2000) summarizes laboratory studies of growth rates (*r*) of freshwater gastropod species. In these experiments, *r* ranges from 0.03 to 5.24 across a range of freshwater gastropod species, although no limpets are included.

Because of the number of unknowns, a demographic matrix (Caswell 2001) is not possible for

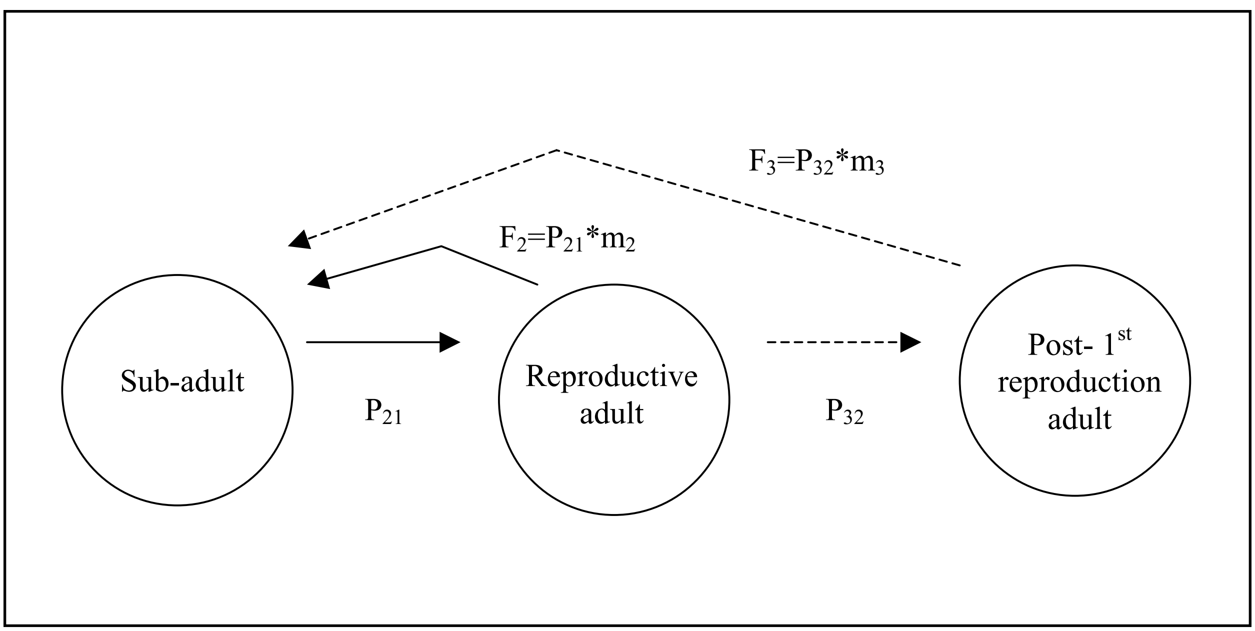


Figure 4. Life cycle diagram for *Acroloxus coloradensis.* Dotted lines indicate the uncertainty of whether adults breed more than once and whether they even survive after reproducing.

this species. As mentioned above, the fate of adults after breeding is unclear, so the life cycle itself is uncertain. Caswell (2001, pgs 60-62) provides an example of an incorrect lifecycle diagram for a plant species where an extra stage produced a growth rate estimate of 1.8 when the correct diagram estimates a growth rate of 2.4. In addition, no life tables are available for *Acroloxus coloradensis* from which to obtain values for survival rates. The surveys from an undisclosed national park lake give population densities, but they do not break the information into mature and immature individuals because distinguishing characteristics are not known. Life table information is not available for any other species in the genus either. Some authors assign missing values for missing stages to obtain a stable growth rate of 1. However, there are so many missing values in this model, that is not possible. In addition, the stable growth rate assumption may not be valid for this species because snail populations can be somewhat cyclical.

No population viability analysis for this species is available in the literature.

Social pattern for spacing

Density varies considerably both within and among sites (see discussion above in abundance section). No information is available on territory or home range.

Patterns of dispersal

No information is available on the differences between dispersal in adult and juvenile *Acroloxus coloradensis*. Gastropods can move on the muscular foot that extends from their shell. Whether juveniles have a higher propensity to move within a location is unknown; some observational evidence exists that may support the opposite. For example, Riebesell's (personal communication 2004) first observations of individuals colonizing artificial tiles (presumably from elsewhere in the same lake) were larger individuals. In testing for potential dispersal by waterfowl among ponds, Boag (1986) found that smaller individuals adhered more readily to feathers. This may suggest that younger individuals may be more likely to successfully reach other ponds if they do disperse by air.

Connectivity

Although limpets do move while grazing for food, populations may be isolated from one another because the aquatic species would need to traverse miles of dry land to reach other suitable water bodies unless connecting streams exist. Outlet streams between lakes provide potential migration pathways between populations in lakes in the same watershed (e.g., Peterson and Lost Lakes) or in adjacent watersheds (e.g., an undisclosed national park lake and an unnamed pond).

Boag (1986) hypothesizes that freshwater gastropods may be transported by attaching to the feathers of waterfowl, but this has not been observed for *Acroloxus coloradensis*. Boag found that individuals could survive flight conditions of up to 10 km (6.2 mi), but only individuals less than 3 mm (0.12 in) could remain attached for long. Perhaps juvenile *A. coloradensis* could be transported in this way. If such passive dispersal occurs among *A. coloradensis* locations, it is likely to be a rare occurrence.

Some other dispersal methods apparently occur for some freshwater gastropods. Bronmark (1985) studied gastropods in 45 ponds in Sweden. Small ponds with no breeding birds present did not differ from large ponds in the number of gastropod species present, indicating that some species were able to move among ponds without the assistance of bird transport. How this occurred is unknown, so whether such methods would apply to *Acroloxus coloradensis* is not clear.

Limiting factors

Obviously *Acroloxus coloradensis* requires an aquatic habitat. The characteristics and quality of the habitat may limit where the species can live and/or the size of the population. Some presumed limiting factors are discussed here; others could certainly exist.

The amount of desiccation that limpets can survive is unknown. If Riebesell's hypothesis that individuals are encased in ice for part of the winter is correct, it would suggest some desiccation resistance (Riebesell personal communication 2004).

Some fluctuation in water levels may be acceptable to these animals. However, Clarke (1993) suggests a link between the lowering of the water level and the population decline in Peterson Lake. During a survey in the summer of 1993, one lake containing *Acroloxus coloradensis* was reported to have water fluctuations of 1.5 to 2.1 m (5 to 7 ft) (Pioneer Environmental Services, Inc. 1993). The methods of measuring these fluctuations are not given, and the large numbers may possibly be due somewhat to wave action (Riebesell personal communication 2004). The time of year of the fluctuation is also important because "Freshwater mollusks are adapted to deal with natural events such as the gradual reduction in water levels which occur during warm-weather droughts. Many snails survive by simply crawling downward while the water levels drop. If snails are stranded by sudden water level drops in the winter, however, they will be too torpid from the cold to react properly…" (Clarke 1993, pgs 15-16).

Freshwater gastropods require calcium to build their shell, and they obtain the calcium from the surrounding water or from food (McMahon 1983). Most (95 percent) freshwater basommatophorans reside in water bodies with at least 3 mg Ca per kg H_2O (0.0001 oz Ca per 2.2 lbs H_20) (McMahon 1983), indicating that lower calcium levels may limit the ability of these species to survive. McKillop and Harrison (1972) examined population densities of 11 pulmonate species in soft, medium, and hard water locations in Ontario. Water hardness was a factor of how much calcium was present. The pulmonates had higher densities in medium and hard water locations. For example, the only limpet included, *Ferrissia parallela*, was most dense in medium-hardness locations (from 5 to 40 mg Ca per L [0.000175 to 0.0014 oz Ca per 0.27 gal]).

Growth, development, and survival are affected by low calcium and low pH. Low calcium treatments (<3.0 mg per L) in a laboratory study of the freshwater pulmonate, *Planorbella trivolvis*, resulted in abnormal egg development and death of juveniles (Hunter 1990). Snails exposed to low pH (pH<5) showed lower fecundity (no eggs hatched at low pH) and lower adult growth rates than snails at pH>7 (Hunter 1990).

Riebesell et al. (2001) suggest that *Acroloxus coloradensis* may be limited to lakes in an elevation band low enough to have enough calcium and other ions, but high enough to have rocky substrate that is not too muddy (as is common in highly productive lakes and lakes with large amounts of runoff, such as is seen commonly at lower elevations).

Lodge et al. (1987) developed a model, supported by data from studies of freshwater gastropods in a variety of habitats, that suggests that when calcium is sufficient, disturbance, predation, competition, and food availability determine the presence of snails. One can only infer that these same factors are important for *Acroloxus coloradensis*.

Community ecology

Nothing has been published about the community ecology specific to *Acroloxus coloradensis*. Therefore, this section draws on information from other freshwater gastropods.

Predators

Fish predation has been shown in some, but not all, cases to affect snail density (summarized in Dillon 2000). Insects (notably the North American waterbug, *Belostoma flumineum*), leeches, crayfish, turtles, salamanders, rats, birds, and other mollusks are also known predators of freshwater gastropods (Dillon 2000). Specific predators of *Acroloxus coloradensis* in Region 2 and the actual impact on the populations are unknown.

Competitors

Some mollusk species compete with others for food resources (Dillon 2000). Other mollusks occur in the same habitats as *Acroloxus coloradensis* (Lee and Ackerman 2001), but it is unknown whether competition with these other species has any impact on the populations. Using the underside of rocks may help to reduce competition with other mollusk species that use the surface of rocks. This subdivision of habitat has not been tested however.

Exotic species potentially have much stronger effects. *Dreissena polymorpha* (zebra mussel) has shown mixed effects on gastropod populations (as discussed in Strayer 1999 and citations therein). *Dreissena polymorpha* have increased some gastropod populations by providing additional food through their feces, improving water clarity for plants, and increasing the amount of hard substrate available (Strayer 1999 and citations therein). In other situations, their presence has been detrimental to populations by increasing fine sediments or by clinging to large individuals (Strayer 1999). *Acroloxus coloradensis* may be at risk should *D. polymorpha* enter their habitats because the former apparently do not inhabit silty areas (see habitat discussion above). Currently *D. polymorpha* are not known to occur in Colorado (McMahon and Bogan 2001).

Other exotic species that are known from the western United States, such as *Potamopyrgus antipodarum* (New Zealand mudsnail), could also negatively affect native freshwater gastropods (Strayer 1999, Richards et al. 2001). *Potamopyrgus antipodarum* has now been discovered in Colorado (Colorado Division of Wildlife 2004). Most western locations of the mudsnail appear to be in river systems (Richards et al. 2003), so whether *Acroloxus* *coloradensis* populations in mountain lakes are at risk is unknown. More information is needed to understand these potential interactions.

Parasites and disease

Parasites are fairly common in freshwater mollusks. Trematodes are among the most common, with more than 19 species of trematodes known from Louisiana limpets alone (Turner and Corkum 1979, as cited in Dillon 2000). These limpets did not include any *Acroloxus coloradensis*. No studies of the parasites of *A. coloradensis* have been conducted, so it is unclear what species may be present and what effects they may have on the host.

Symbiotic and mutualistic interactions

Symbiotic and mutualistic interactions with *Acroloxus coloradensis* are unknown.

Envirogram

Figure 5 shows an envirogram (after Andrewartha and Birch 1984) depicting the hypothesized important ecological relationships. An envirogram (after Andrewartha and Birch 1984) is a graphical representation of the 'ecological web' of complex pathways that influence an animal's survival. The center (centrum) of the web is the focal animal, in this case *Acroloxus coloradensis*. 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. The most important factors in this case include water level, water quality, calcium, amount of siltation, and food availability. This figure should be treated as a hypothesis, since many parts of the biology of *A. coloradensis* are unknown.

Conservation

Threats

Much of the basic biology of *Acroloxus coloradensis* remains unknown (see discussion above). Without detailed information on microhabitat requirements and life history, it is impossible to state the effects of management activities with certainty. The discussion here is based on the limited information available on *A. coloradensis*, supplemented with information on other freshwater snail species. This discussion is not meant to imply that these activities necessarily pose a dire threat to the species as a whole. Rather, the information is presented so that activities can be evaluated on a case by case basis at the local level.

Furnish et al. (1997) provide a list of activities that "may alter water quality or the physical habitat" and therefore require a survey for sensitive species according to the Northwest Forest Plan. Their list is as follows: "1) disturbance of soil, rocks or vegetation that would result in elevated water temperature, or increased sedimentation and/or turbidity; 2) reduction in large woody debris quantity or quality in stream channels; 3) disturbance or reduction in the recruitment of litter; 4) changes in hydrology which may affect water flow and vegetation communities; 5) increases in soil compaction; 6) chemical poisoning from herbicides or pesticides; 7) introduction of exotic plant or animal species; and 8) changes in microclimate (i.e., water temperature, current velocity, stream side shading, turbidity, stream discharge)." Although *Acroloxus coloradensis* resides predominantly in lakes, seepage into lakes where it lives may contribute to maintaining acceptable water levels and temperatures (Riebesell personal communication 2004).

Changes in water levels

Even though *Acroloxus coloradensis* can probably survive some change in water level because they are mobile, they still depend on the presence of water. Low water levels caused by weather-related drought conditions are difficult to alleviate. However, diversion or impounding of water can contribute to low water levels in some areas. Clarke (1993) suggests that low water levels after water was diverted from Peterson Lake for snow-making contributed to the decline of the *A. coloradensis* there, even though some natural water level fluctuation occurred at that lake. The timing of the water fluctuations is important as well as Clarke notes "Freshwater mollusks are adapted to deal with natural events such as the gradual reduction in water levels which occur during warm-weather droughts. Many snails survive by simply crawling downward while the water levels drop. If snails are stranded by sudden water level drops in the winter, however, they will be too torpid from the cold to react properly…" (Clarke 1993, pgs 15-16).

Roads

No studies directly address the effect of roads on freshwater gastropods. Roads could potentially have

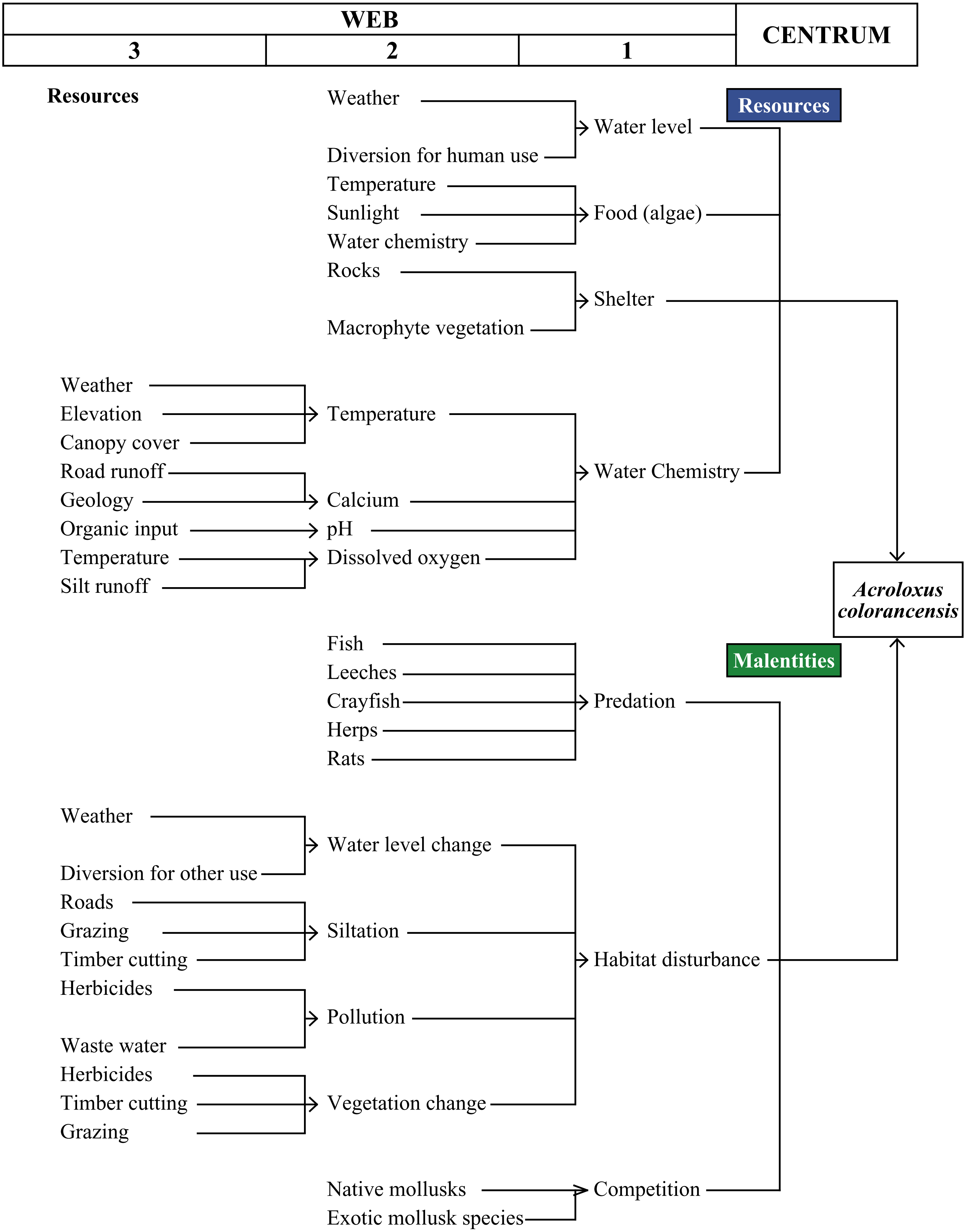


Figure 5. Envirogram showing hypothesized relationships among ecological factors and *Acroloxus coloradensis*.

negative effects if they increase the amount of fine sediment in the water.

Road runoff 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. Because this work includes only mussels, not gastropods, and because it has been conducted in areas with mostly paved roads, it is unknown whether these results apply to *Acroloxus coloradensis* habitat in Region 2.

Three lakes in Colorado (including one with *Acroloxus coloradensis*) had very high calcium levels and conductivities (Riebesell et al. 2001). These sites were adjacent to roadways, and Riebesell suggests that the high levels could be due to salts, dust, and/or emissions from the roads. However, it is impossible to determine from this whether the roads are impacting the population or not.

Motorized recreation

Potential effects from roads are discussed above. Motorized recreation off roads near water that contains gastropods could be detrimental if erosion is increased or if gastropod habitat is directly damaged by vehicles entering the water.

Non-motorized recreation

No studies are available on the impacts of non-motorized recreation on gastropods. Responsible recreational activities such as leave-no-trace camping or fishing that occur at these habitats are not likely to have large impacts as long as pollution is not increased and snail microhabitat is not disturbed. However, hikers, fisherpersons, and campers could potentially trample the shoreline and disturb habitat. For example, several tiles used in a study by Riebesell that were located near a hiking trail disappeared, suggesting some recreational user disturbance (Riebesell personal communication 2004).

Timber harvest

No information is available on the effect of timber harvest on *Acroloxus coloradensis*. Harvesting near *A. coloradensis* habitat could have a negative effect if removal of vegetation increased inflow or the amount of seepage (and therefore fine sediments) into the water or if it increased the temperature of the water.

Large-scale deforestation decreased species richness for several invertebrate groups (Ephemeroptera, Plecoptera, and Trichoptera) (Harding 2003). Three freshwater gastropod taxa (*Potamopyrgus antipodarum*, *Physa* spp., and *Lymnaea* spp.) were identified in the study, but they were more common in the agricultural streams than the forested streams. Whether the results for gastropods are statistically significant is not clear from the study. Since only three gastropod taxa were present, it is difficult to draw conclusions that might apply more generally. Also, these were riparian systems, so different effects may occur in lake systems.

Mining

Mining waste that enters the water may decrease pH and therefore affect snail populations (Harman 1974). (See Limiting Factors section above for a discussion of the importance of pH). Whether this is a factor at *Acroloxus coloradensis* locations is unknown.

Remnants of historical mining activity near Lost Lake indicate that, at least in some situations, *Acroloxus coloradensis* can co-exist with mining. Whether the population was positively or negatively impacted by these activities on Lost Lake is impossible to determine since population surveys prior to and during the activities are not available.

Over-utilization

No information suggests that collection or study for commercial, recreational, scientific, or educational purposes threatens the species. However, extreme caution should be used in future studies that disturb habitat or destructively sample individuals because of limited known population sizes. Careful review of permit applications and proposed studies is probably warranted.

Fisheries management

No studies have specifically addressed the effects of fisheries on *Acroloxus coloradensis*. Two potential management issues could present conflicts with *A. coloradensis* survival. If fish are introduced into lakes where they did not previously occur, *A. coloradensis* could potentially face additional predators. Also, chemicals used to poison undesirable fisheries in lakes or streams in order to reclaim them for native fish can be detrimental to mollusks.

Pesticide treatment

Although freshwater bivalve mollusks are often mentioned as bioindicators of chemical pollutants, much less information is available about the effects of chemicals on freshwater gastropods. A summary of the available information is provided in Harman (1974) and is drawn on here. Copper sulfate and hydrated lime are strong molluscicides and are sometimes used to control diseases such as swimmer's itch. Herbicides (e.g., Acrolein [2-propenal], Paraquat [1,1'-dimethyl 1-4, 4'-bipyridynium], Diquat [1-1'-ethylene-2-2'-dipyridylium], disodium endothall, Simazine [2-chloro-4,6-bis [ethyl amino]-s-triazine], 2,4-D [2,4-dichlorophenoxyacetic acid]) and insecticides (e.g., DN-111 [2 cyclohexyl-4,6-dinitrophenol dicyclohexylamine salt] and DNOC [sodium salt of 4,6-dinitro-o-cresol]) are also detrimental to snails. Other chemicals (e.g., toxaphene, dieldrin, and sodium arsenite) apparently have species-specific effects, with some species eliminated and others surviving. Testing on *Acroloxus coloradensis* has not occurred.

Harman (1974) also indicates that the application of herbicides that do not directly kill snails may be harmful if the chemicals eliminate the vegetation that the snails are using for food or for protection from predators.

Exotic species

Exotic species potentially have much stronger effects on *Acroloxus coloradensis*. *Dreissena polymorpha* have shown mixed effects on gastropod populations (as discussed in Strayer 1999 and citations therein). They have increased some gastropod populations by providing additional food through their feces, improving water clarity for plants, and increasing the amount of hard substrate available (Strayer 1999 and citations therein). In other situations, they have been detrimental to populations by increasing silt or by clinging to large individuals (Strayer 1999). *Acroloxus coloradensis* may be at risk should *D. polymorpha* enter their habitats because *A. coloradensis* apparently does not inhabit silty areas (see habitat discussion above). Currently *D. polymorpha* are not known from Colorado (McMahon and Bogan 2001).

Other exotic species that are known from the western United States, such as *Potamopyrgus antipodarum*, could also affect native freshwater gastropods (Strayer 1999, Richards et al. 2001). *Potamopyrgus antipodarum* has now been discovered in Colorado (Colorado Division of Wildlife 2004). Most western locations appear to be in river systems (Richards et al. 2003), so whether *Acroloxus coloradensis* populations in mountain lakes are at risk is unknown. More information and study is needed to understand these potential interactions.

Blowdown

No studies have investigated the effects of blowdown on freshwater gastropods. If a large blowdown event occurred near enough to water containing *Acroloxus coloradensis* that runoff or water temperature increased, then it could have an impact by making the habitat unsuitable.

Fire

No information is available that addresses the effects of fire on freshwater gastropods. A 10-year post-fire study of macroinvertebrates in Cache Creek in northern Yellowstone National Park found that richness, density, and dominant taxa differed between burned and unburned creeks (Minshall et al. 2001). The researchers determined that these changes were due to the loss of streamside and/or canopy vegetation as well as increased amounts of runoff entering the stream. Fires that had similar effects on habitats housing *Acroloxus coloradensis* could negatively impact the populations.

Grazing

No information is available on the effects of livestock grazing on *Acroloxus coloradensis*. Grazing in areas with gastropods could be detrimental if gastropods are trampled, water levels are reduced, pH of water is altered, or aquatic vegetation is reduced. These potential effects are irrelevant at sites where grazing does not occur.

Conservation Status of Acroloxus coloradensis in Region 2

Only a few populations of *Acroloxus coloradensis* are known in Region 2, and at least one of these has declined. Priority areas with regard to conservation should include all lakes known to host the species. Habitats vary in their capacity to support this species depending on their water chemistry and the amount of disturbance. When populations reach very low levels, they are vulnerable to extinction. Further investigation is needed to understand the full range of the species and whether the species overall is declining or holding its own. More information is also needed to determine if declining populations can recover.

Potential Management of <u>Acroloxus coloradensis</u> in Region 2

Implications and potential conservation elements

In order to best combat the potential decline in *Acroloxus coloradensis* in Region 2, healthy aquatic systems must be maintained. Baron et al. (2003, pg 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 are further developed by Baron et al. (2003), as summarized below. They suggest trying to match natural flow patterns and to maintain chemical levels at a level equal to that found in relatively pristine waters in the area. Some sediment and organic matter are needed for aquatic species, but excessive erosion can choke off normal flow. Logging and road management can interfere with natural particle distribution. In lakes with *A. coloradensis*, mining could potentially add sediments. Chemicals used for weed or insect control could kill individuals or the vegetation on which they depend. Fisheries activity may pollute lakes with chemicals or add predators. Human recreational activities may directly disturb habitat or individuals. Maintaining natural temperature and light in the aquatic ecosystem allows for natural nutrient cycles, proper amounts of dissolved oxygen, and the survival of native species found in the aquatic environment.

Tools and practices

Any future projects on *Acroloxus coloradensis* should consider the potential impacts on populations and attempt to minimize them.

Inventory and monitoring populations and habitat

Several surveying methods have been used for sampling *Acroloxus coloradensis*. The appropriate method will vary, depending on the particular makeup of the habitat at that location. For example, habitats with individuals living among vegetation along the shoreline will require a different sampling strategy than habitats where individuals are living only on rocks on the bottom of the lake.

Dillon (in prep.) describes collecting techniques for freshwater snails. These include checking underneath rocks, on plants, and on floating debris. He also recommends using a net to examine the sediments and vegetation on the bottom of the pond.

Strayer and Smith (2003) provide an excellent discussion of sampling strategies for mussels that apply to gastropods as well. When the objective is to inventory areas for the presence of a species, Strayer and Smith (2003) 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 hidden individuals not seen in visual searches, can be estimated.

If the objective is to estimate population size, Strayer and Smith (2003) recommend a random sampling design for a uniformly distributed population, and a stratified, systematic, or double-sampling method for patchy populations. With *Acroloxus coloradensis*, the scale of the study contributes to the pattern observed. For example, a lake may exhibit *A. coloradensis* clumped into rocky areas. The distribution within preferred habitat may be uniform, clumped, or patchy (Riebesell personal communication 2004).

Studying the impact of a particular disturbance is 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 (2003) 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. This is probably especially true for catastrophic events such as pollution events or catastrophic fires. For additional information on statistical analyses of surveys, see Strayer and Smith (2003).

Because repeated sampling involved disturbing rocky substrates, Riebesell et al. (2001) set up artificial substrates to monitor *Acroloxus coloradensis* in an undisclosed national park lake in Colorado. The substrate consisted of 40 clay tiles, each 19.5 cm (7.68 in) x 19.5 cm (7.68 in), placed 1 m (3.28 ft) apart in two transects. Although this method is less destructive to the habitat than pulling up rocks from the bottom, it is not entirely clear how the density on the tiles relates to the density on the surrounding rocks of the "natural" lake bottom. Individuals may be attracted to the tiles from other areas of the lake due to the presence of algae on the tile. This would result in a higher population estimate from the tiles than would be observed from rocks. However, a long-term study that repeatedly visited the tiles would at least be able to observe trends in density for the tile substrate. A comparison to counts from a few adjacent quadrats on the natural rocky substrate would also strengthen this method although the logistics of identifying and repeatedly manipulating natural substrates would be difficult.

Population and habitat management approaches

Management options for aquatic gastropods range from hands-off to monitoring to intensive relocation/reintroduction approaches. Current approaches to manage *Acroloxus coloradensis* in Region 2 are basically hands-off. Specific guidelines about how to avoid affecting the snails are lacking.

Riebesell (1993) suggested some actions to reduce potential impacts within Rocky Mountain National Park:

- ❖ rerouting a hiking trail that comes very close to *Acroloxus coloradensis* habitat
- ❖ posting keep-off signs in preferred habitat areas
- ❖ keeping campsites away from habitat
- ❖ refraining from using poison for fish management.

Monitoring of populations is possible as evidenced by the work of Riebesell et al. (2001), which is described above. Such a monitoring program could be extended to additional lakes in the region.

Restoration/reintroduction has been suggested in the recovery plan for at least one endangered freshwater snail species (U.S. Fish and Wildlife Service 1997). However, as yet this aspect of the plan has apparently not been implemented. Without more information on the *Acroloxus coloradensis* populations and their microhabitat requirements, it is unknown if reintroduction is a practical approach for Region 2.

Information Needs

Very little information is available on any aspect of the biology and life history of *Acroloxus coloradensis*. Of critical importance in managing the species is an understanding of its distribution and its habitat needs. Any studies to address these questions need to be carefully designed to minimize their impacts on the populations.

The response of *Acroloxus coloradensis* to changes in habitat is not well understood. Information on how it responds to changes in temperature, water level, or water clarity and the relationship of these factors to management activities would allow better planning of buffers and mitigation measures.

Understanding various aspects of the life cycle (breeding, development, survival, etc.) is important for several management tasks. For example, this information would be useful for planning monitoring times, as well as when to avoid disturbance, such as during breeding.

Recommended research priorities for *Acroloxus coloradensis* in Region 2 are as follows:

- ❖ Do additional populations of *A. coloradensis* exist?
- ❖ Are existing populations holding steady?
- ❖ If populations are declining, can causes be determined and remedied?
- ❖ What are the microhabitat requirements for *A. coloradensis*?
- ❖ Can bottlenecked populations (i.e., Peterson Lake) recover?
- ❖ What is the life cycle of *A. coloradensis*?

The first three items are of high priority and essential for short-term protection of the species. The next two items are not as critical, but they are necessary for longer-term management of the species. The last item would help in management but is not critical.

DEFINITIONS

Apex — the peak of the shell.

Foot — the muscle that gastropods use to move about.

Hermaphrodite — contain both male and female reproductive organs, may or may not self-fertilize.

Limpet — a group of gastropods with cap-like shells.

Macrophyte — large aquatic plants, in this report referring to vegetation larger than algae.

Microhabitat — habitat immediately surrounding the snail, a subset of the entire lake.

Periostracum — the outer shell covering.

Pulmonate — a group of gastropods with lungs.

Operculum — tissue that seals the shell opening of some gastropod species.

Striae — faint lines on the shell.

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