Oreohelix strigosa cooperi (Cooper's Rocky Mountain Snail): A Technical Conservation Assessment

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COVER PHOTO CREDIT

Oreohelix strigosa cooperi (Cooper's Rocky Mountain snail). Photograph by T. Anderson.

SUMMARY OF KEY COMPONENTS FOR CONSERVATION OF *OREOHELIX STRIGOSA COOPERI*

Status

In the Rocky Mountain Region of the USDA Forest Service (USFS), *Oreohelix strigosa cooperi* (Cooper's Rocky Mountain snail) is known only from the Black Hills National Forest. It is a sensitive species in the Rocky Mountain Region and a management indicator species for the Black Hills National Forest. Known locations of this species are concentrated in the northern and western sections of the Black Hills National Forest. At local levels, snail populations fluctuate with weather and time of year.

Primary Threats

Because of its limited dispersal ability and sensitivity to environmental conditions such as temperature and moisture, populations of this species are subject to extirpation from events that alter or destroy habitat at a particular location. Recolonization of an area after a disturbance is unlikely for isolated populations. Management activities that change moisture levels, ground temperature, and amounts of litter and vegetation cover are likely to negatively affect this species. The primary potential threats include road building, fire, timber harvest, mining, grazing, and motorized recreation.

Primary Conservation Elements, Management Implications, and Considerations

In order to adequately protect this species, locations must be recognized and USFS guidelines must be enforced. Further information is needed on this species' life history, microhabitat needs, and sensitivity to disturbance in order to allow for finer-scale management decision-making.

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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). *Oreohelix strigosa cooperi* (Cooper's Rocky Mountain snail) is the focus of an assessment because it is considered a sensitive species in Region 2 (www.fs.fed.us/r2/projects/scp/sensitivespecies/) and a management indicator species (MIS) on the Black Hills National Forest. 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 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. As a MIS, this species serves as a barometer for species viability on the Black Hills National Forest. Managers can use this species 1) to estimate the effects of planning alternatives on fish and wildlife populations (36 CFR 219.19 (a)(1)) and 2) to monitor the effects of management activities on species via changes in population trends (36 CFR 219.19 (a)(6)).

This assessment addresses the biology of *Oreohelix strigosa cooperi* throughout its range in Region 2. 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 available on scientific knowledge. The assessment goals limit the scope of the work to critical summaries of scientific knowledge, discussion of broad implications of that knowledge, and outlines of information needs. The assessment does not seek to develop specific management recommendations. Rather, it provides the ecological background upon which management must be based and focuses on the consequences of changes in the environment that result from management (i.e., management implications). Furthermore, it cites management recommendations proposed elsewhere and examines the success of those recommendations that have been implemented. This assessment does not presume that the species deserves specific conservation status; instead, it provides a summary of information upon which management decisions can be based.

Scope

This assessment examines the biology, ecology, conservation status, and management of *Oreohelix strigosa cooperi* with specific reference to the geographical and ecological characteristics of the USFS Rocky Mountain Region. This document places any literature on this species in the ecological and social contexts of the Black Hills Rockies. Similarly, it is concerned with the behavior, population dynamics, and other characteristics of *O. s. cooperi* 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 in a current context.

In producing the assessment, I reviewed refereed literature, non-refereed publications, research reports, and data accumulated by resource management agencies. Not all publications on *Oreohelix strigosa cooperi* 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) were important in estimating the geographic distribution of this species, but these data require special attention because of the diversity of persons and methods used to their collection.

The assessment was designed as a summary of existing, readily available information, and therefore it does not attempt to revise taxonomy, evaluate museum identifications, or conduct further field surveys for the species. I am aware that a study on the genetics of *Oreohelix* is underway at the University of Colorado, and the results will be highly relevant to this report. However, these data are not yet complete and are therefore not available to address at this time.

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, I note the strength of evidence for particular ideas and describe alternative explanations where appropriate.

In cases where articles or reports make statements without supplying the supporting data, I point out the lack of support for the authors' statements. Discussions of uncertainty involved in 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 be available in the future.

Uncertainty about taxonomic issues is a common problem with mollusks, and this species is no exception. In order for a taxonomic change or a new species to be recognized scientifically, it must be published in a widely-available, peer-reviewed format. Therefore, this assessment is written with the currently-accepted taxonomy in mind, with the recognition that future work may result in changes in species status, distribution information, etc.

Uncertainty also comes into play when life cycle models are discussed. Due to the lack of basic biological information on the species, it is extremely difficult to develop an accurate population model. Since the basic demographic parameters are unknown, mathematical 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. 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 conservation status of this species pertains specifically to Region 2 and does not necessarily apply to species in other areas.

Publication of Assessment on the World Wide Web

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

Oreohelix strigosa cooperi is not included on the federal list of endangered, threatened, or candidate species in the United States (U.S. Fish and Wildlife Service 2003). The Global Heritage status is G5T1, meaning the subspecies is considered critically imperiled, but the *O. strigosa* species is fairly secure (NatureServe 2003). The status of *O. s. cooperi* varies among states within its range. In South Dakota, the species is listed as an S2 species, which means it is vulnerable to extinction in the state (NatureServe 2003). Its status in Wyoming is unknown because invertebrates are not tracked by the Wyoming Natural Diversity Database. However, the Wyoming Game and Fish Department has recently (2005) compiled a list of Wyoming Species of Greatest Conservation Need that includes *O. s. cooperi* (http://gf.state.wy.us/wildlife/CompConvStrategy/index.asp).

In Region 2 of the USFS *Oreohelix strigosa cooperi* is considered a sensitive species, and on the Black Hills National Forest, it is considered a MIS.

Existing Regulatory Mechanisms, Management Plans, and Conservation Strategies

Within the Region 2 of the USFS, only the Black Hills National Forest addresses the management of this species. The management guidelines state the goal is to "ensure that all identified colonies of … *Oreohelix strigosa cooperi* … are protected from adverse effects of livestock use and other management activities" (1997 Revised Forest Plan, Amendment One, Revised Standard #3103).

While the overall goal is adequate to protect this species, more specific guidelines are needed for managers to understand what specific activities may adversely affect this species and what steps might be useful to mitigate impacts. A better understanding of the distribution and ecology of this species is probably needed (see Information Needs section) before mitigation measures can be designed specifically for *Oreohelix strigosa cooperi*. However, guidelines with specific standards for management activities in known snail habitats and directives promoting healthy land snail communities could be designed at the forest level.

Biology and Ecology

Systematics and general species description

Members of the genus *Oreohelix* are pulmonate terrestrial gastropods (i.e., land snails with lungs). They belong to Phylum Mollusca: Class Gastropoda: Order Stylommatophora. The latest edition of recognized mollusk names lists *Oreohelix* species in the family, Oreohelicidae (Turgeon et al. 1998).

Oreohelix species in the Black Hills have an ambiguous taxonomic history. W. G. Binney (1858) originally referred to these animals as *Helix cooperi*. Pilsbry (1939) included specimens from the Black Hills, Cypress Hills in Alberta Canada, and fossil deposits in Iowa under the name *O. strigosa cooperi*. More recently, Frest and Johannes (2002) elevated the subspecies back to species designation and referred to it as *O. cooperi*. This causes confusion with earlier references, where *O. cooperi* sometimes refers to another species that is now called *O. subrudis*. Neither *O. cooperi* nor any subspecies of *O. strigosa* are listed by Turgeon et al. (1998).

Preliminary results from a study of Oreohelicidae in Utah "indicate that the current taxonomy of the land snail *Oreohelix* does not match its evolutionary relationships" (Perez-Losada et al. 2004). Several other recent studies in other western states have proposed new *Oreohelix* species and/or subspecies (Frest and Johannes 1995, Ports 2004). This indicates that the taxonomy of the Oreohelicidae is currently in flux.

Whether the Black Hills specimens are of species or subspecies rank requires a thorough analysis of the entire genus and is beyond the scope of this report. Frest and Johannes (2002) provide a lengthy discourse making the case for full species status based on qualitative descriptions of morphological characteristics, especially shell characteristics. Goodfriend (1986) reviewed several situations in which environmental conditions, such as reduced moisture, affected the shape and size of land snail shells. Regardless of whether this is the case in the genus *Oreohelix*, peer-reviewed presentation of quantitative data on the shell morphology, drawings of internal anatomy, and oftentimes genetic data are required for full-species validation in the modern scientific climate.

The taxonomic entity referred to in this report as *Oreohelix strigosa cooperi* is described in Pilsbry (1939, after Binney 1858) as having a white shell with a reddish-brown band or bands (**Figure 1**). The shell has about five whorls. The outermost whorl is rounded, and the aperture (shell opening) is also rounded. The umbilicus (the depression/opening on the underside of the shell) is one-fifth the diameter of the shell. The peristome (the edge of the aperture opening) is reflected (turned back) at the place it meets the umbilicus. (See Glossary for definitions of terms used in this report). Black Hills specimens described in Pilsbry (1939) range from 9 to 22 mm (0.35 to 0.86 inches) in diameter and 6 to 17 mm (0.23 to 0.66 inches) in height. Frest and Johannes (2002) describe juveniles as having brown shells with 2 to 2.25 whorls at 'birth' and measuring 3.5 to 4.0 mm (0.14 to 0.15 inches) in diameter.

Frest and Johannes (2002) further differentiated Black Hills *Oreohelix strigosa cooperi* specimens from other members of the *O. strigosa* group based on the presence of narrow, irregular striations on the shell. Pictures of these striations compared to other groups are not provided in their report, so it is unclear how distinct these are. Pilsbry (1939) includes other *Oreohelix* groups as also having fine growth lines without much description, so more details are needed to determine whether these patterns are useful diagnostic characteristics.

Pilsbry (1939) also used characteristics of the male reproductive system to distinguish *Oreohelix*

Figure 1. Photograph of *Oreohelix strigosa cooperi* from the Black Hills National Forest. Scale shows 1 cm (1 mm between small lines). Photo by T. Anderson.

strigosa cooperi from other members of the genus *Oreohelix*. He stated that "the anterior third of the penis has about six unequal ribs in the cavity, the remainder being papillose within…" (p. 444). This is consistent with his description of the *O. strigosa* group as having the "[ribbed] portion of the long penis decidedly less than half the entire length" (p. 418). Brandauer (1988) examined penial morphology in *Oreohelix* specimens from Colorado and concluded that these characteristics were not consistently reliable in differentiating between *O. strigosa* and *O. subrudis*. Brandauer apparently did not examine specimens from the Black Hills, so it is unknown whether these characteristics can differentiate between specimens from the Black Hills and other regions. Frest and Johannes (2002) allude to studying the internal anatomy (pp. 83-84). While they state that Pilsbry's dissections are "quite adequate for most species" (p. 82), they do not explicitly describe their methods or their findings on the internal anatomy.

A study currently underway at the University of Colorado examining the genetic relationships among the species and subspecies in the genus *Oreohelix* may help to clarify the taxonomic relationships and place the Black Hills specimens within the context of Oreohelicidae in general.

Distribution and abundance

The genus *Oreohelix* is one of several terrestrial snail genera that are found only in the Western Division of North America, which refers to the mollusks found from the Great Plains west to the Pacific Ocean (Henderson 1931). The genus *Oreohelix* stretches across western North America from southern Canada to southern Arizona and New Mexico (Pilsbry 1939, Bequaert and Miller 1973).

A statement on the distribution of *Oreohelix strigosa cooperi* is intimately tied to how the species or subspecies designation is assigned. Pilsbry (1939) included specimens from the Black Hills, Cypress Hills in Alberta, Canada, and fossil deposits in Iowa under the name *O. s. cooperi*. Fossil records for *O. s. cooperi* exist from Pleistocene deposits in Iowa and Illinois (Frest and Rhodes 1981). Frest and Johannes (2002) consider the Black Hills populations to be the only living populations (**Figure 2**). In South Dakota, *O. s. cooperi* is known from Lawrence and Pennington counties (Frest and Johannes 2002, South Dakota Division of Wildlife 2003). Mollusk distribution is not tracked in Wyoming (Dutcher personal communication 2003), but Frest and Johannes (2002) include Crook and Weston counties

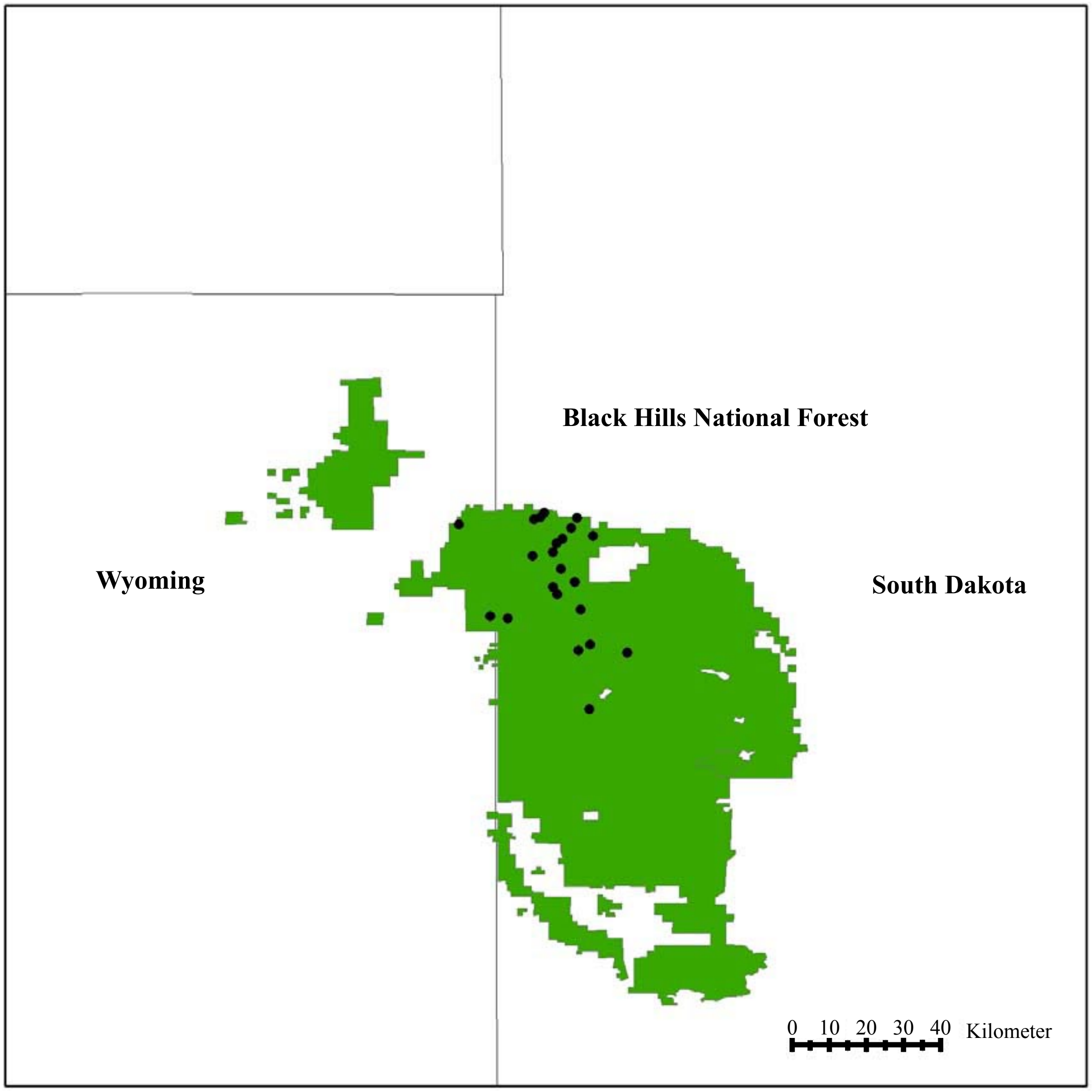

Figure 2. Known distribution of *Oreohelix strigosa cooperi*. Green represents the boundaries of the Black Hills National Forest, the only forest in USDA Forest Service Region 2 with known populations of *O. s. cooperi*. Known locations are represented by black dots.

in Wyoming within the species' distribution. No other states within Region 2 have documented occurrences of *O. s. cooperi*.

Frest and Johannes (2002) reported 39 populations of *Oreohelix strigosa cooperi*, based on collections of living snails as well as shells. Approximately 70 additional locations are assigned to new, unnamed *Oreohelix* species although these taxonomic revisions have not been officially published and accepted. As Frest and Johannes (2002) note, *O. s. cooperi* locations are concentrated in the northern and western sections of the Black Hills. Additional sampling in the southern regions of the Black Hills (Anderson 2003, In press) indicates *Oreohelix* populations do not currently extend throughout the area. Fossil records from the southern Black Hills also do not include *Oreohelix* species among the snail fauna (Theler 1996, Jass et al. 2002).

The change in historical distribution of *Oreohelix strigosa cooperi* (from including at least part of the Midwest to only occurring in the Rocky Mountains) is possibly due to climate changes during the Pleistocene era (Frest and Rhodes 1981). Certainly, natural events, such as fires and landslides, and human-induced, large-scale habitat changes could impact the abundance of snails (see Conservation section for further discussion of these impacts). However, no data are available on the historical abundance of the species to fully evaluate the effects of such historical changes.

The Black Hills populations recorded by Frest and Johannes (2002) are confined to two creek systems, so most individual populations are only separated by less than a few miles. These populations may still be considered isolated if individuals are not able to disperse between them. Information on dispersal of *Oreohelix strigosa cooperi* is not available, but see the Demography section for a discussion of snail dispersal in general.

Outside the Black Hills, the closest known populations of any species of *Oreohelix* are found in south-central Montana and the Bighorn Mountains in Wyoming (Pilsbry 1939, Hendricks 2003). Again, these are not considered the same species by Frest and Johannes (2002). Genetic analysis of the relationship of these groups to the Black Hills specimens could be enlightening.

Population trend

Although some authors speculate that regional *Oreohelix* populations have declined (Brandauer 1988), very little data have been documented. Frest and Johannes (2002, Table 4 therein) suggested that two populations of *O. strigosa cooperi* had disappeared because researchers only found dead shells or because no live snails were found between visits in 1991 and 1999. An additional population reported by Pilsbry (1939) in Deadwood was not relocated in recent surveys (Frest and Johannes 2002). However, these "extinction" observations are subject to the same difficulties as outlined below for trend data, and the sites should probably be re-examined for confirmation.

Pilsbry does not describe population sizes even anecdotally, so there is no basis for comparison with current numbers. The only estimates of population sizes of *Oreohelix strigosa cooperi* for Frest and Johannes (2002) and are summarized in **Table 1**. (Information on other *Oreohelix* in the Black Hills, currently assigned to new *Oreohelix* species by Frest and Johannes, are not included in this table.) Where quantitative numbers are given, the estimates were obtained by averaging the number of live adult snails within 0.25 m^2 (2.7 ft^2) quadrats randomly placed around the site. Where no quantitative values are given, the "Ranges are approximately as follows: rare would indicate less than 1 individual per m^2 [10.8 ft^2]; uncommon, about 1-5 per m^2 [10.8 ft^2]; common ca. 5-10 per m^2 [10.8 ft^2]; abundant 10-20 or more per m^2 [10.8 ft^2]; very abundant = or >20-40 per m^2 [10.8 ft^2]" (Frest and Johannes 2002, pp. 15-16). Each estimate is based on observations from one day. It is unclear whether their estimates only included individuals at the surface, or if researchers overturned loose litter or rocks to search for snails.

Some locations were sampled in multiple years and therefore have more than one estimate. However, it is impossible to make any statements about population trends for two main reasons. First, sites were not necessarily sampled with the same intensity in both years nor were surveys conducted at the same time of year (1991 surveys took place in July, while 1999 surveys occurred in September). Many studies have shown that snail populations vary over time (e.g., Williamson et al. 1977), and although the temporal variation in *Oreohelix strigosa cooperi* in Region 2 has not specifically been studied, it is reasonable to assume they will follow patterns similar to other land snails. Second, although Frest and Johannes (2002) considered both years "wet" and gathered data for quantitative estimates only "during favorable weather conditions", the conditions at a particular site were not necessarily the same in both years. Since moisture and other environmental conditions can affect snail activity levels (see discussions below), snails may not have been equally observable on the two days. More information is needed on population sizes before trends can be determined.

At the regional level, *Oreohelix strigosa cooperi* is only known from the Black Hills. This could change if additional surveys uncover new populations. At the local level, snail populations fluctuate based on weather and time of year. For example, *Discus macclintocki* populations in Iowa fluctuate with moisture levels (Henry et al. 2003). In addition to actual population size fluctuations, activity levels vary with temperature, moisture, and/or time of year, making snails more noticeable at certain times when they are active at the surface rather than aestivating.

Activity pattern and movements

Land snails aestivate when conditions are not favorable. Moist times during late spring through early fall would probably be best for viewing *Oreohelix strigosa cooperi* on the Black Hills National Forest.

Land snails crawl on their muscular foot that extends out of their shell. The amount of dispersal is highly variable among snail species, with larger species generally moving longer distances than smaller species. For example, juvenile giant African snails (*Achatina fulica*), which as adults weigh about 30 g (1.06 oz.), moved up to 500 m (0.31 miles) in six months when released in a study in the Bonin Islands

Table 1. Estimated population sizes of *Oreohelix strigosa cooperi* in the Black Hills National Forest.

Location Number[a]	1991/1992 Population Size[b]	1999 Population Size[b]
1	Rare live	Very rare live
2	Abundant	NS
3	Fairly abundant at base of slope	Abundant at spots, uncommon overall, 2 to 4 per m^2
4	Very rare at base of slope, moderately common	Somewhat abundant, 8 per m^2
5	Moderately common	Recollected, but no mention of population size
6	Very abundant shells, few live	Uncommon live, 2 to 3 per m^2
8	Abundant live	Somewhat uncommon live, 5 per m^2
9	Rare, one live snail	NS
10	Rare shells only	NS
11	Moderately common to rare	Somewhat abundant, 4 per m^2
14	Rare old shells	NS
22	Common	NS
23	Common	NS
24	Patchy	NS
25	More abundant at base	10 to 20 per m^2
26	Rare live	NS
28	Rare shells only	Rare live, 2 to 5 per m^2
31	Uncommon live	NS
43	Rare shells only	NS
46	Rare shells only	None
47	Shells only	NS
48	Shells only	NS
51	Rare live	None
53	Common live	NS
86	Present, but no mention of population size	Confined to certain spots on slope
139	Present, but no mention of population size	NS
142	Very rare	One live snail
143	Rare	Rare, one live, others shells only
146	Mostly shells	Mostly shells, rare live, 1 to 5 per m^2
153	Small colony	Uncommon, 1 to 2 per m^2
154	One snail	Abundant
172	Moderately abundant, rare near creek	NS
213	NS	Uncommon
214	NS	Common
215	NS	Somewhat abundant
227	NS	Very rare
254	NS	Rare, <1 per m^2
332	NS	Mostly dead, <1 per m^2
346	NS	10 to 15 per m^2

[a]Numbers of locations reflect those used by Frest and Johannes (2002).

[b]Estimates are for living snails only, unless otherwise stated. NS= not sampled.

in the Pacific (Tomiyama and Nakane 1993). Adults in their study moved much less. Adult *Theba pisana*, which measure 1.5 cm (0.59 inches) (Abbott 1989), dispersed up to 300 cm (9.83 ft.) over 100 days in a European study (Cowie 1984). Some species are apparently more sedentary, perhaps because of the patchiness of their habitat. For example, studies of the medium-sized (5 mm [0.2 inches]) *Discus macclintocki* in Iowa found that individuals rarely moved even 2 m (6.56 ft.) (Anderson 2000, Henry et al. 2003). Adult *Albinaria corrugata*, which reside on boulders in the Swiss Alps, moved less than 2 m (6.56 ft.) over a one-year period 90 percent of the time (Schilthuizen and Lombaerts 1994). Evidence that juveniles disperse farther than adults was found for *Achatina fulica* (Tomiyama and Nakane 1993), but not for *T. pisana* (Cowie 1984) or *Albinaria corrugata* (Schilthuizen and Lombaerts 1994). Dispersal may also vary with the season, as in *Arianta arbustorum* in the Swiss Alps, which averaged 2.6 m (8.5 ft.) per month in June and 1.1 m (3.6 ft) per month in August (Baur 1986). The genetic neighborhood, the estimated distance moved from birth until breeding, was estimated at 350 m (1144 ft.) for *Meridolum corneovirens*, a rare species in Australia (Clark and Richardson 2002). No information is available for dispersal distances or age differences in dispersal patterns for *Oreohelix strigosa cooperi*.

Snails are also subject to passive dispersal. Snails (*Arianta* spp.) in the Swiss Alps rolled downhill due to gravity, were pushed by avalanches, or were swept away by heavy rains and streams (Baur 1986, Baur et al. 1997). Other studies indicate that streams are major paths for gene flow in snails (Arter 1990, Ross 1999). Movements by rock slides, snowmelt events, flooding, or stream flow could be a factor in moving *Oreohelix strigosa cooperi* among habitats within the same watershed in the Black Hills.

Long-range passive dispersal of snails is likely accomplished with the help of wind and birds (Rees 1965). However, this has not been observed in *Oreohelix strigosa cooperi*, and if it occurs, it is probably a rare event since the species would need to be transported by birds from perhaps as far as the Bighorn Mountains to appropriate habitat in the Black Hills. Therefore, *O. s. cooperi* in the Black Hills are completely isolated from *O. s. cooperi* in other geographic locations (i.e., Alberta), if indeed these other locations are the same species (see discussion above on taxonomy and distribution). Populations within the Black Hills that are on different drainages may be partially isolated if they are separated by inhospitable habitats, unless human activity happens to move the snails between locations. Again, specific information on movements of *O. s. strigosa* is not available.

Habitat

Oreohelix species have not been studied extensively enough to distinguish between habitats used versus those selected, preferred, or required. Also, information is not available on a small enough scale to determine if there are differences between microhabitats needed for foraging versus brooding of young. Therefore, in this section, habitat will refer only to where *O. strigosa cooperi* are found. **Figure 3** and **Figure 4** show types of habitat in the Black Hills National Forest where *Oreohelix* are found.

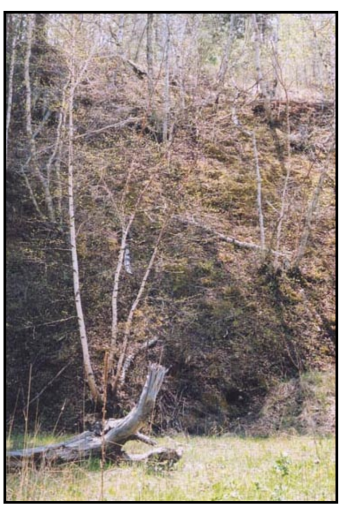

Figure 3. Photograph of habitat where *Oreohelix strigosa cooperi* is located. Photo by T. Anderson.

Figure 4. Photograph of habitat where *Oreohelix strigosa cooperi* is located. Photo by T. Anderson.

Frest and Johannes (2002) report *Oreohelix strigosa cooperi* from forested areas and from talus slopes. They describe habitats with ponderosa pine (*Pinus ponderosa*) as the dominant tree species, but with a strong secondary deciduous tree presence including boxelder (*Acer negundo*) and birch (*Betula* spp.). They also list alder (*Alnus* spp.) as a common deciduous species, which could be a case of mistaken identity with hazelnut (*Corylus* spp.), since alders are not known to occur in the Black Hills National Forest (Burns personal communication 2003) or in the Black Hills area (Larson and Johnson 1999). Frest and Johannes (2002) also mention blue spruce (*Picea glauca*) as a significant component at some sites. They also describe locations in riparian forest that include blue spruce, ponderosa pine, dogwood (*Cornus stolonifera*), horsetail (*Equisetum* spp.), stinking elderberry (*Sambucus pubens*), and willow (*Salix* spp.). Interestingly, Frest and Johannes (2002) do not mention aspen (*Populus tremuloides*) in the habitats with *O. s. cooperi* although other *Oreohelix* species are commonly found in aspen stands in the region (Beetle 1989, 1997). Occurrence in aspen may represent an ecological difference among *Oreohelix* species or subspecies, or it may be that aspen stands in the Black Hills require further evaluation as potential *Oreohelix* habitat.

Soil type also plays a role in determining appropriate snail habitat. Frest and Johannes (2002) state that all of the *Oreohelix strigosa cooperi* populations were found on calcareous soils, supporting the idea that calcium is important for these snails.

The relationship of *Oreohelix strigosa cooperi* habitat to elevation is unclear. Frest and Johannes (2002) do not expressly give elevation range, but they do "indicate that altitude also does not correlate with two common size measures for *O.* [*s.*] *cooperi*" (p. 87). While elevation may not be important for habitat selection within the Black Hills, this may need to be analyzed more closely.

The litter layer is very important to snails for food and shelter. When describing snail habitats in the Black Hills, Frest and Johannes (1991, p. 16) state, "Well-developed litter (but not thick or fungus-matted) was preferable, i.e. areas with very rich and comparatively wet, but loose soil. *Oreohelix* could thrive with relatively little cover and in relatively thin litter; other species were less tolerant. *Oreohelix* tended to avoid the most moist areas, while smaller snails [other species] preferred such habitats." I have observed *Oreohelix* in a wide variety of litter types in the Black Hills, from predominantly coniferous needle litter (**Figure 5**) to litter with a greater deciduous component (**Figure 6**), and even in places with relatively thin litter (**Figure 7**). It is unknown whether the range in litter thickness is compensated by more or less cover provided by overstory vegetation. *Oreohelix* in the Black Hills have also been observed climbing on logs and trees up to 1 m (3.3 ft.) above the forest floor (Frest and Johannes 2002).

No information is available on the relationship of habitat to winter conditions.

Figure 5. Photograph of *Oreohelix strigosa cooperi* on litter with a large coniferous needle component. Photo by T. Anderson.

Figure 6. Habitat with a larger deciduous component. Photo by T. Anderson.

Figure 7. Habitat with less litter and more bare ground. Photo by T. Anderson.

Food habits

Herbivorous snails eat by scraping their radula along food surfaces (see general works on invertebrates, such as Pearse et al. 1987, for more information). *Oreohelix strigosa cooperi* feeds "primarily upon partially decayed deciduous tree leaves and degraded herbaceous vegetation" (Frest and Johannes 2002, p. 88). It is unknown whether *O. s. cooperi* prefers decaying leaves from a particular plant species. Henderson (1924) reports finding *Oreohelix* species "occasionally…feeding upon green leaves, but as a general thing when active I have found them upon dead leaves and decaying wood, from which fact I infer that they feed largely upon minute fungi and perhaps the bacteria of decay, though this has not yet been demonstrated…" (pg. 110). As with most land snails, *O. s. cooperi* also require calcium to successfully build their shells. The calcium can be obtained from the limestone rocks in the habitat. The required foods would be readily available in many, but not all, areas of the Black Hills National Forest. No information is available on whether feeding habits are different between juvenile and mature *O. s. cooperi*.

Breeding biology

Oreohelix are hermaphrodites (Pilsbry 1939). No documented cases of self-fertilization are known for *O. strigosa cooperi*, but this may occur. The breeding biology of *O. s. cooperi* is largely unknown, and indeed information on the breeding biology of *Oreohelix* species in general is very poorly documented. Frest and Johannes (1991) extrapolate from unpublished observations on a different *Oreohelix* species in Idaho to make the following statements, "The snails are seasonally active, with the common periods of activity being April-June and September-November. In many cases, breeding takes place in October-November or by April-May, and young are shed in May-June or

September-October. When conditions allow, snails are also active in winter, and many are quite resistant to freezing. The young hatch internally (egg laying is characteristic of most land snails) and can be retained in the adult for some time after internal hatching. … Breeding is annual, and growth to adulthood commonly requires just under one year. Normal lifespan is less than two years in the wild, but some adults may survive for longer time periods. …the stress of reproduction and birth is not necessarily fatal for *Oreohelix*" (pp. 3-4).

Frest and Johannes further expand in their 2002 report that "it seems likely that most individuals mature in little longer than one-two years, and that most breed at least once, as noted. Many may live 2-6 years and hence could be multiple breeders (annually or semiannually iteroparous). Under the extremely wet conditions in June, 1992, many individuals were active and some copulation was observed. It is possible that under such circumstances young could be released twice in the same year; but the population structure at the localities we collected does not support this" (p. 88). Their observations of breeding in June 1992 could also represent differences between the yearly activity of Idaho *Oreohelix* species and *O. strigosa cooperi*. They do not report data to support their life history statements, so it is unclear how they determined the life span and whether individuals breed more than once. Their observations are consistent with opportunistic breeding, so that in a moist year breeding might occur more than once.

Frest and Johannes' statements on the rate of maturity contrast with other work. Beetle (1987) studied individuals of the related species, *Oreohelix subrudis*, collected from Fremont County, Wyoming. These individuals were kept in captivity and allowed to mate and produce offspring. From three to 16 snails were born in each of seven broods. The adults died a week or so after giving birth. None of the offspring survived longer than six weeks. Beetle stated that nematode infection may have caused the juvenile deaths. However, she did not rule out other factors due to conditions in captivity such as the plastic containers in which they were stored or their diet, which included lettuce, aspen and willow leaves, rabbit pellets, cucumbers, and paper.

Beetle (1987) also tracked growth rates of wild-collected juveniles over two years in captivity. The results showed that growth rates varied among individuals. In addition, after two years in captivity, the juveniles had not reached the average shell size found in the wild, leading Beetle to speculate that three years may be necessary to reach adult size. Whether that is related to an individual's ability to reproduce is unknown. Also, whether the results would be different in the wild is unknown. These two sources come to such different conclusions that the questions of rate of maturity, life span, and number of breeding periods will require further work to arrive at a satisfactory understanding.

No information is available on breeding site fidelity or dispersal of young. No information is available on how brood size or other breeding biology might vary geographically or as individuals age.

As mentioned above, Frest and Johannes (1991, 2002) suggest some parameters for the breeding periods of *Oreohelix strigosa cooperi*. Although more study would be useful to refine these time periods for different populations, it is likely that the population would be most sensitive to disturbance at these times from management activities or natural disturbances. It may be necessary to conduct monitoring during active periods, but if actual breeding periods can be separated from other active periods, perhaps the monitoring could be scheduled around the breeding times.

Demography

Population dynamics are determined by rates of survival and reproduction, life history characteristics, and movement in and out of the population. If specific data can be gathered on the demography of the species, management and monitoring is much easier. Unfortunately, most of this information is not available for mollusk species. In addition, the small size and patchy nature of many mollusk populations create other concerns.

Genetic characteristics and concerns

Small, isolated populations of animals are subject to inbreeding, which can lead to decreased genetic diversity and possibly reduced fitness and even extinction in the long run (Saccheri et al. 1998). Snail colonies are likely to be somewhat isolated from one another, so inbreeding could become an issue. However, if isolated colonies are the norm for the species and/or if selfing is common, then the species may not be affected by lower genetic diversity. A study of the genetic diversity within *Oreohelix strigosa cooperi* is not available.

Genetic study of another member of the genus *Oreohelix* has been conducted and is discussed here to illustrate the utility of such data. Rees (1988) used allozymes to examine variation at three loci in both *O. strigosa* and *O. subrudis* at two different locations. Each species had different alleles at the three loci. *Oreohelix strigosa* (n = 68) showed no variation within or among populations for those three loci. *Oreohelix subrudis* (n = 28) showed variation within populations at one of the three loci. These results show that genetic variation can clearly be used to differentiate among species. However, the lack of variation within populations may have several explanations, including selfing, selection, or fixation due to a small population size at some point in history. Studies of the genetics of *Oreohelix* in the Black Hills will allow an understanding of whether distinct species exist and what amount of diversity exists within the species.

Future studies on genetic diversity in *Oreohelix* species are likely to be in the form of DNA sequence data. Studies of DNA sequence variation for many snail species show extremely large amounts of variation in the mitochondrial DNA gene 16S (Thomaz et al. 1996, Ross 1999). Ross (1999) concluded that with such a large amount of genetic diversity and proper protection of populations, the endangered snail, *Discus macclintocki*, had "a good chance of surviving" in Iowa. Should genetic variation be present within Black Hills populations of *O. strigosa cooperi*, then concern over reduced genetic fitness is alleviated.

Hybridization

It is unknown if *Oreohelix strigosa cooperi* hybridizes with any other species. Since *O. s. cooperi* rarely comes into contact with any other *Oreohelix* species (Frest and Johannes 2002), it would not often have the chance to hybridize. However, cryptic species and/or subspecies may exist.

Life history characteristics

No information is available on recruitment, survival, immigration, or emigration rates of *Oreohelix strigosa cooperi*. Age of first reproduction could be anywhere from one to three years, as discussed above. Actual field data on age at first reproduction are not available. The proportion of the population that is breeding and the characteristics of non-breeders are unknown.

A life-cycle diagram is shown in **Figure 8**. This diagram is tentative because several aspects of the life history of *Oreohelix strigosa cooperi* are unknown. For example, the age at first reproduction is unclear and likely depends on environmental conditions. Furthermore, authors' views of reproduction cycles range from Beetle (1987) suggesting death of the adult after giving birth to Frest and Johannes (2002) who state multiple broods in a year may be possible. Frest and Johannes (2002) suggest individuals mature in one year or less while Beetle (1987) suggests three years may be required. This life cycle diagram is a stage-based cycle (Caswell 2001) because maturity is not necessarily a standard time frame and probably varies with environmental conditions. The three stages of the life cycle shown are 1) sub-adults or juveniles, 2) mature, reproductive adults, 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

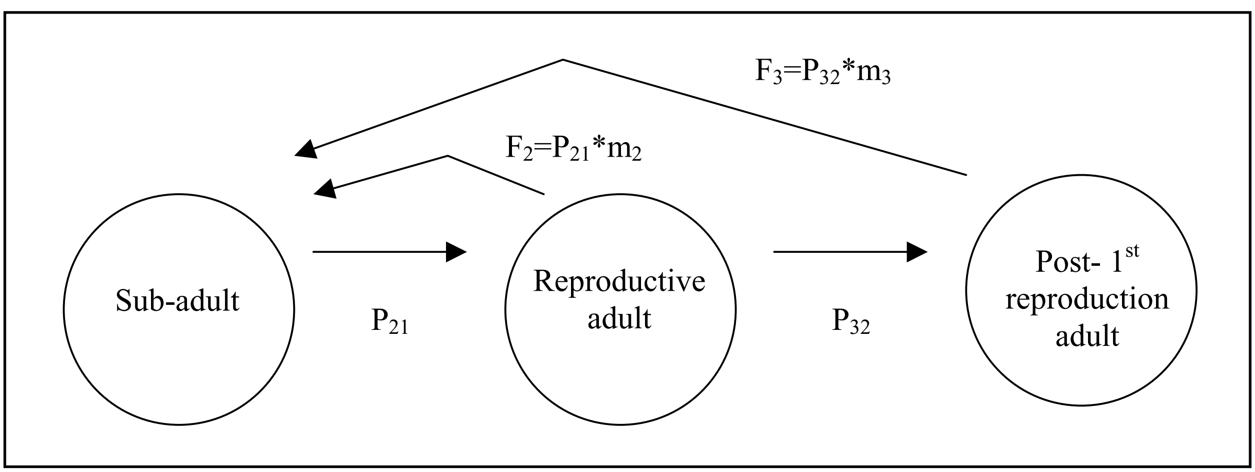

Figure 8. Life cycle diagram for *Oreohelix strigosa cooperi*.

the adult stage (P_{21}). Should numerical data become available in the future for survival and productivity of *O. s. cooperi* at these stages, this diagram could be used to construct a demographic model could be constructed (after McDonald and Caswell 1993, Caswell 2001).

A demographic matrix (Caswell 2001) is not provided for *Oreohelix strigosa cooperi* because of the multitude of unknown factors for this species. As previously mentioned, the fate of adults after breeding is unclear, so the life cycle itself is uncertain. The differences in what authors have suggested would actually change the life-cycle diagram itself, not just the numbers in the matrix. For example, based on Beetle's (1987) data, the post-reproductive class is basically absent. With Frest and Johannes' (2002) ideas, not only is the time to maturity (P_{21}) much less, but mature adults reproduce multiple times and live for several years. Caswell (2001, pp. 60-62) provides an example of an incorrect life-cycle diagram for a plant species where an extra stage in the diagram produced a population growth rate (λ) estimate of 1.8 when the correct diagram estimates $\lambda = 2.4$. In addition, no life tables are available for this species from which to obtain values for survival rates. The only surveys available give ranges of densities for the population and do not break the information into mature and immature individuals. Life table information is not available for any other species in the genus either. Some authors assign values for missing stages to obtain a stable growth rate of 1. However, because 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 (see discussion on population size estimates). No Population Viability Analysis models are available for this species either.

Ecological influences on survival and reproduction

Snails are heavily influenced by environmental conditions. They aestivate in unfavorable conditions, which can extend the time to maturity and/or the time between breeding periods.

Social spacing

No information is available on whether *Oreohelix strigosa cooperi* individuals have territories or what the home range of an individual snail might be. Rough estimates of densities reported by Frest and Johannes (2002) range from less than one per m^2 (10 ft^2) to large colonies of 10 to 20 snails per m^2 (10 ft^2).

Patterns of dispersal

No information is available on the dispersal patterns of *Oreohelix strigosa cooperi*. A general discussion of snail dispersal is found above in the Activity pattern and movement section.

Spatial characteristics

Populations of *Oreohelix strigosa cooperi* in the Black Hills National Forest are usually separated by less than a few miles. The degree to which these populations are isolated depends on their dispersal patterns, which are largely unknown. Forthcoming information from a genetic study may provide further information on how the Black Hills individuals are related to *Oreohelix* populations elsewhere.

Factors limiting population growth

Studies that directly address limits to population growth of *Oreohelix strigosa cooperi* are not available. However, it is likely that populations are generally limited by changes to their habitat that affect the temperature, moisture level, amount of shelter, or type of food available. Increased temperature and/or decreased moisture in the habitat will increase the amount of desiccation in the snails. Decreased litter layer or change in the vegetation components of the litter may decrease the shelter the snails have, not only from predators, but also from desiccation. Changes in the type and/or structure of vegetation in the area will affect not only the temperature and moisture, but also the amount of litter and food available.

Community ecology

Almost nothing has been published about the community ecology specific to *Oreohelix strigosa cooperi*. Therefore, this section draws on information from other terrestrial land snail species.

Predators

Snails are prey for some birds (Ehrlich et al. 1988) and rodents. Other invertebrates may also prey on snails. Which vertebrate and invertebrate species in the Black Hills utilize *Oreohelix strigosa cooperi* and how much pressure predation puts on the snail population is unknown.

Competitors

Presumably other snail species and other small herbivorous invertebrates may compete with *Oreohelix strigosa cooperi* for food. Since *O. s. cooperi* rarely co-occurs with any other *Oreohelix* species (Frest and Johannes 2002), they apparently do not compete against other *Oreohelix*. However, cryptic species and/or subspecies may exist. There is no evidence that competition is limiting the species' range.

Parasites and disease

Several snail species in the region (in the genera *Euconulus*, *Gastrocopta*, *Pupoides*, *Pupilla*, *Vallonia*, and *Vertigo*) are known to be secondary hosts for parasites such as lungworms that infect sheep (*Protostrongilus* spp.) and rabbits (*P. sylvilagii*) (Thorne et al. 1982). However, no reports of these parasites infecting *Oreohelix* species are known. It is unclear whether this is because *Oreohelix* species are somehow resistant to infection, or whether *Oreohelix* species have just not been in the areas where the studies have occurred. Because some *Oreohelix* populations are found in riparian woodlands, it is likely that they may come into contact with deer, elk, or livestock feces that might be infected with parasites, so the opportunity for infection is there. Beetle (1987) indicated that nematodes were factors in the death of juvenile *O. subrudis* in captivity, but she did not mention the species of nematodes. This may be an example of an opportunistic infection and may or may not occur in nature. The mortality rate of snails in the wild due to parasite infection is unknown.

Symbiotic and mutualistic interactions

Symbiotic and mutualistic interactions with *Oreohelix strigosa cooperi* are unknown.

Envirogram

An envirogram showing the hypothesized important relationships for *Oreohelix strigosa cooperi* is shown in **Figure 9**. Envirograms (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 *O. s. cooperi*. 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, food, cover, calcium, and moisture are essential for the snails to survive. Predation, desiccation, and habitat loss are shown as having negative impacts on *O. s. cooperi*.

CONSERVATION

Threats

Snails face many potential threats to their survival. The disturbances that occur in the region are treated individually below. In most cases, the effects of management activities on *Oreohelix strigosa cooperi* have not been directly tested, so information from other snail species is summarized and the relationships to *O. s. cooperi* are discussed below. Management activities can affect snail populations directly or indirectly through habitat degradation, and both types of effects are discussed. The discussion of the management activities below focuses on how these activities may potentially impact snails and their habitat. 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.

Fire

Although fire is a natural disturbance with which *Oreohelix strigosa cooperi* has presumably evolved in the Black Hills, there are still potential concerns regarding how the species may recover from natural and prescribed fire events. With minimal dispersal abilities, individuals may not be able to move to other suitable areas after a fire. Any additional barriers to dispersal (i.e., roads) or loss of habitat further complicate recovery of populations.

Wild or prescribed fires can potentially eliminate essential habitat for the snails. Snails might potentially survive low intensity fires under cover, but locations of high intensity burning would be detrimental. Ponderosa pine stands in the central Black Hills historically had fire intervals of about 20 years (Brown and Sieg 1996). This type of frequently burned habitat did not have the fuel load to support high intensity fires (Schoennagel et al. 2004). However, changes in forest management and drought conditions have led to fuel buildup in recent decades, which does allow high intensity fires in these areas.

Formal studies of the effects of fire on *Oreohelix strigosa cooperi* have not been conducted. Some known populations of *Oreohelix* (assigned to a new

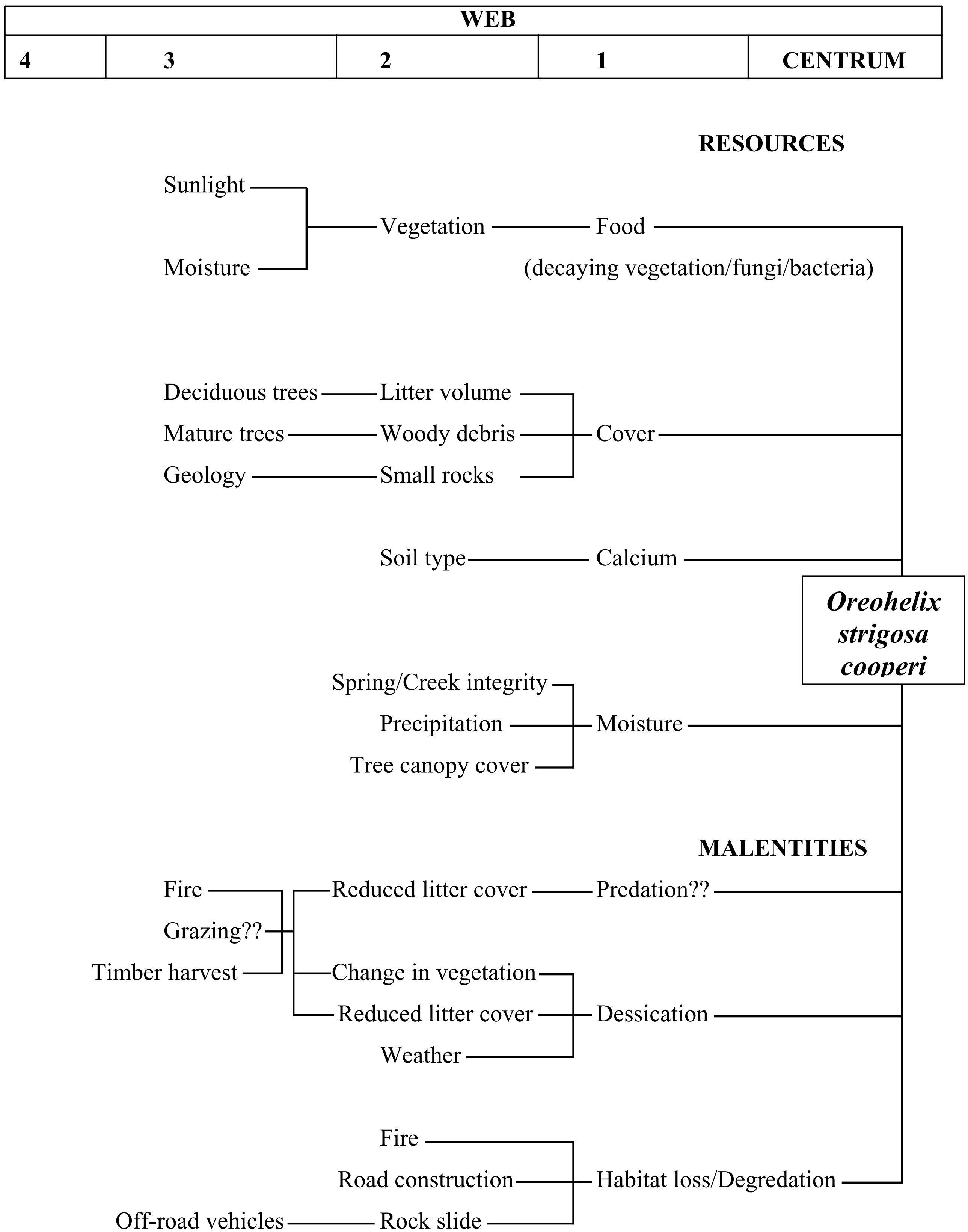

Figure 9. Envirogram for *Oreohelix strigosa cooperi*.

unnamed species by Frest and Johannes 2002) are located within areas that have been burned in wildfires over the last few years (**Figure 10**). No live snails of any species were found at five locations within the perimeter of a burn that occurred in 2000. The fire resulted in a typical mosaic with more and less severely burned areas, and it is unclear how severe the fire was at these specific sites. The sites were re-surveyed by USFS personnel in 2001 or 2002 (Burns personal communication 2003). However, these visits were not sampled multiple times, so more information is needed to conclusively say the snails are no longer present. The long-term effect of the fires on these populations has yet to be determined because the snail's ability to re-colonize is largely unknown.

No other information is available about *Oreohelix strigosa cooperi* specifically. What follows is a summary of information drawn from studies on other species. Little information is available about the effect of fire on snails, and the available data give conflicting conclusions.

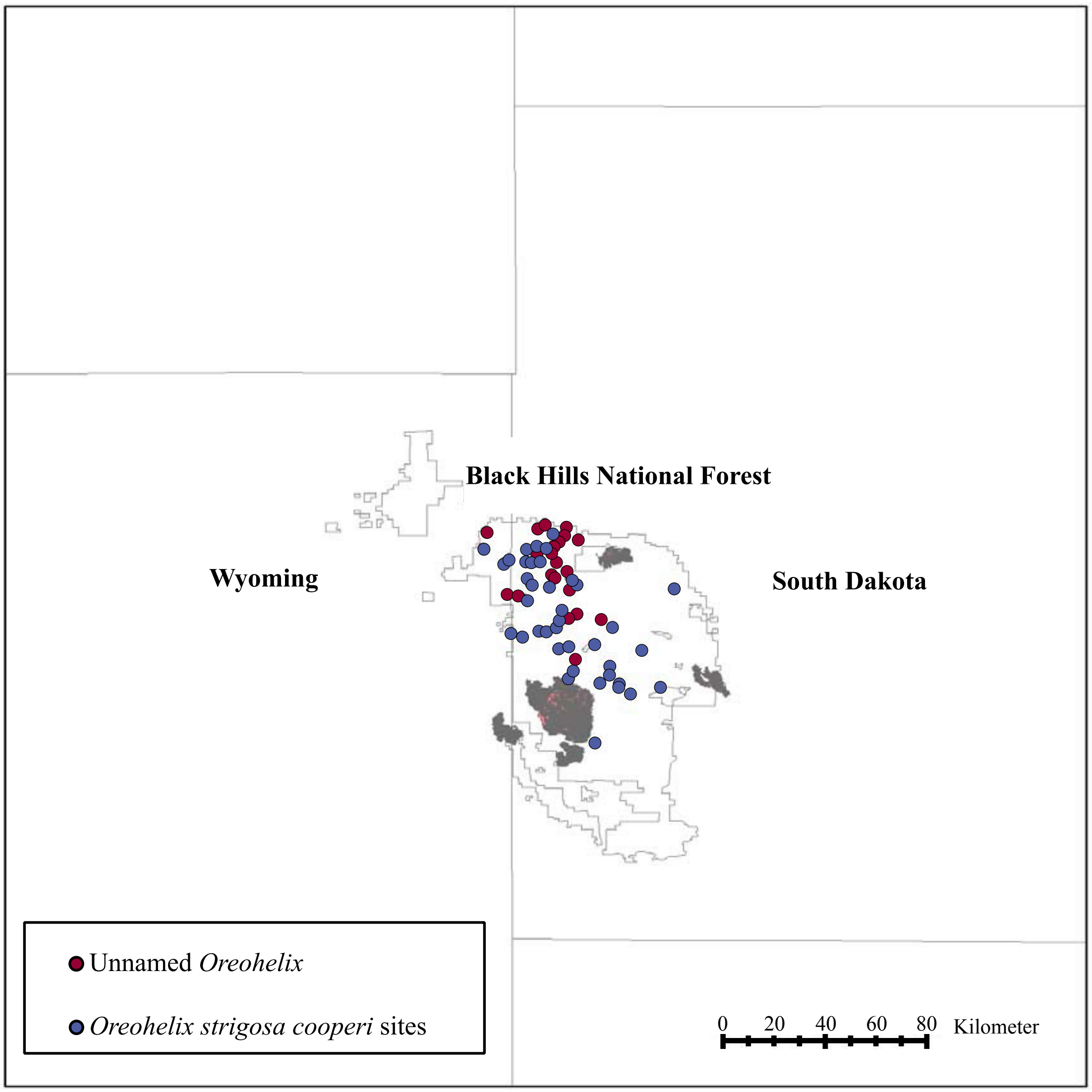

Figure 10. Recent large fire in relation to known locations of *Oreohelix strigosa cooperi* and other *Oreohelix* in the Black Hills National Forest. Several large fires have occurred in the Black Hills in the last three years. The area burned in these fires is shaded in gray on the map. Some *Oreohelix* sites are located within the boundaries of these burns. Additional unnamed *Oreohelix* locations are located within the Bear Lodge region (the isolated chunk of forest northwest of the main section of the Black Hills National Forest), but these are not included on the map and have not been affected by fires. (Fire boundaries and snail location GIS layers provided by Black Hills National Forest personnel.)

Strayer et al. (1986) studied forest sites in Maine that had burned at least three years before the study began. They found no significant evidence that fires permanently affected the snail community in the forest. Several factors make it difficult to apply these results directly to western forests. First of all, the burned sites were small (Strayer et al. consider them to be small, but do not give actual sizes) and within a landscape of forest from which they could be recolonized. Secondly, the deciduous component of the Maine forest is greater than the deciduous component in most western forests. In general, eastern forests are moister than western forests. Also, it is not clear how intense the fires were in this study. Small, low-intensity fires may have quite different effects than the severe wildfires in the western forests.

Ruesnik (1995) studied the snail community in England's chalk grasslands. These areas are heavily managed with grazing, mowing, and some burning. In this area, the variation in management strategies among sites allowed the survival of a variety of grassland species. However, some change-over in species composition did occur at some sites. Some non-grassland species were present in the site with both burning and grazing, but the burning had occurred more than 40 years previously. Unfortunately, the set-up of this study does not allow any conclusions to be drawn specifically about burning apart from mowing.

In contrast to the effects of fire discussed above, Beetle (1997) found that fires had a major impact on snails in Yellowstone National Park. This study focused on moist aspen groves. Beetle searched for snails in burned and unburned aspen groves over a five-year period following the 1988 fires. In the year following the fires, she found fewer individual snails and fewer species in the burned areas than in the unburned areas (the article does not give specific numbers or results of any significance tests). The number of species found in the burned areas declined further in subsequent years. A severely burned grove, where all aspen litter burned, had no living snails five years after the fire. Beetle comments that aspen groves in Yellowstone are fairly isolated, which makes recolonization difficult.

Karlin (1961) found no snails in Montana coniferous forests five years after a fire, where "replacement by lodgepole pine, aspen, and larch was well initiated" (p. 65). Snails were present in stands burned 23 years previously in areas "with burned stumps of alpine fir and the Engleman spruce which were being replaced by lodgepole pine and aspen" (pp. 64-65). Richness and abundance of many snail species were significantly reduced on burned grassland sites in the Midwest (Nekola 2002). The effects differed among species depending on their ecological preferences. In France, Kiss and Magnin (2003) found that diversity and abundance of snails decreased after fires, but the type of habitat influenced which species survived. For example, areas with rocks did not burn as intensely, so snails at those locations tended to survive in higher numbers. In addition, oak (*Quercus pubescens*) stands had deep litter that encouraged the presence of *Pomatias elegans*, but it apparently could survive the fires by burrowing deeper into the soil than other species.

Kiss et al. (2004) found that the composition of snail communities in France was not affected under low intervals of fires. They presume that the snails are able to survive in small refuges. The overall community composition was more influenced by geography than by fire disturbance in these sites. However, in areas where regular disturbance (fire and/or other anthropogenic disturbances that altered the landscape) occurred over decades or longer, the snail community shifted to species more specialized to dry areas. No *Oreohelix* species were included in this study.

A study in an agricultural area of Germany found that the number of live snails is reduced by more than 50 percent after controlled winter burning (Page et al. 2000). They also found that small snails have difficulty recolonizing burned areas.

How snails recolonize areas after fires is still not clear, but presumably their refuges are critical sources. Although specific refuge areas are not known, presumably they would include moist areas with deciduous litter, such as aspen areas. Unless future information suggests that *Oreohelix strigosa cooperi* individuals are able to survive low-intensity fires or are able to disperse to regularly recolonize depleted areas, extreme care should be used to minimize burning in areas where they are known to reside.

Roads

Although no studies specifically address *Oreohelix strigosa cooperi*, road building can negatively affect snails in several ways. First, the physical process of construction can eliminate snail habitat and/or kill snails immediately. Brush clearing or weed spraying along roads for maintenance could also damage snails and/or their habitat. Several known locations of *O. s. cooperi* are located near roads (see Frest and Johannes 2002) and are especially susceptible to these activities if not noted by road crews.

In addition, roads may change the natural distribution or movements of snails. Some snail species have been shown to avoid roads (Baur and Baur 1990, Meadows 2002), which may further isolate populations. Meadows (2002) found that the road avoidance exhibited by *Oreohelix peripherica wasatchensis* was due to the absence of leaf litter, so even small paths (the smallest measured in Meadows' study was 0.7 m wide) have an effect if no litter is present. Roadsides resurfaced with limestone actually attracted higher masses of snails in a Kentucky forest because they provided calcium that was in short supply elsewhere in the low-pH environment (Kalisz and Powell 2003).

Timber harvest

No specific data are available related to how *Oreohelix strigosa cooperi* responds to timber harvest. A sensitivity model developed for an Australian carnivorous snail, *Tasmaphena lamproides*, indicates that snail populations will remain viable longer in areas where clearcutting occurs if contiguous forest areas are maintained to allow dispersal (Regan et al. 2001). The relevance of this model to *O. s. cooperi* is unknown because dispersal rates are unknown and *O. s. cooperi* appears to have a naturally patchy distribution (i.e., it is usually found in areas with some deciduous component rather than in the ponderosa pine that makes up the majority of the forest matrix – see habitat description above).

A study in riparian boreal forest in Sweden showed decreases in the number of individuals and the number of species of snails in clearcut areas (Hylander et al. 2004). Wet sites with enough moisture to allow bryophyte layers to survive clearcut activities did not show a decrease. When buffer strips were left 10 m on either side of the stream, species were retained although the number of individuals decreased.

Clear-cutting is not generally done in the Black Hills National Forest where *Oreohelix strigosa cooperi* lives. Specific data on the effects of other types of silvicultural treatments are unknown. However, it is logical in a species that depends on microhabitat conditions that any action affecting the amount of litter, soil moisture, or temperature would negatively impact snails at that location.

In addition to the effects of the actual removal of the overstory vegetation, other aspects of logging activities could potentially affect snail habitat. For example, compaction of soil from heavy equipment could potentially crush snails. Disturbance or removal of ground vegetation, litter, decaying logs, or rocks may also reduce the cover available for the species. No studies are available that address such effects.

Grazing

Grazing also has a potential effect on *Oreohelix strigosa cooperi*. Although grazing animals have lived in the area historically, livestock grazing could potentially affect snail populations if livestock crush snails directly or if their trampling changes the habitat or dries up springs, thereby changing the moisture regime. Fleischner (1994) reviewed many studies of the effects of grazing in riparian habitats in the western United States. Although not specifically addressing snails, the potential effects he discussed that are relevant to soil organisms near streams include increased soil compaction, increased soil temperature due to vegetation removal, removal of soil litter, and changes in vegetation.

Frest and Johannes (2002) indicated that *Oreohelix strigosa cooperi* were generally absent from grazed areas. Individual *O. s. cooperi* sites likely vary in their susceptibility to the effects of grazing. Sites not within grazing allotments and extremely steep sites are not likely to be used by cows. Sites near springs or on relatively level ground may be more susceptible to negative grazing effects.

Very few scientific studies have addressed the effect of grazing on snails. Morris (1969) found fewer snails in grasslands grazed by cattle than in ungrazed grasslands in Britain. The response was species-specific, depending on how sensitive the species was to the more xeric conditions following grazing. One species increased in abundance by one in grazed areas, two species showed equal numbers, and seven species had higher abundances in ungrazed areas -- including four species found exclusively in the ungrazed areas. Ruesnik (1995) also found similar differences in the snail communities in grazed and ungrazed areas.

Motorized recreation

No information is available on the effects of motorized recreation on *Oreohelix strigosa cooperi*. Motorized recreation that creates new roads or bare paths will essentially create new barriers for the snails, as do existing roads. (A discussion of the effects of roads is given above.) Off-road recreation could also be destructive to snail habitat or to the snails themselves if the activity occurs directly in the habitat area. Off-road motorcycles were shown to have trampling effects on vegetation such as increased percent of bare ground and increased trail width and depth in forest habitat in Montana (Weaver and Dale 1978). Soil compaction was also demonstrated to occur from off-road vehicle use in desert shrubland soils in Nevada (Lei 2004). Direct effects of trampling on snail communities have not been studied, but it could potentially affect the amount of moisture in the soil.

Individual snail locations most likely vary in their susceptibility to the effects of grazing. Although extremely steep locations are probably the most fragile, they are probably not used for motorized recreation. Moderately steep locations may be the most susceptible because they may be the most attractive for off-road vehicles, especially if the tree cover is sparse.

Non-motorized recreation

No information is available on how *Oreohelix strigosa cooperi* responds to non-motorized recreation. No studies have investigated the effects of non-motorized activities directly on snail populations, but some information is available that suggests some indirect effects of such activities on soil and/or vegetation. For example, Weaver and Dale (1978) showed that horses and, to a lesser extent, hikers did cause trampling effects in forest habitat in Montana. These trampling effects included an increased amount of bare ground and increased soil compaction. These effects were more pronounced on slopes than on flat areas. Hiking and bicycling also increased soil compaction in desert shrubland habitats in Nevada (Lei 2004).

Such off-road recreation could potentially be destructive to snail habitat or to the snails themselves if the activity occurs directly in the habitat area and snails are crushed. Individual snail locations most likely vary in their susceptibility to these effects based on their geography and/or topography. Extremely steep, cliff-like habitats are probably not commonly used for this type of activity, but they could be susceptible to rockfalls that may alter the snails' habitat. Moderately steep locations may be most affected, especially if trails are nearby.

Blowdown

No information is available on how *Oreohelix strigosa cooperi* responds to blowdown events. Although a falling tree could potentially have an immediate effect on a snail colony, a blowdown event would probably have a larger effect due to habitat change. A blowdown that removes most of the overhead canopy will change the temperature and moisture regimes at that location, thereby affecting the snails present.

Mining

Frest and Johannes (2002) report negative effects of mining based on the absence of a colony at Deadwood that was previously reported by Pilsbry (1939). No other information is available on the effects of mining on *Oreohelix strigosa cooperi*. However, mining operations that remove vegetation and/or the underlying soil structure of a site would likely have a negative effect.

Weed treatment

No information is available on the response of *Oreohelix strigosa cooperi* to herbicide treatments. However, because the snails are in such close contact with ground vegetation and soil, it is likely that they ingest any herbicide chemicals applied to the area and may be negatively affected.

Exotic species

No information suggests that *Oreohelix strigosa cooperi* interacts strongly with any exotic species currently present in the Black Hills. Unless an exotic plant species outcompetes plant species that provide significant litter utilized by the snails or contains some toxin for the snails, it is unlikely that exotic plants would be a factor. Therefore, logically, exotic species do not currently pose a threat to this species.

Over-utilization

No information suggests that commercial, recreational, scientific, or educational purposes threaten the species. Scientific collection in the well-known Spearfish Canyon locations is regulated by collection permits issued by South Dakota and is evaluated on a case-by-case basis.

Conservation Status of Oreohelix strigosa cooperi in Region 2

Distribution and abundance of *Oreohelix strigosa cooperi* may be declining in localized areas of the Black Hills due to recent fire activity or other localized disturbances. However, this has not been definitively demonstrated.

Because snails have limited dispersal ability and are sensitive to temperature and moisture conditions, they are vulnerable to habitat changes. Environmentally stochastic events, such as fire and trampling, can eliminate local populations from an area, and recolonization is difficult because of the limited dispersal ability of snails. Current management guidelines in the Black Hills National Forest attempt to protect areas known to be snail habitat. However, some management activities such as road building, weed spraying, or timber harvesting may negatively affect local populations, and care should be taken when these are conducted near snail populations. As long as habitat is mapped, management activities take into account the presence of snails, and representative populations are monitored, the species can probably be conserved. However, it is unlikely the species will not be able to adjust if large portions of its current habitat are eliminated.

Potential Management of Oreohelix strigosa cooperi in Region 2

Implications and potential conservation elements

Much of the basic biology of *Oreohelix strigosa cooperi* remains unknown, and without detailed information on microhabitat requirements and life history of this species, it is impossible to state the effects of management activities with certainty. The discussion here is based on the limited information on *O. s. cooperi* that is available, supplemented with information on other snail species.

Consequences of environmental change

Snails are generally susceptible to activities that modify their preferred habitat and/or change the temperature and moisture at the soil or litter level. Additional microhabitat conditions (e.g., soil type, type and amount of plant ground cover, soil pH, depth and type of litter, amount of cover from rocks or woody debris) also play a role in where the snails can survive. Therefore, activities that significantly change these factors in the snails' environment are likely to affect the abundance and/or distribution of the species. However, specific tolerances of *Oreohelix strigosa cooperi* are unknown, so it is only possible to discuss theoretical effects.

Management activities that remove canopy cover, such as timber harvesting, can increase soil temperature and reduce moisture levels, causing snails to dry out and possibly die (a major cause of death for snails is desiccation [Solem 1984]). Even harvesting timber near a snail colony could potentially lower the moisture levels, so a buffer area is probably required. Data on how small of a temperature or moisture change affects *Oreohelix strigosa cooperi* and how wide of a buffer area is necessary are not available but should be investigated. The amount of litter or other cover, elevation, aspect, and other microhabitat conditions may also affect soil temperature, and therefore, the width of buffer needed may vary among sites.

Activities that change the amount of ground vegetation and/or litter directly, such as fire, grazing, and understory management practices, can eliminate food and/or cover for the snails. Snails may be at immediate risk from these practices through trampling or burning, but these changes may also make the habitat unsuitable at least for the short term, and possibly for longer time periods if substantial changes are made. Data on how much litter and what species of ground cover are required by *Oreohelix strigosa cooperi* are not available, but these should be investigated.

Activities that fundamentally change the structure of the talus or cliffs (e.g., road building or other structure development, severe off-road motorized recreation, mining, gravel quarrying) can eliminate shelter for the snails. This may lead to increased exposure to predators or increased risk of desiccation. Activities that damage springs or otherwise change the moisture regime at a site can affect the amount of soil moisture available to the snails. This may affect the population size or distribution of a colony.

Page et al. (2000) provide several recommendations for prescribed burns in European snail habitat. Burns should be planned for the time of year during which all snails will be hibernating (i.e., temperatures -10 ^{o}C [+14 ^{o}F]). They also recommend fast fires to minimize effects on snails. Lastly, they recommend a minimum burn interval of three years, but they note that small snails may require longer to recolonize areas. Killeen (2003) suggests that although many fires are likely detrimental to snails, rapidly moving, spring fires that do not destroy the roots of plants have not affected populations of *Vertigo moulinsiana*.

Chemicals applied to an area, such as herbicides or fire retardant chemicals, may be ingested by snails. If chemicals cannot be avoided, Burke (1999) recommends that they be applied during dry times, when snails are less likely to be active at the surface.

Desired environmental conditions

Specific tolerances of *Oreohelix strigosa cooperi* are currently unknown, so this discussion represents a conservative understanding of desired conditions. The desired conditions should be revised as more information becomes available. Conditions differ among individual snail colonies, so management strategies must be evaluated on a colony-to-colony basis, until such time as general tolerances are understood. The most conservative management approach would attempt to keep the current conditions at each location with regards to talus structure, moisture regime, vegetation species composition, canopy cover, and amount of ground cover. These conditions should be maintained for as long as populations are relatively stable. Should a downward trend be noted, then other management approaches may need to be invoked to establish conditions more similar to sites where populations are stable.

Strategies to conservatively manage the snails could include:

- ❖ eliminating any management activities within the boundaries of the known snail colonies
- ❖ fencing colonies or restricting activities in areas where motorized off-road recreation is common
- ❖ educating the public on low impact recreation practices.

Buffer areas around known snail colonies should be of sufficient width so management activities nearby do not change the temperature and moisture levels at the snail colony. Because many colonies are located on steep locations where management activities and recreation do not normally occur, no action is probably required for such sites. Less conservative management strategies, for example eliminating the need for fences, could be sufficient if monitoring or other studies showed activities were having no effect on the snails or their habitat. Eliminating all disturbances at all colonies will not be possible since some activities are not under the control of managers (i.e., wildfire). In such cases where disturbance does occur, the snail population should be monitored, and restoration approaches should be developed if necessary.

In cases where vegetation restoration is necessary because individual snail colonies are decreasing, care must be taken to not further disturb the underlying structure of the site while attempting to improve it. Increasing the deciduous trees and/or shrubs in order to increase the deciduous litter component at sites with declining populations may be helpful. For sites in riparian areas, restoring stream flow to maintain moisture levels may be helpful. Repairing damaged mosses or reforesting areas to increase canopy cover may also be helpful. However, without further information on specific microclimate preferences, it is impossible to recommend specific amounts of deciduous material needed for restoration.

Tools and practices

Oreohelix strigosa cooperi has not been extensively studied. However, methods used for studying other snail species generally apply to *O. s. cooperi*, and these are discussed here.

Inventory and monitoring

Inventory and monitoring involves four separate aspects: species inventory, habitat inventory, population monitoring, and habitat monitoring. Each of these will be addressed separately.

Species inventory involves general surveys to determine the distribution (presence/ absence) of the species. Species inventories are commonly done either by hand-searching the vegetation and litter for snails or by collecting litter/soil samples and sifting through them at a later time. Sampling has also been done using cardboard cover boards as “traps” (Hawkins et al. 1998). Emberton et al. (1996) suggest that a combination of soil/litter sampling and timed hand-searching is most efficient for a wide range of snail species. Soil/litter sampling has the advantage of including empty shells in the sample, so rare species have a higher chance of being found. An alternate survey method, sometimes used dry environments, involves wetting down an area with water and observing snails that surface (Grimm personal communication 2003).

The Bureau of Land Management (BLM) in Oregon has developed a protocol to survey for terrestrial mollusks (Bureau of Land Management 1998). Their Terrestrial Mollusk Survey Protocol could be applied to areas in Region 2 to determine what areas support *Oreohelix strigosa cooperi* or other snail species. This protocol includes standardized hand-searches for a variety of snail species.

Habitat inventory involves surveying to determine whether appropriate habitat is available for the species.

This assumes that the exact habitat requirements for the species are known. Because the habitat requirements for *Oreohelix strigosa cooperi* are somewhat general, it may be necessary to conduct a snail survey at the location to determine if the habitat is actually suitable for the species. Specific microhabitat characteristics important for *O. s. cooperi* might involve specific soil moisture levels, pH, calcium levels, soil type, plant or fungi species, etc. Once the specific requirements are identified for the species, habitat inventory becomes much more reliable. Source versus sink areas for the species could potentially be identified through such habitat inventories. However, with a patchily distributed species like *O. s. cooperi*, source habitat becomes somewhat speculative since populations will not be present in all possible habitats.

Population monitoring that actually evaluates the size of the population requires a sampling method that can provide a statistical estimate relating the size of the sample to a known area. Three basic methods exist to sample snails in order to obtain population estimates: soil sampling, mark-recapture, and cardboard (or wood) boards used as traps. The strengths and weaknesses of these three methods were evaluated by Oggier et al. (1998) in Swiss grasslands. Soil sampling that consists of removing and searching soil from stratified random locations has been well-supported (Bishop 1977) because it avoids biases. However, Oggier et al. (1998) point out that soil sampling is extremely time consuming and is destructive to both the habitat and the animals, since snails are removed to the laboratory for identification. The actual amount of soil and/or litter sampled varies among studies, and the efficiency of different strategies can be impacted by the time of year and the species in question (Kuznik 1997). Emberton et al. (1996) suggest that a combination of soil/litter sampling and timed hand-searching is most efficient when interested in a wide range of snail species.

Mark-recapture methods consist of hand-searching vegetation and litter across a grid and marking the individuals observed. Repeated visits to the grid provide data that can be used for statistical estimates of population size. Some handling of the snails is usually necessary, unless the snails are large and remain visible when inactive (Schilthuizen and Lombaerts 1994), which is not likely to be the case for *Oreohelix strigosa cooperi*. Oggier et al. (1998) found this method to be less time intensive and cause less disturbance to the snails and the habitat. They were able to alleviate some trampling disturbance by elevating a walkway over their grid. However, mark-recapture methods cannot be done with the smallest species or with species that cannot be identified in the field. Mark-recapture methods are also somewhat weather-dependent. Traps consisting of corrugated cardboard or wooden cover boards have also been used (Boag 1982, Hawkins et al. 1998). Oggier et al. (1998) found that the cover board method has the least time commitment and causes the least disturbance, but it is dependent on weather. Boag (1982) watered areas under the boards in dry areas in order to increase captures. Some snail species may respond differently to the traps than other species (Boag 1982). Nevertheless, Oggier et al. (1998) considered cardboard sampling boards to be the best method for large areas. Boag (1982) also points out that cover boards provide a better picture of what life stages make up the current population than either hand-searching (which may not pick up all life stages equally) or soil sampling (which includes dead shells).

Populations can also be monitored using a combination of boards and mark-recapture methods. In Iowa, a federally endangered snail has been monitored by setting up a grid in its habitat and conducting mark-recapture studies (Ostlie 1991, Anderson 2000, Henry et al. 2003). With large snails like *Oreohelix strigosa cooperi*, snails could easily be marked with fingernail polish or bee tags. This would allow biologists to estimate population size and to monitor population trends. There are several potential difficulties with this approach. First, someone who can identify the snail species in question is required in the field. With a relatively large species like *O. s. cooperi*, this can be overcome with brief instructions. A second difficulty is that the approach is time intensive because repeated visits must be made to a site to record recaptures. Because of the time requirements, monitoring populations across an entire forest may not be practical, but representative populations could be monitored with less effort. A third difficulty is that baseline information on the variability in the *O. s. cooperi* populations over time is not available. Without this information, it is difficult to determine ideal time periods for monitoring, and it is virtually impossible to interpret trends. However, as information is gathered, trends will eventually emerge.

Monitoring habitat is a possible alternative to detailed population estimates. Habitat monitoring must be conducted at each population location because the snails are tied to a specific location. The overall habitat quality in a forest or even a stand may or may not apply to the specific spot where the snails reside. Important elements to include in a habitat monitoring would be a visual on-the-ground inspection of the area to determine if the integrity of the habitat had changed. For example, on a steep site, did an avalanche occur that may have crushed snails or removed part of the habitat? Was a fire intense enough to remove important vegetation? Perhaps certain habitat characteristics could be monitored, such as depth of litter layer, presence of deciduous trees, soil temperature.

Population and habitat management approaches

Management options for snails range from hands-off to monitoring to intensive hands-on relocation/reintroduction approaches. The current management strategy in the Black Hills National Forest is basically a hands-off approach whereby known snail colonies are avoided during management activities that might potentially disturb the snails (e.g., prescribed burns, road building, grazing, timber removal, weed spraying). Protecting known and potential snail habitat is essential to maintaining populations of the species.

The USFS recommendations for preserving an undescribed *Oreohelix* species, the Chelan mountainsnail, in Washington also include recommendations to avoid most management activities directly on the snail habitat areas (Burke 1999). Setting aside preserves for snail species of concern has also been practiced in Europe (Alexander 1998). This approach is the least time-intensive. One drawback is that it does not provide information on the health of the population at the forest-wide level since no monitoring is done. Combining reserve areas with monitoring has been the strategy for some snail species in Europe (Drake 1998) and Iowa (Henry et al. 2003).

Henry et al. (2003) developed a monitoring protocol for *Discus macclintocki*, a land snail in Iowa. This protocol uses cover boards and mark-recapture methods to track a subset of populations. Sampling data collected each year, together with environmental information such as temperature and moisture levels, are allowing managers to begin to detect trends in the populations. This approach can be somewhat intrusive on fragile habitat, and Henry et al. are considering longer intervals between sampling. This approach is much more time-intensive than a hands-off approach because repeated visits are needed at each site for marking and recapturing individuals. However, it does have the advantage of providing data on the status of the species, at least at the sites included for monitoring.

Captive breeding and relocation/reintroduction programs have been developed for some critically imperiled snail species. One example of such a program is described in Mace et al. (1998) where Polynesian tree snails (Family Partulidae) became imperiled when an exotic carnivorous snail was introduced. Zoos around the world are collaborating to maintain captive colonies of these species until they can be reintroduced to areas where the carnivorous snail has been eradicated. The program involves raising the animals in captivity, managing a breeding program to maintain genetic diversity, and, hopefully, releasing the snails back into the wild. Obviously, this approach is extremely expensive and time-intensive. It also requires detailed knowledge of the species' nutritional and habitat requirements in order to successfully raise them in captivity. Even then, the animals may be susceptible to disease or the loss of behaviors necessary to survive in the wild, so it should only be considered as a last resort.

An alternative strategy for preserving snails and their habitat occurred in England when *Vertigo moulinsiana*, a rare marsh snail, was found in an area undergoing road development (Stebbings and Killeen 1998). In this case, a new marsh was constructed by moving the turf and the resident snails to another suitable area. Early results showed that breeding continued in the new areas, suggesting the snails may become established in the new area. Again, this method is expensive and is not suitable for habitat types that cannot be reconstructed.

Information Needs

The distribution of *Oreohelix strigosa cooperi*, as it is currently defined taxonomically, is believed to be restricted to the Black Hills. Future information on the taxonomic relationships within the Oreohelicidae may help define how unique the Black Hills *Oreohelix* populations are. Finding additional populations within the Black Hills is also possible.

Within the Black Hills, Frest and Johannes (2002) have proposed two additional species of *Oreohelix*. Verification of these species is important for the management of *O. strigosa cooperi*. If they are all the same species, additional populations of *O. s. cooperi* can be recognized, possibly decreasing management concerns at some areas. If they are different species, and are also unique to the Black Hills, then their management needs would be very similar to *O. s. cooperi*. Genetic studies can provide information on the uniqueness of the Black Hills *Oreohelix* populations and whether multiple species exist within the Black Hills.

The response of *Oreohelix strigosa cooperi* to changes in habitat is not well understood. Information on how *O. s. cooperi* recolonize areas after fires and how timber thinning treatments affect the litter layer is essential in order to understand how management affects the species. Understanding the species' sensitivity to temperature and moisture changes and the relationship of these factors to timber harvesting, grazing, and road building would allow better planning of buffers and mitigation.

Although information on general habitat is known, preferred microhabitat is still somewhat undefined, as is information on foraging and shelter needs. Information on predators in the region is virtually non-existent.

Temporal population patterns are not well understood. This information is important for establishing proper times for monitoring as well as for suggesting times to avoid disturbance, such as during the breeding period. Dispersal patterns are unknown for *Oreohelix strigosa cooperi*. Understanding dispersal would provide insight into how connected (or isolated) populations are, as well as provide understanding as to how disturbed areas might be recolonized.

Knowledge of the demography of *Oreohelix strigosa cooperi* is extremely limited. Because reproduction rates, survival rates, and dispersal rates are unknown, it is impossible to analyze persistence at the local and/or regional scales.

Methods are available to monitor population trends, but they are not currently being utilized. Population estimates can be determined from mark-recapture studies as discussed above. Trends can be determined as data are gathered over several years.

Restoration methods for *Oreohelix strigosa cooperi* habitat are not readily available. Because information is lacking on the microhabitat needs of this species, it is difficult to envision being able to currently restore damaged habitat with high success. In addition, without relocating snails to the restored habitat, it is difficult to envision recolonization from distant populations, unless new information on dispersal patterns surfaces.

The recommended research priorities for *Oreohelix strigosa cooperi* in Region 2 are as follows:

- ❖ **High Priority** (essential for short term protection of species)
  - ❖ Determine the taxonomic relationship of *Oreohelix strigosa cooperi* to other *Oreohelix* in the Black Hills through genetic and/or morphological studies
  - ❖ Estimate population sizes and determine population trends by conducting mark-recapture studies at multiple occurrences
  - ❖ Determine how snails respond to disturbances (e.g., fire, grazing, timber harvest) through experimental study and/or observations. This could be addressed partially (and at lower cost) with models if demographic data were available
  - ❖ Identify microhabitat needs of the species (e.g., understory, soil, litter requirements) through observational study.

- ❖ **Moderate Priority** (probably necessary for longer-term management)
  - ❖ Identify seasonal activity patterns and relationship with environmental variables through observational study
  - ❖ Quantify demographic rates (e.g., survival, reproductive) for this species through mark-recapture study or observational study. This could also be combined with a lab-rearing study.

- ❖ **Low Priority** (helpful, but not critical, for management)
  - ❖ Examine predation on this species through observational study
  - ❖ Examine competition between other snail species and *Oreohelix strigosa cooperi* through observational or experimental study.

DEFINITIONS

Aestivation – a resting state into which snails enter when conditions are not favorable, (i.e., temperatures are too high or moisture levels are too low)

Allozyme – a genetic method that looks at variation in individual organisms at the protein level. Recall DNA is converted into proteins in the transcription and translation processes. Not all DNA codes for proteins and not all changes in the DNA result in detectable differences in proteins

Aperture – the opening in the shell leading into the shell itself; the snail body extends from this opening (**Figure 11**)

Cover-board – a wooden or cardboard sheet placed on the ground in one method of counting snails. The snails use the board for shelter and often remain attached to the board or at the surface underneath so they can easily be seen and counted.

Desiccation – the act of drying out

Gastropod – a group of mollusks that includes snails and slugs

Hermaphrodite – an individual that contains both male and female reproductive organs

Iteroparous – an organism that reproduces more than once during its life

Peristome – surrounds the aperture; also called the lip

Pulmonate – a snail that has lungs

Radula – rows of teeth used to scrape food particles off a surface; found in all mollusks

Ribs – raised lines on a snail shell that are perpendicular to the direction of the whorls (**Figure 11**)

Umbilicus – the opening on the underside of some snail species' shells depending on the shape and coiling pattern of the shell (**Figure 11**)

Whorls – spiral layers of the shell found around a central axis (**Figure 11**)

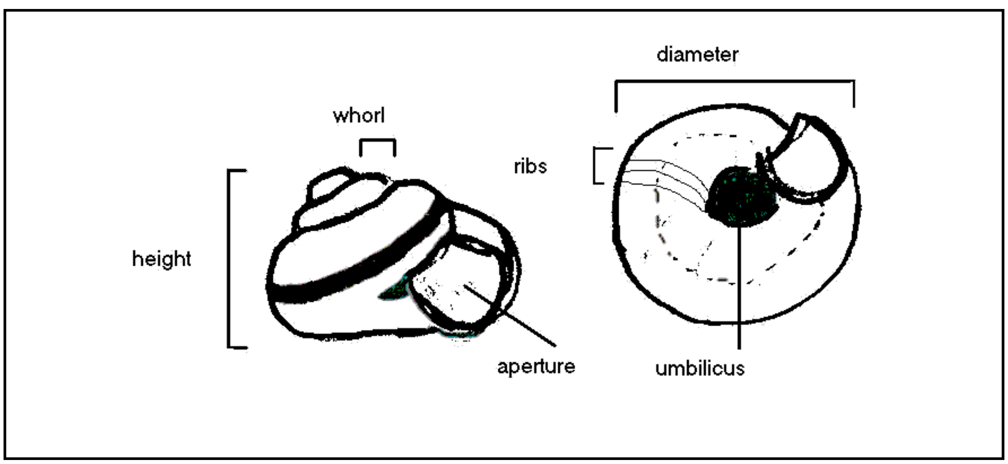

Figure 11. Shell morphology terms.

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