Astragalus molybdenus Barneby (Leadville milkvetch): A Technical Conservation Assessment

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AUTHOR'S BIOGRAPHY

Juanita A. R. Ladyman received her B.S. degree (with First-class honors) in Biochemistry from London University, England. Her first professional position was as plant pathology laboratory technician and, later, as greenhouse research supervisor with the Arid Lands Research Center on Sadiyat Island in the United Arab Emirates. She obtained her Ph.D. degree in Botany and Plant Pathology from Michigan State University, where she was also a research assistant with the D.O.E. Plant Research Laboratory. She worked as a plant physiological ecologist and plant scientist for Shell Development Company conducting research on the physiology, ecology, and reproductive biology of economically important plant species and their wild relatives. She then worked for a plant biotechnology company in their Genetic Transformation and Plant Tissue Culture Division. For the last 11 years, she has worked in the area of conservation, particularly on rare, endemic, and sensitive plant species in the southwest United States. For three years of that time, she was the botanist with the New Mexico Natural Heritage Program. She has conducted research and monitoring programs on both non-vascular and vascular species. She currently is a partner in *JnJ Associates*, an environmental consulting company in Colorado.

COVER PHOTO CREDIT

Astragalus molybdenus (Leadville milkvetch). Photo taken by author.

Summary of Key Components for Conservation of *Astragalus molybdenus*

Status

Astragalus molybdenus (Leadville milkvetch) is a rare Colorado endemic. It is designated a sensitive species by the Rocky Mountain Region, U.S. Forest Service but not by the Bureau of Land Management. The NatureServe Global rank for this species is vulnerable (G3). It is designated imperiled (S2) by the Colorado Natural Heritage Program and is designated a sensitive species by the Colorado Natural Areas Program.

Primary Threats

Recreational uses that disturb habitat, such as off-trail motorized vehicle traffic and intensive foot traffic, pose a significant threat to some populations. As the human population grows in areas within easy access to *Astragalus molybdenus* habitat and recreational use increases, the impacts may become substantially more significant. Mining activities are likely to have impacted some populations in the past. At the current levels, mining activities are not perceived as a significant threat to the species in general, although individual populations may be impacted in the future. Sheep and goat use is common within *A. molybdenus* habitat, and the effect on long-term population viability is unknown. Invasive weeds may pose an additional risk to long-term sustainability. Wet nitrogen deposition (acid rain) poses a substantial risk to forb communities in alpine tundra in some areas in the Rocky Mountains. Global warming is a potential threat to all species currently restricted to sub-alpine and alpine-tundra zones.

Primary Conservation Elements, Management Implications and Considerations

Astragalus molybdenus is a regional substrate endemic. It is restricted to limestone and calcareous soils at elevations above 2,900 m in Gunnison, Park, Pitkin, Lake, Hinsdale, and Summit counties. There are no formal written management plans directly concerning *A. molybdenus*. The current information available suggests that several populations are relatively secure because they occur in areas that are afforded protection either by their remote location, or by land use designation, for example Research Natural Area, Wilderness Area, and Area of Critical Environmental Concern. There is a dearth of information concerning this species abundance, distribution, biology, and optimal management procedures. Under the current regulations this species may not receive the priority for further study that would help ensure long-term security.

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INTRODUCTION

This assessment is one of many being produced to support the Species Conservation Project for the Rocky Mountain Region, U.S. Forest Service (USFS). *Astragalus molybdenus* (Leadville milkvetch) is the focus of an assessment because it is a sensitive species in the Rocky Mountain Region of the USFS (Region 2). Within the National Forest System, sensitive species are plants and animals whose population viability is identified as a concern by a Regional Forester because of significant current or predicted downward trends in abundance or significant current or predicted downward trends in habitat capability that would reduce a species distribution (FSM 2670.5 (19)). Sensitive species may require special management, and therefore knowledge of their biology and ecology is critical.

This assessment addresses the biology of *Astragalus molybdenus* throughout its range in Region 2. The broad nature of the assessment leads to some constraints on the specificity of information for particular locales. This introduction defines the goal of the assessment, outlines its scope, and describes the process used in its production.

Goal of Assessment

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

Scope of Assessment

This *Astragalus molybdenus* assessment examines the biology, ecology, conservation status and management of this species with specific reference to the geographic and ecological characteristics present in the Rocky Mountain Region. Although some of the literature relevant to the species originates from field investigations outside the region, this document places that literature in the ecological and social contexts of the central Rockies. Similarly, this assessment is concerned with reproductive behavior, population dynamics, and other characteristics of *A. molybdenus* in the context of the current environment, rather than under historical conditions. The evolutionary environment of the species is considered in conducting this synthesis but placed in a current context.

In producing the assessment, refereed literature, non-refereed publications, research reports, and data accumulated by resource management agencies were reviewed. The assessment emphasizes the refereed literature because this is the accepted standard in science. Non-refereed publications and reports were regarded with greater skepticism and used only when information was unavailable elsewhere. Many reports or non-refereed publications on rare plants are often 'works-in-progress' or isolated observations on phenology or reproductive biology. For example, demographic data may have been obtained during only one year when monitoring plots were first established. Insufficient funding or manpower may have prevented work in subsequent years. One year of data is generally considered inadequate for publication in a refereed journal but still provides a valuable contribution to the knowledge base of a rare plant species. Unpublished data (for example, Natural Heritage Program and herbarium records) were important in estimating the geographic distribution and population sizes. These data required special attention because of the diversity of persons and methods used to collect the data. Records associated with locations at which herbarium specimens had been collected at some point in time were weighted higher than observations only.

Treatment of Uncertainty

Although *Astragalus molybdenus* has been known for over a century, the information on which to base an assessment is incomplete. Generally, 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 includes 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 critical experiments in the ecological sciences, and often observations, inference, good thinking, and models must be relied on to guide the understanding of ecological relations.

In this assessment, the strength of evidence for particular ideas is noted, and alternative explanations are described when appropriate. While well-executed experiments represent a strong approach to developing knowledge, alternatives such as modeling, critical assessment of observations, and inference are accepted approaches to understanding features of biology and ecology. For this particular species of *Astragalus*, uncertainty has been generated by allopatry, which is the occurrence of species in different geographical regions. The question as to whether three similar, but widely disjunct, populations should be named as species or varieties is a judgment based on the observations of users and the tools of taxonomy.

Publication of the Assessment on the World Wide Web

To facilitate use of species assessments in the Species Conservation Project, they are being published on the Region 2 World Wide Web site. Placing the documents on the Web makes them available to agency biologists and the public more rapidly than publishing them as a book or report. More important, it facilitates revision of the assessments, 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 release on the Web. This assessment was reviewed through a process administered by the Center for Plant Conservation, employing at least two recognized experts on this or related taxa. Peer review was designed to improve the quality of communication and increase the rigor of the assessment.

Management Status and Natural History

Management Status

In 1990, *Astragalus molybdenus* was nominated for listing as Threatened or Endangered, Category 2 by the U.S. Fish and Wildlife Service, as provided in the Endangered Species Act of 1973 (16 U.S.C. 1531-1536, 1538-1540). Category 2 candidates were "taxa for which information in the possession of the Service indicated that proposing to list as endangered or threatened was possibly appropriate, but for which sufficient data on biological vulnerability and threat were not currently available to support proposed rules" (U.S. Fish and Wildlife Service 1996). In 1996, the U.S. Fish and Wildlife Service discontinued the use of designating species as Category 2 (U.S. Fish and Wildlife Service 1996), and there are no current plans to list *A. molybdenus*.

Astragalus molybdenus is designated sensitive by the USFS. This indicates that it "is a plant species identified by the Regional Forester for which population viability is a concern as evidenced by a significant current or predicted downward trend in population number or density and/or a significant current or predicted downward trend in habitat capability that would reduce a species' existing distribution" (USDA Forest Service 1993). The Bureau of Land Management (BLM) does not designate this species as sensitive, and it is afforded no official attention by this agency (Colorado Bureau of Land Management 2002). The NatureServe Global Rank is vulnerable (G3), and the National Heritage Status Rank is also vulnerable (N3) (NatureServe 2003). However, NatureServe follows Kartesz and Meacham (1999) and excludes plants in Montana, which are recognized as a separate species, *A. lackschewitzii*, but includes plants from both Colorado and Wyoming (NatureServe 2003). Presumably, if *A. molybdenus* was recognized as a Colorado endemic, it would receive a rank to reflect its greater rarity. It is designated imperiled (S2) by the Colorado Natural Heritage Program (NHP) (Colorado Natural Heritage Program On-line Rare Plant Guide). The Colorado Natural Areas Program designates *A. molybdenus* a sensitive species (West personal communication 2002).

Existing Regulatory Mechanisms, Management Plans, and Conservation Strategies

Astragalus molybdenus occurs on private land, National Forest System land, and land managed by the BLM. Occurrences on private land are often within patented mining claims and are not protected (Ray 2001). The landowners are unlikely to even know that the species occurs on their land. Several occurrences are on BLM land, where they are also afforded no specific protection.

The majority of the known occurrences are on National Forest System land, where the taxon is designated sensitive (USDA Forest Service 1993). The USFS has conducted relatively few formal surveys. The agency is not currently monitoring known populations nor has it in the past. However, when occurrences are found in the performance of other field work, they are typically documented (Austin 2001). Field guides have been compiled for the Pike-San Isabel National Forest and specifically for the Leadville Ranger District to assist field staff in identifying sensitive species, which include *Astragalus molybdenus* (Szepanski 1992, Kettler et al. 1993).

Several substantial occurrences of *Astragalus molybdenus* were found within the Maroon Bells-Snowmass Wilderness Area (Rossignol 2001). Only foot and horse traffic are allowed in designated wilderness areas. Plants may experience livestock grazing, because these occurrences are within an active domestic sheep grazing allotment (Johnston personal communication 2002). In addition, although cattle allotments are below the timberline, cattle may occasionally trespass and graze above the timberline where *A. molybdenus* grows (Ray 2001).

One population of *Astragalus molybdenus* is likely all, or at least partly, within the Hoosier Ridge Research Natural Area (RNA) that was established in 1991 (USDA Forest Service 1995a). The Hoosier Ridge RNA straddles the Pike-San Isabel National Forest and the White River National Forest. This RNA was established to include a high concentration of rare plant species, specifically including *A. molybdenus*. In order to protect all the plant species, the Continental Divide Scenic Trail, which crossed the site, was re-routed out of the area. A power line also crosses the site. RNA management guidelines suggest that activities associated with its maintenance be "managed closely" (Colorado Natural Heritage Program 1998). There is no evidence of recent mining activity. However, there are approximately seven unpatented mining claims in the area that include parts of the RNA (Ray 2001). Several mining groups filed an appeal challenging the RNA designation. In response, the Chief of the Forest Service withdrew the RNA designation and ordered its re-evaluation by the Regional Forester. That was accomplished in 1995 (USDA Forest Service 1995b). Not withstanding the re-evaluation, in 1999, Park Lake Resources, Limited Liability Company, and Park County Mining Association again filed an action challenging the Forest Service's designation of the RNA (Appeal to the U.S. District Court 1999). At that time the Court decided that the issue was "not ripe for review from either the agency's or the court's perspective." Essentially this means that under the present circumstances the plaintiff would be little affected, or unaffected, by the RNA but, if circumstances changed, they could return to the court at a later date. Recreational facilities, roads, trails, and motorized access are prohibited within the RNA. Livestock grazing is also prohibited, although some inadvertent trespass may occur because the Bross sheep and goat allotment surrounds the Hoosier Ridge RNA (Ray 2001).

Astragalus molybdenus also occurs within the proposed Taylor Peak RNA that spans the White River and Gunnison national forests (Lyon 1995). Taylor Peak RNA will likely encompass populations described at Taylor Pass, which is 2.5 miles northeast of Taylor Peak. The objectives of the Taylor Peak potential RNA area are fourfold: 1) it aims to protect elements of biodiversity, 2) it should serve as a reference area for the study of succession and long-term ecological changes, 3) it should provide a site for non-manipulative scientific research, and 4) it should serve as a control area for comparing results of manipulative research and resource management in other areas with similar ecosystems (Lyon 1995). Therefore, potential management actions would appear to be considered in the context of sustainable *A. molybdenus* populations. Current travel management for the Taylor Pass area is "closed to all off-road travel, summer and winter" (Johnston personal communication 2002). One important conservation value of these two RNAs is the preservation of genetic diversity of *A. molybdenus*, because significant genetic differences were shown between the Taylor Pass and Hoosier Pass populations (Lavin and Marriott 1997).

At least two populations, separated by approximately 3 miles, are within the boundaries of the Mosquito Pass Area of Critical Environmental Concern (ACEC) managed by the BLM. The Mosquito Pass ACEC was established to provide protected habitat for the Penland alpine fen mustard, *Eutrema penlandii*, a federally listed threatened species (Zwaneveld personal communication 2002). *Eutrema penlandii* also grows in calcareous soils derived from limestone or dolomite in alpine tundra at similar elevations to *Astragalus molybdenus*. However, it grows in moister areas, specifically the moss-covered peat fens with perennial sub-irrigation due to snowmelt (Spackman et al. 1997). Therefore, although many protective measures may apply to both species, there is the risk that populations of the fen mustard will be protected, for example re-routing a trail, at the expense of *A. molybdenus*. Off-road vehicle use is very low within the ACEC, except in the area immediately along the Mosquito Pass Trail, and there are currently no active sheep grazing allotments in the ACEC (Zwaneveld personal communication 2002). However, the exact locations of the *A. molybdenus* populations are unclear, and all, or part, of the populations may be on private, patented mining lands that intermingle with BLM lands within the ACEC.

The Gunnison National Forest has implemented two management strategies that may reduce risks to *Astragalus molybdenus* (Austin personal communication 2002). A change in travel management, whereby all mechanized vehicles must remain on established and designated trails and roads, should alleviate the threat of habitat destruction. In addition, local native species are primarily to be used for re-vegetation projects. This will avoid introducing aggressive and invasive, non-native species. Using local species will reduce the possibility that genetic dilution caused by cross-pollination with non-adapted species will occur. In the event that local species are unavailable, annual, non-persistent species such as barley will be planted or, if the areas are small (< 1 acre), no re-seeding may be done. Successful outcomes have been achieved with the latter strategy (Austin personal communication 2002).

The existing laws afford this species some protection on the National Forest System lands. The designation of sensitive by the USFS is very valuable, as it raises awareness of this little-understood species. The designation also requires that a Biological Evaluation determining impacts to the taxon or its habitat must be made prior to any significant federal project, such as a timber sale, on Forest Service lands (USDA Forest Service 1994). Although no formal management plans specifically for this species appear to exist at the present time, Forest Service personnel do consider extant populations when designing management protocols and evaluating development projects (Johnston and Austin personal communications 2002). Even though there are areas on USFS land where populations appear secure, the protections afforded this species may be transient. For example, if the mining consortium that filed suit in 1999 formally proposes a plan of operations, "the Forest Service may approve it, may require modification, or may even modify or withdraw the RNA designation" (Appeal to the U.S. District Court 1999).

As part of an educational program, rather than a conservation plan *per se*, one plant is growing *in situ* in the "Mosquito Range" display in the Wildflower Treasures Garden at the Denver Botanic Garden (Grant personal communication 2002). Plants were grown from seed obtained from the Mosquito Range, and the plant is now growing in substrate and rocks also taken from the Mosquito Range (Kelaidis personal communication 2002). This individual was observed to be flowering in the spring of 2002 (personal observation).

Biology and Ecology

Classification and description

Systematics and synonymy

Astragalus is a member of the Fabaceae or Leguminosae (pea) family. *Astragalus molybdenus* was first described as *A. plumbeus* (Barneby 1949). However, the species name was already occupied, and so the name was revised to *A. molybdenus* (Barneby 1950). "*Plumbeus*" was first chosen as it means lead, or gray metal, in Latin and would have suited both the plant's appearance and where it was first collected, near Leadville, Colorado. However, "*molybdenus*" is also appropriate as the metal molybdenum is grayish in color and mined in the Leadville area (Bates and Jackson 1984). Interestingly, *A. plumbeus*, endemic to the Kugitang Range in central Asia, is also restricted to limestone and has grayish-colored leaves and stems (Gontscharov 1946). *Astragalus molybdenus* is referred to as *A. plumbeus* in Harrington (1964).

Barneby (1964) originally placed *Astragalus molybdenus* as the only species in the *Minerales* section in the *Phacoid* (*Phaca*) Phalanx (subgenus) of North American *Astragalus*. This position was based on the morphological similarities to *Astragalus leptaleus* that is in the related section *Astragalus*. However, Barneby recognized there were difficulties with his treatment of *A. molybdenus*, and he pointed out that it also had morphological characters similar to members of the section *Polares*. There is now phylogenetic evidence that *A. molybdenus* and the related species *A. shultziorum* and *A. lackschewitzii*, are closely related to species in the *Polares* section of the Homaloboid phalanx of North American Neo-astragalus (Wojciechowski personal communication 2002). *Astragalus molybdenus* is an aneuploid (2n=12), a characteristic of North American Neo-astragalus rather than the euploid, Old World group that has a basic chromosome number of 8 (Barneby 1964, Spellenberg 1976, Lavin and Marriott 1997, Wojciechowski et al. 1999). In addition, the characteristic of the mature pod, which is deciduous from a persistent, ventrally ruptured calyx, can also be used to pinpoint the relationships of this group to the Homaloboid sub-group (Lavin and Marriott 1997).

In 1964 Barneby reviewed the entire *Astragalus* genus. In his discussion on section *Minerales* he noted that a specimen closely related to *A. molybdenus* had been collected from Wyoming in 1923. In 1980, a population of such plants was (re)discovered by Leila and John Shultz. A year later, Barneby (1981) described them as *A. shultziorum*. Isely (1986) also recognized this species in his extensive review of *Astragalus*. Welsh (1998) formally recognized the relatedness between the two taxa by establishing *A. molybdenus* var. *shultziorum* in Wyoming and *A. molybdenus var. molybdenus* in Colorado.

In 1982, a population of plants very similar to both *Astragalus molybdenus* and *A. shultziorum* was found in Montana. Lackschewitz et al. (1994) recognized it to be a disjunct population of *A. molybdenus*. Isely (1998) and Welsh (1998) both accepted this interpretation of the taxon and reported that *A. molybdenus* occurred in both Montana and Colorado. Schassberger and Shelly (1990) reported several more populations of the species in central Montana, but they questioned that the plants were actually *A. molybdenus* and proposed that research should be undertaken to study the issue.

In 1997, Lavin and Marriott recognized the Montana populations as *Astragalus lackschewitzii*. Using restriction site polymorphisms, Lavin and Marriott (1997) demonstrated that certain chloroplast DNA sequences are exceptionally divergent among the three taxa, on the order of 1.5-2%, and support the recognition of three distinct, but related, taxa. In addition, at the morphological level there are at least 14 quantitative and qualitative traits possessed by *A. molybdenus* that are significantly different from both the other two species (Lavin and Marriott 1997). The clade developed from research of Lavin and Marriott (1997) also suggests that *A. shultziorum* is more closely related to *A. lackschewitzii* than to *A. molybdenus*.

Therefore, current evidence suggests that there are actually three related but distinct taxa: *Astragalus shultziorum* endemic to Wyoming, *A. lackschewitzii* endemic to Montana, and *A. molybdenus* endemic to Colorado (Barneby 1981, Marriott 1990, Lavin and Marriott 1997, Dorn 2001). The database managed by the Missouri Botanical Garden recognizes *A. molybdenus* and *A. shultziorum* at the varietal level, that is, *A. molybdenus* var. *molybdenus* and *A. molybdenus* var. *shultziorum* (TROPICOS 2002). National databases do not necessarily represent the national standard in plant taxonomy. One reason is that, because of their sheer enormity, they are slow to be updated with the most current information.

Thus at the present time, there are two taxonomies, neither sufficiently tested. One has *Astragalus molybdenus* endemic to Colorado. The other has *A. molybdenus* in disjunct occurrences within Wyoming and Colorado, but with two varieties: one endemic to Colorado and the other endemic to Wyoming. In either case, the Colorado populations represent a unique taxon that is endemic and rare and worthy of consideration in land management decisions.

History of species

John Merle Coulter first collected *Astragalus molybdenus* in 1873 on Mt. Lincoln in the Park Range at 13,000 feet, and the specimen was deposited at the New York Botanical Garden Herbarium (Barneby 1964). Barneby first recognized *A. molybdenus* as a unique taxon in 1949, when he described it as *A. plumbeus*. Current evidence indicates that this taxon is only known from Colorado (see Systematics and synonymy).

Non-technical description

Astragalus molybdenus is a low, loosely tufted, or "matted", perennial plant (**Figure 1** and **Figure 2**) . The root is a slender taproot. It has a subterranean, branched caudex and propagates vegetatively via extensively branching subterranean stems that persist as rhizome-like branches that adventitiously root to form plants (Barneby 1964). The plants may eventually have independent root systems (Barneby 1964). The vegetative growth habit has been described as rhizomatous-stoloniferous (Isely 1985, Isely 1998), a creeping rhizomatous rootstock (Barneby 1949), a creeping rhizome (Harrington 1964), and strongly rhizomatous (Lavin and Marriott 1997). The stems and leaves are variously thinly to densely hairy making the foliage a silvery-gray or ashen-green color. The stems generally lie partially on the ground. The leaf stalk is 1 to 7 cm long with 9 to 25, usually 13 to 19, oval to oval-oblong leaflets that are often folded. The flowers are pink-purple, violet or whitish and striped purple. Small black hairs cover the calyx tube, at the base of the flower. The legumes (pods) are 7 to 10 mm long, somewhat compressed, ascending, and slightly incurved. When the pod is cut in cross section it is clearly one chambered. This is a useful diagnostic feature because some *Astragalus* species have two-chambered pods (Spellenberg personal communication 2003). The pods have very short or no stalks. The pods tend to remain on the plants and are slow to dehisce and release the seeds. *Astragalus molybdenus* has relatively large seeds (Barneby 1964).

Figure 1. Photograph of *Astragalus molybdenus* (photograph by author).

Figure 2. Illustration of *Astragalus molybdenus*. The illustration is by Janet Wingate and used with her permission.

Both quantitative and qualitative differences separate *Astragalus molybdenus* from *A. shultziorum*, endemic to Wyoming, and *A. lackschewitzii*, endemic to Montana. In summary, the flowers of *A. molybdenus* have larger standard petals, longer calyx tube, denser, tangled, and uniformly black trichomes on the calyx, and usually four ovules per ovary (Lavin and Marriott 1997). Species in Wyoming and Montana generally have eight ovules per ovary. Other differences exist, but in many cases, characteristics, for example leaflet number, may overlap or be shared by two of the three species. *Astragalus molybdenus* is easily distinguished from sympatric *A. aboriginum* var. *glabriusculus* and *A. robbinsii* var. *minor* as both are larger plants and their pods have stipes (short stalks between the pod body and the calyx). However, *A. molybdenus* resembles two other *Astragalus* species, *A. alpinus* and *A. leptaleus*. Although all three are in the same geographic range, the habitat of *A. molybdenus* only overlaps that of *A. alpinus*. *Astragalus leptalus* grows in moist meadows and among aspen (Barneby 1964, Weber and Wittman 2001). Because of the morphological similarities among the three species, their diagnostic properties are shown in **Table 1**. The fruits are distinctive, but if fruits are absent, *A. molybdenus* can be confused with a depauperate *Oxytropis deflexa* (Spackman and Fayette 1998). A distinguishing feature on vegetative specimens is that the stem hairs on *O. deflexa* are primarily spreading or retorse, whereas in *A. molybdenus* they are appressed or ascending. If flowers are present, the tip of the keel is also a useful distinctive feature. The tip of the keel in *A. molybdenus* is bluntly triangular. In *O. deflexa*, the tip is roundish and usually has a slender point, described as a mucroniform beak, at the very end (Barneby 1989, Spellenberg personal communication 2003).

References to technical descriptions, photographs, line drawings, and herbarium specimens

Technical descriptions are published in Barneby (1949), Barneby (1964), Isely (1985), Isely (1998), Weber (1987), Weber (1991) and Welsh (1998). Photographs of herbarium specimens, as *Astragalus plumbeus* Barneby, are on the New York Botanical Garden Web page (http://www.nybg.org/bsci/hcol/vasc/Fabaceae.html). A description, photograph, and line drawing are published on the Colorado Natural Heritage Program Web site and in Spackman et al. (1997). A description and a photograph are published in Colorado Native Plant Society (1997). An excellent illustration with a good representation of the flower and legume is in Zwinger and Willard (1972). Syntypes collected by Ripley and Barneby in 1949 are located at the New York Botanical Garden herbarium (NY). See **Figure 1** and **Figure 2**.

Distribution and abundance

The total range of *Astragalus molybdenus* falls within Colorado and, therefore, only within Region 2 of the USFS (**Figure 3**). It is one of the few *Astragali* found in the tundra zone of the southern Rocky Mountains. It is endemic to the alpine-tundra regions within Gunnison, Park, Pitkin, Lake, Summit and Hinsdale counties between 2,900 and 4,054 m. It typically grows on limestone and calcareous soils. Because of the elevation and soil restrictions, its potential habitat is far less than the approximate 6,900 square miles (102 miles by 67 miles) over which it is distributed. There are approximately 36 documented occurrences (**Table 2**). Occurrence data has been compiled from the Colorado Natural Heritage Program, botanists who found occurrences in 2001, University of Colorado Herbarium (COLO), Colorado State University Herbarium (CS), Rocky Mountain Herbarium (RM), Kathryn Kalmbach Herbarium at Denver Botanic Gardens (KHD), and the literature (Barneby 1964, Ray 2001). Many older records do not have precise location information. Therefore, occurrences that were observed in the same general area may not be the same populations as originally reported. At least 8 of the 36 occurrences have not been observed since 1975, and one observed in 1873 on Mt. Lincoln may be extirpated (Ray 2001).

Table 1. Diagnostic characteristics of *Astragalus molybdenus*, *A. alpinus*, and *A. leptaleus* (Sources: Barneby 1949, Isely 1998).

Species	Petals	Stipe (stalk)	Pods	Leaflets
Astragalus molybdenus	graduated pink-purpleto whitish- suffused lilac	very short or absent	Ascending	rounded at apex
Astragalus alpinus	subequal, pale blueish – purple	long	deflexed (turned down & pointing backwards)	shallow notch at apex
Astragalus leptaleus	Graduated white	very short	arched down- wards	rounded to pointed at apex

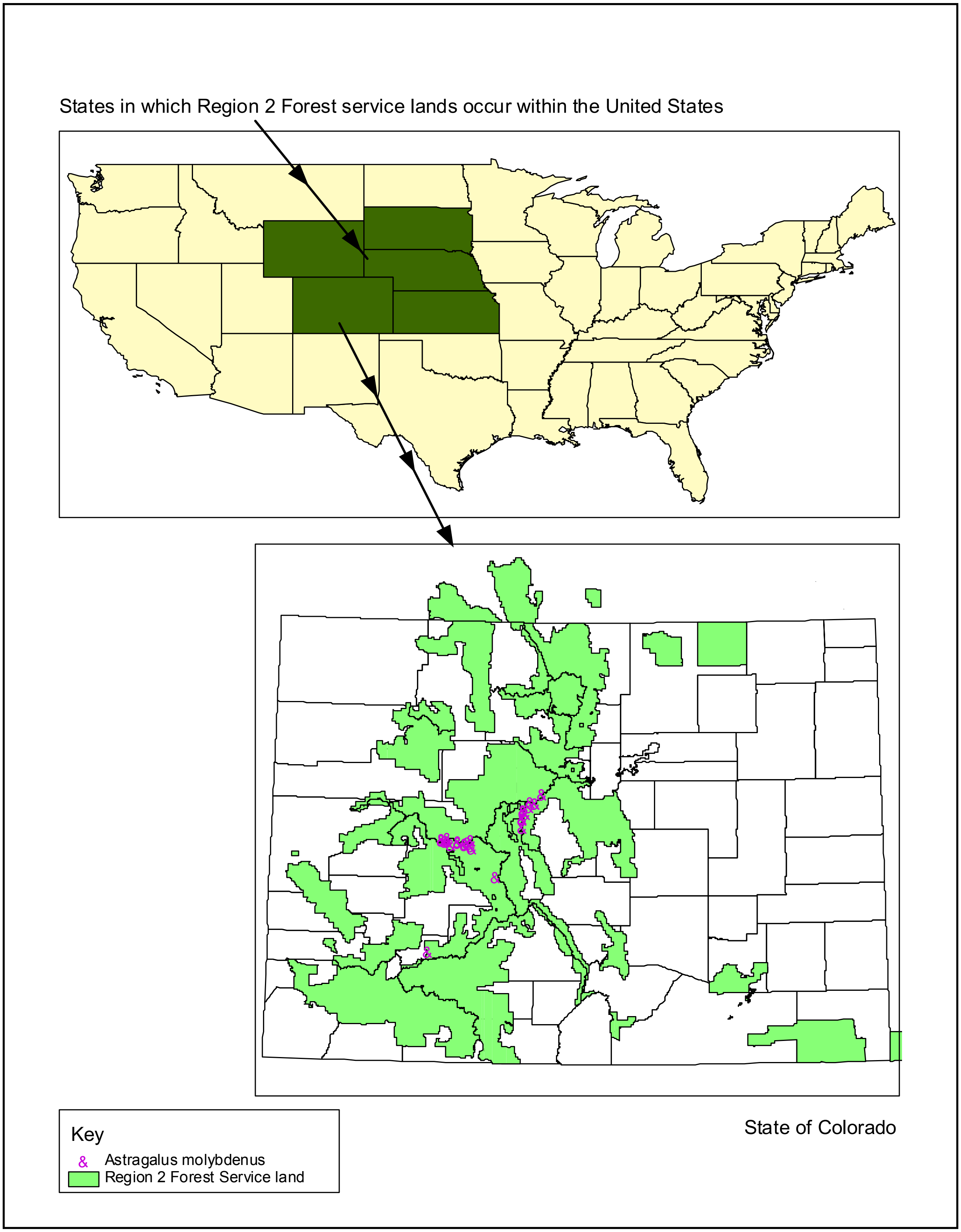

Figure 3. Range of *Astragalus molybdenus*. Some occurrences are on lands managed by other agencies, such as within the Mosquito Range, which are intermingled with National Forest System lands. The resolution of this map is too coarse to pinpoint such locations.

Table 2. Occurrences of *Astragalus molybdenus*. Data comes from Colorado Natural Heritage element occurrence records, herbarium specimens, and the literature (Source: Barneby 1964).

Number	Site Name	County	Ownership[1]	Last date observed	General occurrence description
1	Cannibal Plateau	Gunnison	Gunnison NF	2001	Disturbed site
2	Capitol Peak	Pitkin	White River NF	3-Jul-38	No information
3	Conundrum Creek/Conundrum Pass	Gunnison/ Pitkin	White River NF (Maroon Bells-Snowmass Wilderness)	05-Jul-01	On 40% slope upper back slope open exposure estimate >1,000 stems in 0.5 acres
4	Cumberland Pass	Gunnison	Gunnison NF	23-Jul-70	Gravelly soil in alpine tundra community
5	East Creek/Hawk Creek and Gift Creek/Avalanche Creek drainages	Gunnison	White River NF (Maroon Bells-Snowmass Wilderness)	1-Jan-96	No information
6	French Pass	Summit	Pike and Arapaho NFs	21-Jul-82	No information
7	Hoosier Ridge	Summit	Unknown (Forest Service?)	29-Jul-48	In tundra
8	Hoosier Ridge	Park	White River and Pike NFs	21-Jul-89	Mostly above the tree line. Some areas with fairly thick tundra vegetation and other areas of scree, talus and persistent snowdrifts are sparsely vegetated
9	Hunter's Hill	Gunnison	Unknown	19-Aug-55	Growing abundantly on black shale
10	Iowa amphitheater	Lake	BLM or private	10-Aug-91	On vertically aligned ridges of moderately coarse semi-stabilized scree; Leadville limestone
11	Maroon bells - Elk Range; south ridge of Maroon Peak	Pitkin	White River NF	1-Jul-00	Locally common on stabilized scree on fellfield ridge
12	Mosquito Range, Jones Hill, headwaters of Lynch Creek		San Isabel NF (Buffalo Peaks Wilderness)	11-Aug-95	Relatively well-developed tundra on slope of less than 20 degrees just above timberline. Carpeting discrete 3 sq m area on thin soil over calcareous boulders
13	Mosquito Range, Mosquito Pass, near North London Mine	Park	BLM or private	21-Jul-89	Open tundra cirque, *Kobresia* meadow. Tundra. Alpine area with much bare rock. Plants on talus slope with sparse vegetation
14	Mosquito Range, Mount Sherman Weston Pass just w of Ruby Mine	Park	Pike NF	7-Aug-98	Rocky limestone slope. Locally abundant blanketing slope in late snow melt area
15	Mosquito Range, Pennsylvannia Mountain	Park	Pike NF (may extend onto private land)	16-Jul-78	Sandy and gravelly soil
16	Mount Baldy	Gunnison	Gunnison NF	29-Aug-82	Vegetation cover approximately 4%
17	Mount Belleview		Gunnison or White River NF[2]	1955	No information
18	Mount Bross/Dolly Varden	Park	Arapaho NF (may extend onto private land)	22-Jul-94	Growing in small clumps in rocky gravelly patches on reasonably steep slopes with *Astragalus alpinus* and *A. australis*. Also in areas dominated by willows, sedges and grasses. Some areas bisected by roads and mines
19	Mount Lincoln		Pike NF	1873	No information
20	Mount Sheridan/Mount Sherman	Park	Pike NF (may extend onto private land)	08-Aug-91	Alpine Community
21	Mount Tilton - Elk Mountain	Gunnison	Gunnison NF	30-Aug-82	Gently sloping ridge
22	Mountains east of Leadville	Lake	San Isabel NF	24-Jul-48	Open stony ground above timberline
23	Mt Belleview Summit, Maroon Bells Snowmass Wilderness	Gunnison	White River NF	14-Jul-01	

Table 2 (Concluded).

Number	Site Name	County	Ownership[1]	Last date observed	General occurrence description
24	North Italian Peak	Gunnison	Gunnison NF	25-Jul-55	N. Italian Peak, head of Cement Creek. Tundra
25	North Pole Basin	Gunnison	Gunnison NF	21-Jul-01	Subalpine forest and alpine tundra in grass. Drier sites with seasonal snow melt
26	North Star Mountain - west of Hoosier Pass	Park	Arapaho NF (may extend onto private land)	17-Jul-97	Alpine fellfield on Leadville limestone and on tundra ridge. Mining activity present
27	Pearl Pass area	Gunnison/ Pitkin	Gunnison and White River NF	30-Jul-79	In tiny pockets of fine soil in rock glaciers. Also described in broken rock
28	Ridge near East Creek-Hawk Creek drainage	Mesa	White River (Maroon Bells-Snowmass Wilderness)	29-Jul-96	Tundra community along ridge top; associated species *Oxytropis deflexa*
29	Taylor Pass	Gunnison/ Pitkin	White River and Gunnison NFs	06-Aug-98	Alpine and subalpine peaks and ridges. Open tundra. In rocks and gravel with approximately 60-70% bare ground. In dry to mesic areas. Goats and sheep are using the area. Goats and sheep were using the area at the time of observation
30	Taylor Peak region (see Mathews 1940)	Gunnison/ Pitkin	White River and Gunnison NFs	July-86	Open slopes along roadside on disturbed ground (mine area below and to south)
31	Triangle Park	Gunnison	Gunnison NF	1-Jul-00	Locally common on stabilized scree on fellfield ridge
32	Virginia Ridge	Gunnison	Gunnison NF	30-Jun-55	Ridge summit
33	West Maroon Pass, Maroon Bells Snowmass Wilderness	Gunnison	White River NF	11-Aug-01	No information
34	West of Boreas Pass	Park	Pike NF	25-Jun-93	On grassy tundra with Pulsatilla patens
35	Weston Pass	Park	Pike NF	22-Jun-90	North facing slope, near mine pit and alpine meadow on carbonate soil
36	Weston Pass (may be within Occurrence # 33)	Park	Pike-San Isabel NF	09-Sep-98	On south facing rocky tundra slope among limestone rocks

[1]NF refers to National Forest

[2]This occurrence may refer to Mount BellView (Gunnison National Forest and/or private land) or Bellview Mountain (White River National Forest, Maroon Bells-Snowmass Wilderness)

Four new records were reported in 2001, one of which extends the range southward by approximately 66 miles (Austin 2001).

This species forms loose mats, and therefore the term "individuals" to describe the composition of a population may not be strictly correct. Many plants that appear to be individuals may be linked by some degree of subterranean connection. In addition, "individual" can imply genetic uniqueness, but many individuals within a population may be ramets, or clones. However, the term "individual" is useful to describe an occurrence size as long as it is recognized that the numbers do not necessarily reflect the genetic richness of the population. The abundance of this species is variable. One to two million estimated individuals distributed over an area of 17 acres (Rossignol 2001) have been reported, compared to an isolated occurrence of 20 to 25 stems in an area of 1,800 m^2 (Austin 2001). Occurrences may also be very small. One "mat" covering 3 m^2 was reported as one occurrence. The occurrence at the most southern edge of the taxon's range was very small compared to the dense and expansive populations in the center of its range. There is no evidence to suggest that differences in population size and vigor are due to geographic distribution. One difference between the two areas is the history of land use practices. The southern population was observed in an area with actively eroding soils that had been subject to livestock grazing, whereas the most extensive and dense populations were fairly isolated and within a wilderness area.

Population trend

There are insufficient data in the literature, associated with herbarium specimens, or at the Heritage Program to determine long-term trends over the entire range. *Astragalus molybdenus* has been documented in approximately 36 locations, but very few sites have been visited more than once. The locations of at least eleven occurrence sites, mostly older records, are known to within only one mile (Ray 2001). Unfortunately, when populations of *A. molybdenus* have been reported, the numbers of individuals were seldom counted or estimated. This is especially true of reports more than 15 years old. Therefore, in general, even at sites that have been visited more than once, only the persistence of plants can be confirmed. Population size has been recorded in different ways. Some records indicate plants occur in populations from less than ten to several thousands, or millions, of individuals. Mats of plants and, specifically isolated mats carpeting as little as 3 m^2, have also been reported.

Evidence suggests populations are persistent once established. A collection made by Weber in 1955 (specimen at COLO) may have been from the same location where 1 to 2 million stems was reported in 2001 (Rossignol personal communication 2002). Marriott and Horning (1989) in Colorado Natural Heritage Program element occurrence records reported "101 to 1,000 genets" at a site near North London mine that was likely the site from which Weber collected in 1967 (specimen at COLO). However, there is little evidence to indicate that the abundance of *Astragalus molybdenus* has significantly increased over the decades since its discovery. Because of known extant occurrences near historic and existing mines, there is every reason to believe that some populations were adversely affected by mining activity in the past. It is obviously unknown how the extirpation of sites in the past may have affected the current overall abundance of the species. The effects of ski area developments within its range also are undocumented.

The limited range in alpine-tundra regions in central Colorado imposes restrictions on total potential habitat, and therefore the species is vulnerable to habitat loss. If predictions for continued warming of Colorado are correct, potential habitat for *Astragalus molybdenus* will contract as the alpine tundra zones creep higher in elevation (see further discussion in Threats section).

In summary, this plant appears to be relatively rare, although it can be locally abundant in discrete areas within its habitat. Limited re-surveys of sites first identified in the 1950s and 1960s encourage speculation that populations are persistent, and several are currently very vigorous (Lehr personal communication 2002, Rossignol personal communication 2002).

Habitat

Astragalus molybdenus grows in the alpine-tundra and less commonly in sub-alpine zones at elevations between 2,900 and 4054 m, with the majority of occurrences located between 3,600 m and 4,000 m (**Figure 4**). Where a range was given for an occurrence, the lowest and highest elevations reported were included in the analysis. Evidence indicates that this species is a calciocole as it grows predominantly on limestone and calcareous soils (Spackman et al. 1997, Colorado Natural Heritage Program element occurrence records 2002). *Astragalus molybdenus* has been reported to occur specifically on Lower Ordovician Manitou dolomite and Leadville limestone geological formations but may be found on others (Ray 2001, USDA Forest

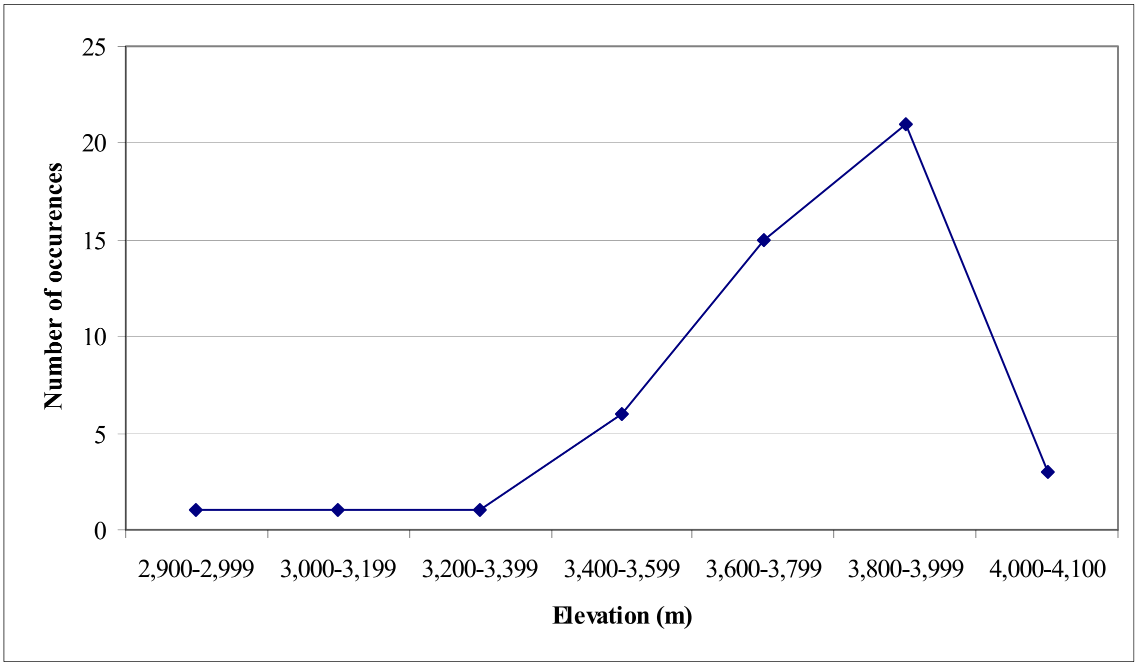

Figure 4. Range in elevations reported for the occurrences of *Astragalus molybdenus.*

Service 1995b, Rossignol personal communication 2002). A population has been reported in the Hoosier Ridge RNA where the geology at the macro-scale ranges from either quartz monzonite and granodiorite at the western half to a sandstone and conglomerate in the eastern half (USDA Forest Service 1995b). However, the sandstone conglomerate formations within the RNA include limestone pellets, and there are also local limestone outcrops (Tweto 1979). Observations indicate that, although calcareous soils were nearby, it was found growing in apparently non-calcareous soils (Ray 2001). However, edaphic conditions such as pH and chemistry can be influenced by adjacent soils and rocks. The extent of the influence of adjacent limestone or calcareous soils will depend upon the soil type, distance away from the limestone, precipitation, and erosion parameters. In addition, although limestone is quite straightforward to identify in the field, calcareous soils may provide a challenge to persons unfamiliar with soils and geology or to the casual observer. Therefore, the current evidence indicates that it is restricted to limestone and calcareous soils.

Plants may occur with fairly thick tundra vegetation, for example vegetation dominated by willows, sedges ("*Kobresia* meadows"), and grasses, or on more sparsely vegetated areas of scree and talus (Isely 1998, Colorado Natural Heritage Program element occurrence records 2002). On the latter unstable, gravelly slopes the total vegetation cover may be less than 4% (Colorado Natural Heritage Program element occurrence records 2002) and the rhizomatous matrix of *Astragalus molybdenus* serves to stabilize the plants (Zwinger and Willard 1972). *Astragalus molybdenus* has also been reported on fellfield associations (Colorado Natural Heritage Program element occurrence records 2002). Fellfields have significant amounts of fine material for soil formation but have features such as exposure to strong winds, little snow cover in winter, and extremes of temperature and moisture that make them relatively dry with little vegetation cover (Willard 1979).

Ecological vegetation types of which *Astragalus molybdenus* are a part have been classified by the USFS as AL03-Kobresia-like sedge/alpine sandwort-alpine sagebrush and AL13-Mountain dryad/curly sedge-alpine fescue (Johnston and Huckaby 2001). Associated species reported with *A. molybdenus* include species of *Acomastylis*, *Aster*, *Besseya*, *Castilleja*, *Draba*, *Dryas*, *Erigeron*, *Eritrichium*, *Kobresia*, *Oxytropis*, *Polemonium*, *Potentilla*, *Salix*, *Trifolium*, and various grasses. In some cases a particular species, rather than just the genus, was reported and these are listed in **Table 3**.

Plants have been reported to grow on slopes facing all aspects except northwest. This exception may be merely sampling error. Slopes where they have been reported are generally less than 35%, but some occurrences have been reported on slopes as steep as 70%. It may be that ease of human access accounts for the more gentle slopes being reported as the most common habitat type.

Astragalus molybdenus is found in dry to mesic habitats. Specific areas where patches of plants are often described are areas with late snow-melt or with persistent snowdrifts (Colorado Natural Heritage Program element occurrence records 2002). This suggests that *A. molybdenus* favors more mesic sites in otherwise dry habitats and also that plants may be located in areas that receive relatively more snow cover that would protect them from wind and cold during the winter. It is well documented that snow cover and duration influence plant distribution in alpine ecosystems (Willard 1979). These two considerations may contribute to the observation that habitat is somewhat hard to predict and "what looks like potential habitat often has no plants" (Colorado Natural Heritage Program element occurrence records 2002). In mid-summer, when surveys are most often conducted, it may be difficult to perceive which areas would accumulate snow sufficiently to avoid the scouring winds and bitter cold. However, recent surveys in the Crested Butte area suggest that *A. molybdenus* flourishes on barren slopes that receive little winter snow cover. Studies relating size of individuals, fecundity, and vigor to habitat characteristics would clarify habitat requirements.

Some of the areas where *Astragalus molybdenus* occurs are in a relatively undisturbed condition and unlikely to be subjected to disturbance in the future (Lehr personal communication 2002.). However, at least one occurrence found in the Gunnison National Forest in 2001 was on a disturbed site with little litter, a high percentage of bare soil, rills indicating that sediment was washing down the hillside, and pedicels indicating past soil erosion. There was also evidence of elk, sheep, and cattle grazing. Approximately 20 to 25 plants were counted in an area of 100 x 200 feet. The plants were described as small with none or few seedlings (Austin 2001). Small numbers of plants may naturally persist for long periods of time in a healthy, sustainable, but isolated population, and there are many different explanations to explain the small size of a population. This population appears to be at the edge of its range and thus the environmental conditions may be somewhat

Table 3. Species associated with *Astragalus molybdenus*, in alphabetical order. This is not an exhaustive list and represents the species reported in Colorado Natural Heritage Program element occurrence records and on herbarium specimen sheets.

Species	Species (cont.)
Achillea lanulosa	*Oxytropis viscida*
Astragalus alpinus	*Penstemon hallii*
Astragalus australis	*Polemonium confertum*
Astragalus australis ssp. *glabriusculus*	*Pulsatilla patens*
Bessya alpina	*Salix artica*
Carex rupestris	*Salix nivalis*
Cerastium beeringianum	*Sedum lanceolatum*
Claytonia megarhiza	*Senecio amplectens* var. *holmii*
Draba aurea	*Senecio wernerifolia*
Erigeron ursinus	*Silene acaulis*
Eriogonum coloradense	*Smelowskia calycina*
Eritrichium aretioides	*Trifolium dasyphyllum*
Geum rossii	*Trifolium nanum*
Oxyria digyna	*Trisetum spicatum*
Oxytropis deflexa	*Valeriana edulis*
Oxytropis podocarpa	*Zygadenus elegans*

stressful for this species. Alternatively, this occurrence may either represent a remnant population existing in degraded habitat or represent early colonization. Long-term monitoring of such a population would be valuable in understanding habitat requirements and the population dynamics of this species.

Reproductive biology and autecology

Astragalus molybdenus reproduces both sexually and asexually. There is no specific information on fertilization strategy. The genus *Astragalus* exhibits a variety of breeding systems with self-compatibility and self-incompatibility both well represented (Kalin Arroyo 1981). Self-compatible flowers may be autogamous (self-fertilized) or xenogamous (out-crossed or cross-pollinated). If the species is self-incompatible it is, of course, restricted to xenogamy. Many *Astragalus* species are commonly insect-pollinated, specifically by bees (Geer and Tepedino 1993). Bumblebees, as well as muscoid flies, are particularly prominent in alpine tundra in Colorado (Moldenke and Lincoln 1979) and are thus likely pollinators of *A. molybdenus*. However, speculation on *A. molybdenus* fertilization strategy can be argued in two ways. Using one argument it seems likely that if *A. molybdenus* were self-compatible it would be autogamous. This is likely for several reasons. Most plant species in alpine tundra are pollinator limited and must compete for visitation (Moldenke 1971). Species with papilionaceous flowers, such as *Astragalus*, are known to have autogamous lineages where pollinators are unreliable (Kalin Arroyo 1981). Several rare species of *Astragalus* in many environments, although not in the tundra specifically, have been demonstrated to be autogamous (Karron 1989, Geer and Tepedino 1993). This trait is due to a combination of species rarity and bee behavior. Bees, unlike most insect foragers, are density dependent foragers and are attracted to dense patches of flowers (Heinrich 1976, Thomson 1982). Areas with low cover such as scree slopes may have relatively infrequent bee visitation.

On the other hand *Astragalus molybdenus* may be predominately out-crossed. One may speculate the low overall cover in many communities of which *A. molybdenus* is a part may work to its favor, as flower-visitation rates may be increased due to lack of competition. Bingham (1999) reported a significant number of arctic, and by extension alpine, plant species are obligate insect-pollinated and primarily out-crossed. She demonstrated that some alpine plant species display relatively long-lived flowers with long stigma receptivity and thus experience extended opportunities for pollination (Bingham 1998, 1999). Bumble-bees, which are the most likely pollinators, are highly efficient, tend to deposit relatively high pollen loads at each visit, and therefore may need to make only a few, or even one, visit for successful fruit production (Bingham 1998). It may be that both self-pollination and out-crossing occur, depending upon conditions.

Flowering occurs from the end of June to the beginning of August, and the mature pod dehisces and seeds disperse in August and September (Lavin and Marriott 1997). Seeds have frequently been observed. However, their longevity in the soil and the seed bank dynamics are unknown. The natural germination rate is also unknown. The seeds of another mat-forming limestone endemic, *Astragalus cremnophylax* var. *cremnophylax*, are retained in the pods that remain within the mat of the parent plant for months (Maschinski et al. 1997). Seeds most frequently germinate within 10 cm of the parent plant, although seeds that germinate further away than 10 cm have a greater probability of survival (Maschinski et al. 1997). The spatially patchy distribution of *A. molybdenus* must, to some extent, be a consequence of vegetative propagation but may also indicate that seed is generally not dispersed far from the parent plant. Seed dispersal processes have not been observed, but dispersal by rodents, soil erosion, or water has been speculated (Austin 2001). Wind, ubiquitous in the alpine-tundra, also may be effective in dispersing seeds. In general, wind-dispersed seeds move only short distances (Silvertown 1987). Pikas (*Ochtona princeps*) have been observed to use *A. molybdenus* (Ray 2001). Typically pikas store vegetation, and this activity may contribute to seed dispersal. A requirement for scarification would be expected, as many members of the Leguminosae have a hard, impermeable seed coat (Spellenberg 1976, Bewley and Black 1982).

Hybridization between *Astragalus* species is a rare phenomenon (Liston 1992, Spellenberg personal communication 2003). In accordance with this observation, no evidence of hybridization between *A. molybdenus* and sympatric species has been observed.

Astragalus molybdenus is a perennial species occurring in relatively stable habitat and corresponds to the profile of a k-selected species having a stress-tolerant life strategy (MacArthur and Wilson 1967, Grime et al. 1988). Evidence suggests that *A. molybdenus* tolerates, and dispersal mechanisms may benefit from, a certain degree of natural disturbance. This is particularly indicated by its growth on scree and talus slopes that are susceptible to periodic slides and localized disturbance. Small plants were also observed in an otherwise barren patch of churned-up soil located under a snow cornice

(Rossignol personal communication 2002). These plants appeared to have originated from existing plants that had been buried under the soil that had slid down from further up the slope. Plants were also observed to colonize an old, disused trail that experiences soil erosion in the Gunnison National Forest (Johnston personal communication 2002).

Demography

Restriction site polymorphism analysis indicates that there is little genetic variation within populations (Lavin and Marriott 1997). Deoxyribonucleic acid (DNA) sequences in three populations of *Astragalus molybdenus* were analyzed using four restriction enzymes and five probes (Lavin and Marriott 1997). The DNA patterns of the two populations closest together, in Park County, were identical but differed from the population in Gunnison County (Lavin and Marriott 1997). This implies that clonal propagation via rhizomes or self-pollination predominates over cross-pollination (Lavin and Marriott 1997). Although the apparent "mat" forming habit may be an extreme consequence of limited seed dispersal, clonal propagation can be inferred to be a particularly dominant stage in the life cycle (Barneby 1964). This vegetative mode of reproduction also suggests that that many of the discrete patches observed in a population are derived from one individual. Adjacent but discrete clusters of plants may be derived from an older, established and extensive cluster that became "sub-divided" from either direct disturbance or by perturbation, such as microbial or insect infestation, that killed middle portions, which eventually deteriorated.

A simple life cycle model of *Astragalus molybdenus* is diagrammed in **Figure 5**. No demographic studies have been undertaken and transition probabilities between the different steps are unknown. Heavy arrows indicate phases in the life cycle that appear most prominent, and lighter weight arrows indicate the phases that are either apparently less significant or unknown. Steps that need to be clarified are noted by "?" at the appropriate arrow. More information is needed to define which life history stages have the greatest effect on population growth and survival.

Astragalus molybdenus' substantial rhizomatous growth appears essential for successful colonization of habitat, especially scree and talus. Population growth by clonal propagation reduces the need for yearly successful seed production and seedling recruitment. Vegetative expansion is a common regenerative strategy of stress-tolerant plants (Grime et al. 1988). However, Barneby (1964) remarked: "a curious feature of *A. molybdenus* is the relatively immense size of the seeds". Because size is related to energy expenditure, that is the allocation of photosynthate, this observation suggests that seed has an important role in the life cycle that is not obvious at the present time. Snow cover may not melt every year in some areas where *A. molybdenus* grows (Rossignol personal communication 2002). It is unknown how long underground stem and root systems of *A. molybdenus* can survive without sprouting, and a seed bank of long-lived, relatively large seeds may be important in this environment.

Demographic differences between populations of a given species at different sites are common (Silvertown 1987). Because of the range of habitat types, *Astragalus molybdenus* populations may exhibit differences in demographics and life cycle strategies. For instance, in a comparison of populations of *Plantago lanceolata*, recruitment from seed was more important to the equilibrium growth rate when plants were growing in a dry grassland than in a wet meadow, where adult survival was more important (Silvertown 1987). Similarly, differences were exhibited between populations of a rare *Arabis* species, *Arabis fecunda*. At a relatively low elevation site, adult survivorship contributed most to population growth, whereas annual fecundity and recruitment were more important at a higher elevation site (Lesica and Shelley 1995). The potential for clonal propagation complicates classic demographic analyses and estimates of minimum population size for population viability. The number of individuals *per se* becomes less important than the number of genetically diverse individuals. Unfortunately, the latter cannot be estimated without time consuming and expensive analyses.

The phenological composition of several populations observed in 1989 was described as "49% in leaf, 49% in flower, and 2% immature" (Colorado Natural Heritage Program element occurrence records 2002). This is only a single observation, but the ways in which this observation may be interpreted raise interesting questions. One interpretation may be that 49% were vegetative, pre-reproductive ramets and 2% were seedlings. The equilibrium growth rate, λ, integrates the effects of survival, growth, and fecundity of the different life history stages into a single parameter and is useful in describing critical stages in life histories (Caswell 1989, Silverton et al. 1993). For long-lived perennials where survival of the adult is most important to λ, 2% seedling recruitment is relatively high and would likely maintain a satisfactory level of

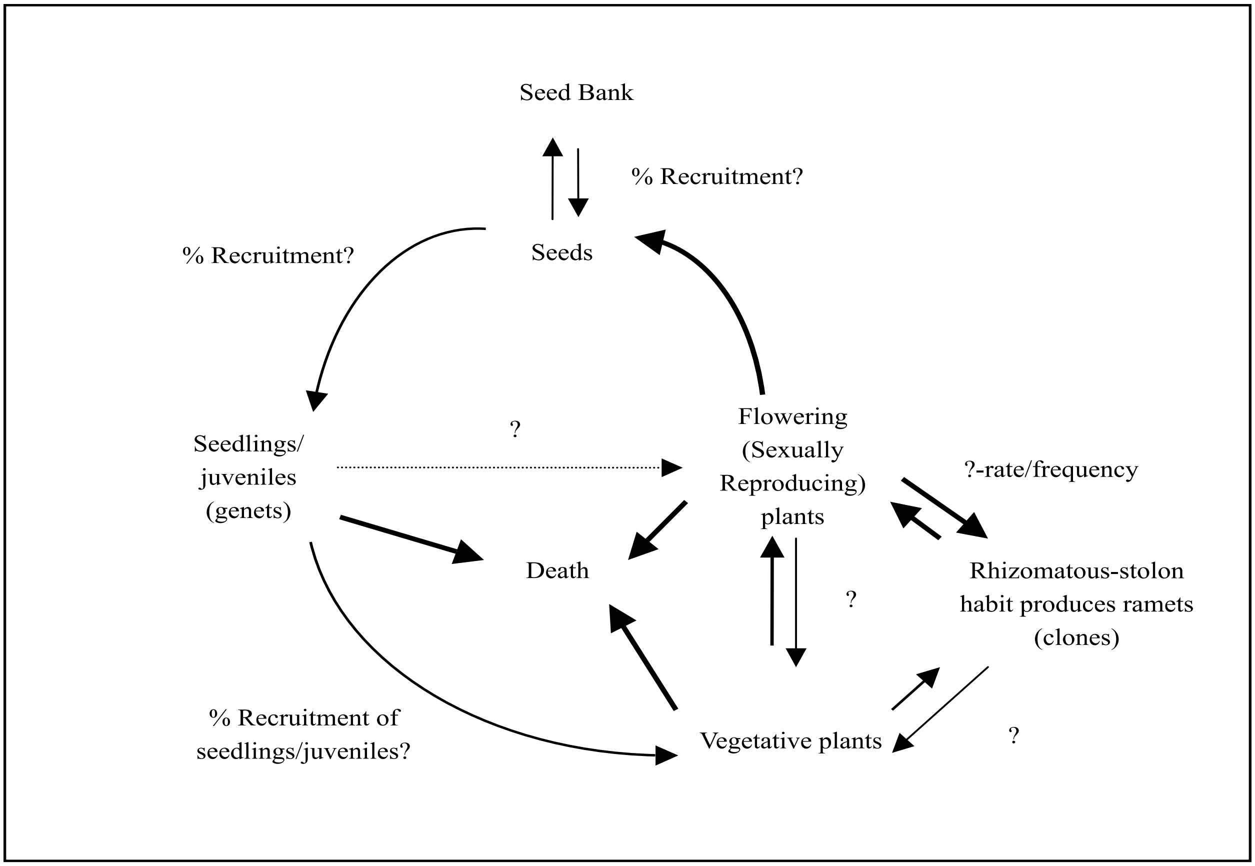

Figure 5. Life cycle diagram for *Astragalus molybdenus*.

genetic diversity within the population (Lesica 1995). However, vegetative to flowering transition dynamics are not documented, and ramet longevity is unknown. Ramets, like any individual plant, may survive less than two years, or substantially more (Silvertown 1987). The observed percentage (49%) of vegetative ramets would be sufficient to replace the flowering ramets (49%), if the latter were only to survive one or two years, but the observed proportion of juveniles (2%) may be of concern for a short-lived species that tends to be more vulnerable to environmental and demographic stochasticity (Frankel et al. 1995). Population growth would be small overall.

If transition from the vegetative to flowering state is not linear and flowering individuals revert to vegetative individuals in some years, it would suggest yet another totally different life cycle strategy where survival of the adult is most important. A third alternative explanation is that there were no seedlings, and very small ramets comprised 2% of the population. In this case, a different conclusion as to maintenance of genetic diversity would be justified, and the extreme case would be that each occurrence was dominated by a single genotype, which may lead to genetic vulnerability (Silvertown 1987). Another parameter that affects population structure is the annual length of rhizome growth. This parameter significantly influences the rate of site colonization, or re-colonization, after disturbance.

Limits to *Astragalus molybdenus* population growth are not well defined. At the present time it appears that growth is restricted by substrate and, in some areas, competition by other species. Dispersal is likely also limited. Because considerable distances of inappropriate habitat separate some populations, local selection pressures may have led to increased fitness to local conditions. This situation has significance if transplanting or reseeding areas are anticipated. Introducing seed from a population from one area may lead to fitness dilution, if plants were to crossbreed with individuals from a population locally adapted to another area.

Community ecology

The population size of this species is quite variable. A million stems distributed over an area of approximately 17 acres (Rossignol personal communication 2002) is in stark contrast to an isolated occurrence of 20 to 25 stems in an area of 1,800 m^2 (Austin 2001). One might predict that disturbance may both positively and negatively influence abundance and distribution. Generally the type, duration, and scale of the disturbance are important. There are also significant differences between natural and human-induced disturbances. *Astragalus molybdenus* obviously flourishes in areas undisturbed by human activity, as evidenced by the number of individuals observed under such conditions (Colorado Natural Heritage Program element occurrence records 2002, Lehr personal communication 2002, Rossignol personal communication 2002). However, it has also been found in areas that have experienced extensive soil erosion and current sheep and goat grazing (Austin personal communication 2002).

Livestock palatability of *Astragalus molybdenus* has not been reported. It has been reported as heavily browsed at some occurrences, and pikas, which are common on the talus slopes and in rocky tundra, may responsible (Ray 2001). Pikas are likely to use *A. molybdenus* because they apparently prefer forbs over grasses and sedges (Zwinger and Willard 1979). Rodents have also been speculated to contribute to herbivory observed on some plants (Austin 2001). Evidence of browsing suggests that *A. molybdenus* does not contain any of the toxic substances that have earned some *Astragalus* species the name "locoweed" (Allen and Allen 1981).

It is likely that *Astragalus molybdenus* does not flourish in highly competitive communities. Although it has been observed in a fairly rich tundra community, it tends to grow in low-competition environments. A turf community that includes *Carex elynoides* and *Trifolium dasyphyllum* was described as "invading *A. molybdenus* habitat", implying that this community appeared to be suppressing *A. molybdenus* growth and/or reproduction (KHD Herbarium specimen collected by Hogan and Yeatts 1995). No diseases or insect predation have been reported. There are also no studies or casual observations on mycorrhizal or rhizobium associations. Roots of some *Astragalus* species are associated with nitrogen-fixing rhizobium species, but there is no direct information for *A. molybdenus*. Nodulated species are frequently found in frigid climates, and *A. alpinus* has been found effectively and abundantly nodulated in tundra sites in Alaska (Allen and Allen 1981). If *A. molybdenus* is nodulated, it may have an important role in soil improvement in the alpine tundra region.

Envirograms for *Astragalus molybdenus* are shown in **Figure 6** and **Figure 7**. An envirogram is a graphic representation of the components that influence the condition of the species and reflects its chance of reproduction and survival. Envirograms have been used especially to describe the conditions of animals (Andrewartha and Birch 1984) but may also be applied to describe the condition of plant species. Those components that directly impact *A. molybdenus* make up the centrum, and indirect components comprise the web (**Figure 6** and **Figure 7**). Unfortunately much of the information is unavailable to make a comprehensive envirogram for *A. molybdenus*. These envirograms are constructed to outline some of the known major components that directly impact the species and also include some more speculative factors that can be tested in the field by observation or management manipulation. Dashed boxes indicate likely, but not proven, resources or malentities. At the micro-site level some interactions can be speculated, such as locally colonizing more mesic sites (see Habitat section) but the lack of direct studies on this species leads to stretching the significance of observations and forming opinions from inference rather than fact. Inferences must be tested and are dangerous in predicting responses to management decisions.

Resources for *Astragalus molybdenus* have been listed as calcareous soils providing a suitable edaphic environment, soil moisture for adequate growth, and pollinators for sexual reproduction. Snow pack itself may be a resource if it gives protection against wind erosion and windchill to some occurrences. However, it was not included in the envirogram as, if it is significant, it is so to only a few populations (see Habitat section). Alternatively, snow pack over consecutive growing seasons may be a significant malentity. Disturbance and rodents have also been included in the envirogram but with less evidence of importance. Disturbance in the form of slides from snow pack and precipitation may be a means of (re)establishing vegetative colonies and aiding dispersal of seeds. Similarly rodents or pika may contribute to seed dispersal. Malentities include invasive weeds, rodents, pikas, extended snow pack, soil erosion, anthropogenic disturbance, and selective herbivory, especially by sheep. Invasive plant species will be direct competitors for resources, such as water, nutrients, and light. Herbivorous rodents and livestock, especially selective feeders such as sheep, can adversely impact both asexual and sexual reproduction and root production. Significant disturbance that directly impacts plants, for example, removal of topsoil and destruction by motorized vehicles or repetitive foot traffic, will

			Centrum
n	2	1	Resources

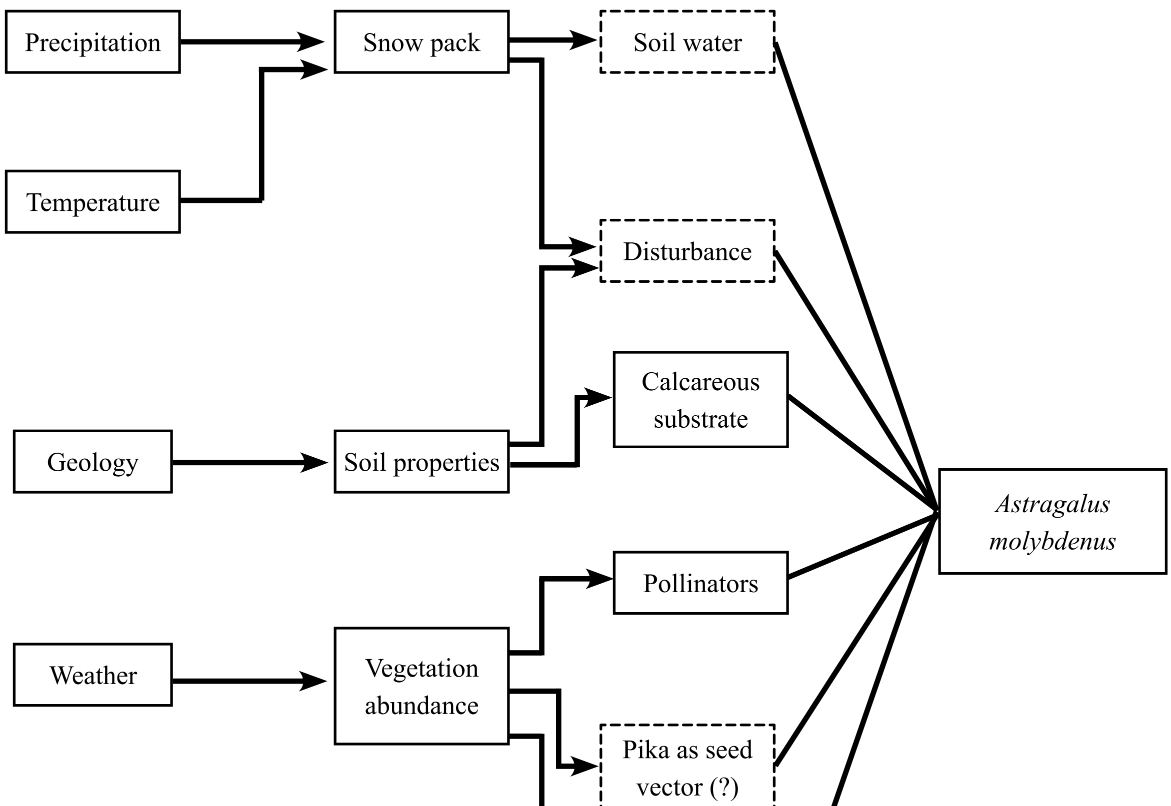

Figure 6. Envirogram of the resources of *Astragalus molybdenus.*

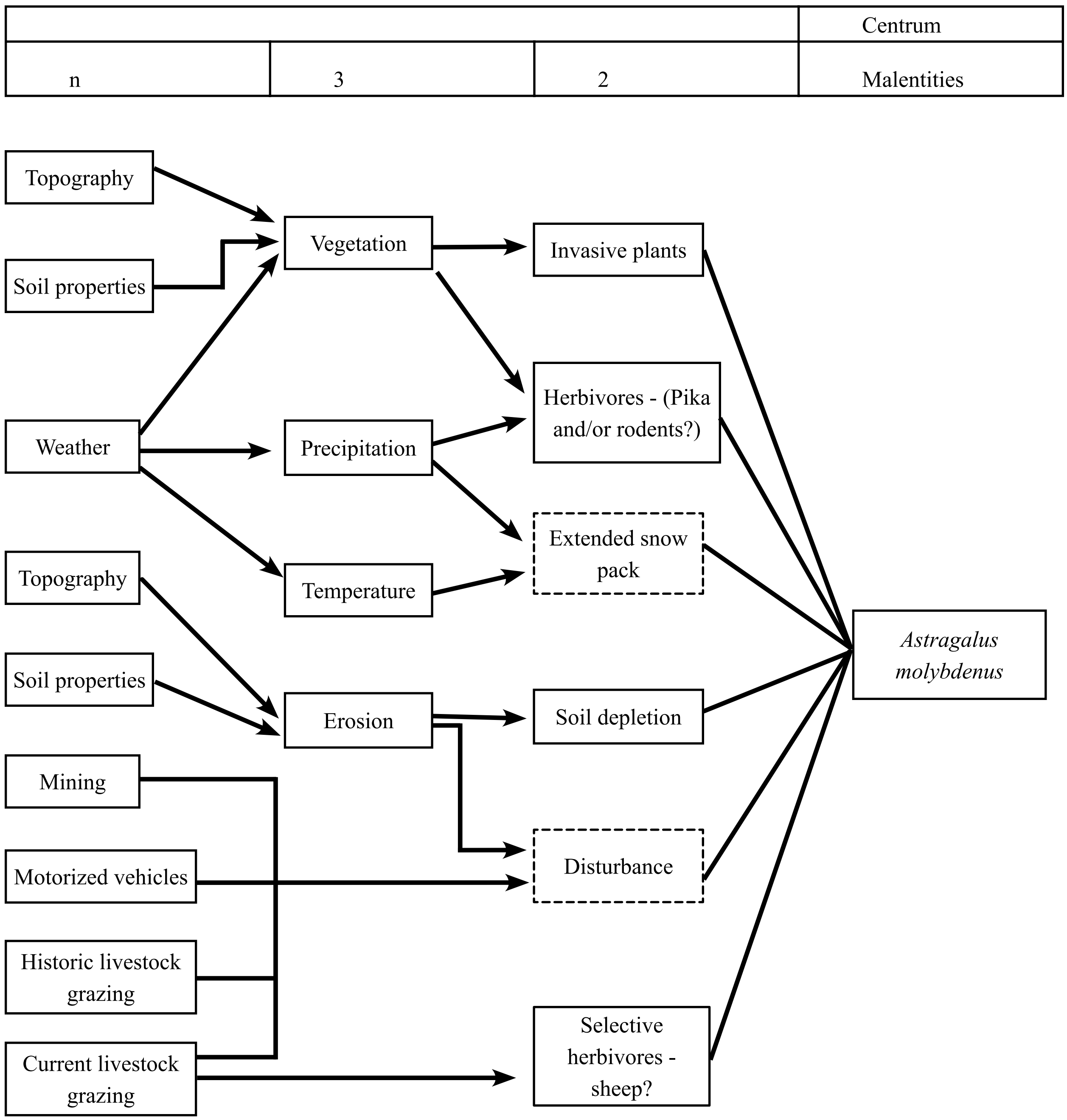

Figure 7. Envirogram outlining the malentities to *Astragalus molybdenus*.

impact populations. Forces contributing to soil erosion are deleterious over the long term. The extent and duration of most of the malentities are important factors and need further study.

Conservation

Threats

Threats and potential threats that have been identified are related to mining, human recreation, herbivory, interspecific plant species competition, global climate change, and pollution. Some of these factors were also alluded to in the Community Ecology section. All of these threats are applicable to at least some populations on land managed by the USFS in Region 2. Although there is little on a local level that can be done to avoid the consequences of the threat of global warming, control of pressures that contribute to stress may mitigate the impacts in the short term to some extent. Each threat or potential threat is discussed briefly in the following paragraphs.

Mining activities have most likely affected some populations, but it is unknown what the consequence to the overall abundance of the species has been. Currently, mining still may threaten some populations (for example occurrences 18, 26, 30, and 35 in **Table 2**). Mining activities do not appear to be a significant threat at the current time on land managed by the USFS but that situation may change in the future (see Existing Regulatory Mechanisms, Management Plans, and Conservation Strategies section).

Recreational activities that include hiking and use of motorized vehicles present a threat. Off-road vehicle (ORV) traffic is perceived as a significant threat on BLM land (Ray 2001). However, snowmobiles, ORVs, dirt bikes, and all-terrain vehicles that leave designated trails can be directly detrimental to habitat and may pose a threat to some populations on National Forest System land (Coles 1996, Johnston personal communication 2002). Although the Continental Divide National Recreation Trail was diverted to avoid some occurrences on the Hoosier Ridge RNA (see Existing Regulatory Mechanisms, Management Plans, and Conservation Strategies section), it is still in close proximity, or across, some other populations on National Forest System land (see occurrences 6 and 34 in **Table 2**). Lasting effects on soil structure and soil compaction are also direct effects of vehicle and foot traffic. Trails generally last a long time in *Astragalus molybdenus* habitat. After 40 years of disuse, one trail has remained clearly defined and without vegetation (Willard 1979). However, Johnston (personal communication 2002) observed that *A. molybdenus* had colonized, or re-colonized, a disused trail in the Gunnison National Forest. Hiking may be a substantial threat. Thousands of people are estimated to walk in the alpine tundra regions each weekend during the spring, summer, and autumn (Morrow radio communication 2002). On one trail alone, 250 people were counted on one weekend day. Hiking trails have become 12 to 15 feet wide in some areas (Morrow radio communication 2002). Some areas, such as the land managed by the USFS on Taylor Pass, currently have such heavy recreational use that re-vegetation measures have been needed at parking areas (Lyon 1995). As small mountain towns become more populated and access to the high country becomes easier, recreational pressures will increase. Ski areas are established within the range and habitat of *A. molybdenus*, but there is no documentation on the impacts of skiing and related maintenance and construction activities. A popular cross-country ski trail within the Bemrose ski network crosses the Hoosier Ridge RNA on the White River and Pike-San Isabel national forests. This activity is not expected to impact the rare species there (Colorado Natural Heritage Program 1998).

Astragalus molybdenus has been reported heavily browsed at some occurrences (see Community Ecology section). Pikas that are common on talus slopes and in rocky tundra were suggested as being responsible (Ray 2001). Presumably this activity at "historically average" levels poses no threat, but any perturbation that increases such activity, for example depletion of pika predators or warmer winter temperatures that increase pika population size, may be detrimental over a long period of time. Goat and sheep grazing is an accepted land use practice in *A. molybdenus* habitat, but there are no studies on the effects of grazing on the species. In general, under current management on National Forest System land, sheep tend to pass through *A. molybdenus* habitat in transit between more verdant pastures (Johnston personal communication 2002). There are no studies to indicate its palatability to livestock, but because it is palatable to pikas it is likely non-toxic to domestic livestock. Sheep tend to be selective in their choice of plant species but predicting the preferred species is difficult (Strasia et al. 1970). This is an important consideration because species that are selected by sheep are documented to be more abundant on ungrazed land, implying that grazing negatively affects abundance (Strasia et al. 1970, Bonham 1972).

Invasive weeds, such as yellow toadflax (*Linaria vulgaris*), spotted knapweed (*Centaurea biebersteinii*), and scentless chamomile (*Matricaria perforata*), have all been reported at or above the treeline and are potential threats (Ray 2001). There is no information available to determine the imminence of noxious weed invasion to any particular occurrence. In addition to noxious weeds, some persistent species that have been used for re-vegetation projects may pose a threat. A turf community that includes *Carex elynoides* was reported to "invade" *Astragalus molybdenus* habitat (see Community Ecology section; occurrence 12 in **Table 2**). Although comparisons between communities comprising different species from different geographic areas must always be treated cautiously, it may be relevant to consider a *Carex* community in Asia and the Middle East. This community, which is promoted by goat and sheep grazing, eventually presents an impenetrable cover so that many native species are extirpated from the community (Pabot 1980).

A significant threat to alpine tundra plants is global climate change. Warming could affect alpine areas, causing tree lines to rise by roughly 350 feet for every degree Fahrenheit of warming. Mountain ecosystems, such as those found in Rocky Mountain National Park, could shift upslope, reducing habitat for many subalpine and alpine tundra species (U.S. Environmental Protection Agency 1997). In the last 100 years, the average temperature in Fort Collins, Colorado, has increased 4.1 °F, and precipitation has decreased by up to 20 percent in many parts of the state. The United Kingdom Hadley Centre's climate model (HadCM2) accounts for both greenhouse gases and aerosols. The Intergovernmental Panel on Climate Change and results from HadCM2 have projected that by 2100 temperatures in Colorado could increase by 3 to 4 °F in spring and fall (with a range of 1 to 8 °F), and 5 to 6 °F in summer and winter (with a range of 2 to 12 °F).

Atmospheric deposition of nitrogen oxides and ammonium are increasing throughout the world. The western United States has been less affected than the east, but there are hotspots of elevated wet nitrogen (acid rain) deposition in southern California and along the Colorado Front Range when compared with the rest of the West (Barron 2001). Acid rain occurring in the high mountain areas of the Colorado Front Range is great enough to cause chemical and ecological change (Baron et al. 2000, Baron 2001, Rueth and Baron 2002). Experiments have indicated that nitrogen additions in alpine tundra influence the species composition of the community (Bowman et al. 1993, Theodose and Bowman 1997). Grasses particularly increased in abundance, at the expense of other species, in dry-meadows in response to additional nitrogen. Therefore, there is the potential that an increase in the amount of nitrogen cycled will have a detrimental impact on *Astragalus molybdenus*. Given the remote locations of most occurrences, other forms of pollution seem an unlikely threat. However, a study sponsored the Colorado School of Mines, the National Park Service, and Public Counsel of the Rockies, analyzed the chemical content of snow near a snowmobile route (Skid Marks Newsletter 2000, Ray 2001). It reported "an unnatural level of pollution", and at least 20 hydrocarbon compounds, some toxic and carcinogenic, were located 50 feet above the snowmobile route. The significance of this finding to the sustainability of populations near such routes, for example west of Hoosier Pass on National Forest System land, cannot be evaluated without further information.

Hybridization, and thus genetic contamination, with native sympatric *Astragalus* and introduced, non-native plant cultivars (for example *A. cicer*) has been proposed as a threat (Ray 2001). However, hybridization between *Astragalus* species is a rare phenomenon, and no evidence of hybridization between *A. molybdenus* and sympatric species has been reported (see Reproductive Biology and Autecology section; Liston 1992, Spellenberg personal communication 2003).

At the current time, the primary threats on National Forest System lands are most likely associated with recreation: off-road vehicles, hiking, and biking. Resource extraction may be significant in the future, depending upon the ease of extraction and the market desirability of any of the many ores that reside beneath *Astragalus molybdenus* habitat. Livestock grazing appears to be of low concern at the current time. However, this would change if it is found that *A. molybdenus* is preferentially selected as forage.

In summary, the threats to *Astragalus molybdenus*, including those concerned with global climate change, are largely dependent upon the extent and intensity. However, the emphasis is "current levels." Even if the intensity of a threat remains the same, an increase in its area of impact will have negative consequences on the species because alpine tundra systems are relatively fragile and are very slow to recover from destructive forces. In addition, the potential colonization by invasive and competitive plant species that will be exacerbated by anthropogenic disturbances and warming temperatures should not be underestimated.

Conservation Status of the Species in Region 2

There is no evidence that the distribution or abundance of this species is declining in Region 2. Recently, Rossignol (2001) and Austin (2001) observed previously undocumented occurrences, and it appears that large tracts of unexplored, suitable habitat exist, which could support more populations (Lehr personal communication 2002, Rossignol personal communication 2002). Evidence supports speculation that this species is subject to considerable environmental stochasticity. Over time, populations are likely subjected to considerable environmental variation that includes variable abundance of herbivores, uncertain weather conditions, and natural disasters such as avalanches, slides, drought, ice storms, and prolonged snowpack. Management practices that increase either the frequency or intensity of natural perturbations, or provide additional stresses may significantly impact population viability. Because of specific designation of land management unit (for example, RNA and Wilderness status) or remote location, there appear to be several populations that are secure within Region 2 at the present time (including occurrences 3, 5, 8, 33, and potentially 29 in **Table 2**). These relatively protected populations may have range-wide importance, because this endemic species is not afforded protection on other land. The security of the populations within the Mosquito Pass ACEC is unclear because their precise locations are not known and they may be on patented mining claims or private land that is intermingled with BLM land in the ACEC.

Management of the Species in Region 2

Implications and potential conservation elements

Mining is likely to have taken a toll on some populations of *Astragalus molybdenus*. Permanent structures and associated vehicular traffic as well as the mine itself disturb large areas and may modify vegetation cover permanently. In addition, because of the fragility of the alpine tundra ecosystem, especially dry sites with a high potential for soil erosion, it is likely some practices such as grazing and some recreational activities have also impacted populations. Some disturbance is a natural feature in the life cycle of *A. molybdenus*. However, there is little information on which to base predictions as to its response to specific disturbance types or levels. For example, one may speculate that a combination of hoof action and non-selective, moderate, transient sheep grazing will have little impact. Correspondingly, the combination of hoof action of a fewer number of sheep that selectively graze the above ground stems over successive years may be severely detrimental to both sexual and asexual reproduction and lead to extirpation or impoverished populations. However, the veracity of either statement is unknown. Palatability, the rates of recovery of above ground tissue, the importance of seed production, and the tolerance to different levels of ground disturbance are all factors for which there is little definitive information on which to base a management plan.

When considering which populations to protect from anthropogenic disturbance, it is important to remember that rare species often exhibit genetic differences between populations. Small populations may be genetically depauperate as a result of changes in gene frequencies due to inbreeding, or founder effects (Menges 1991) and locally endemic species tend to exhibit reduced levels of polymorphism (Karron 1991). However, the value of small populations should not be disparaged. For example, alleles that were absent in larger populations were found in a small population of *Astragalus osterhouti* (Karron et al. 1988). Therefore, without molecular data on genetic structure, in order to conserve genetic variability it is as important to conserve as many populations as possible and "larger" is not necessarily "better". The genetic analysis of Lavin and Marriott (1997) is particularly valuable in providing data on which to base such management decisions. The two populations nearest together in Park County, North London Mines and Hoosier Ridge (only the latter being on Forest Service land; see occurrence 8 in **Table 2**), are genetically very similar but significantly different from the population at Taylor Pass (on White River and Gunnison national forests) in Gunnison County (Lavin and Marriott 1997). The North London Mines and Hoosier Ridge populations are separated from the Taylor Pass population by six mutations. This observation indicates that it is especially important to conserve geographically separated populations, in this case one in each of Park and Gunnison counties, however small they are. This study also emphasizes the importance of detecting any indications of range contraction. It is likely that loss of populations at the edge of the range will cause a significant loss of genetic diversity (see Demography section).

Tools and practices

Documented inventory and monitoring activities are critically needed for this species. Many of the 36 occurrences are derived from herbarium specimens or relatively casual observations by botanists and do not provide quantitative information on abundance and spatial extent of the populations. Evidence of persistence is valuable but will not provide advance-warning signs of dwindling population size and potential extirpation.

Species inventory

Some areas, for example the Maroon Bells-Snowmass Wilderness Area on the White River National Forest, have recently received proportionally more attention than other areas within its range, and perceptions of population distribution may be skewed. The current "Field survey form for endangered, threatened or sensitive plant species" used by the Gunnison National Forest (Austin 2001) and the Colorado Natural Heritage Program both request the collection of data that is appropriate for inventory purposes. An additional formal "space" to show a diagrammatic representation of the occurrence may be useful if an aggregated spatial pattern or "patch structure" needs further explanation. The number of individuals, the area they occupy, and the apparent potential habitat is important data for occurrence comparison. The easiest way to describe populations over a large area may be to count patches, making note of their extent and estimate numbers of individuals within patches. These parameters give important details of population structure. Rossignol (personal communication 2002) used transect methods to determine the population size within a small part of a larger area that he determined had uniformly suitable habitat. He estimated total abundance by extrapolation after making a less intensive survey of the whole area. This latter step is essential. Revision of the extrapolated total abundance can be made according to the observed population structure and habitat conditions throughout the area under consideration. Because of spatial aggregation it is very easy to overestimate abundance when extrapolating from a small area to a larger area. Collecting information on phenology is also valuable in assessing vigor of a population. However, because of the incomplete understanding of the relationship between size and age and the likely difficulties distinguishing ramets from genets, describing individuals as either flowering, vegetative, or juvenile may be the least misleading.

Habitat inventory

Habitat descriptions suggest that, within the restrictions of geology and the eco-climate zones in which it exists, this species grows in a variety of habitats. It would likely be prudent to consider any areas of calcareous soils or limestone in alpine tundra and sub-alpine regions above 9,600 feet as potential habitat. However, there appears insufficient understanding of all the features that comprise "potential" habitat to be able to make a rigorous inventory of areas that will actually be colonized. There are no studies that relate the abundance or vigor of populations to elevation or habitat conditions. The available information supplied with habitat descriptions of the occurrences is generally too diverse to make accurate analyses.

Population monitoring

Because of the mat-like growth form and likely vegetative propagation, discussed in the Reproductive Biology and Autecology section, the term "genets" may be an erroneous description of individuals (Colorado Natural Heritage Program element occurrence records 2002). Description of population size is less ambiguous if counts of "individuals" are made rather than assigning ramet or genet status without detailed study. No monitoring or demographic studies have been reported. Revisits to occurrences have generally provided evidence of persistence rather than evidence of increase or decrease in population size and vigor. Valuable information in a monitoring scheme would be to describe the spatial dynamics of the patches within the populations range over time. Describing the numbers of clusters or "patches" of plants may be the most rapid way to describe populations, but if clusters or "patches" are recorded it is essential that the local areas they cover, as well as the overall extent of the population, be described.

Specific monitoring plots with photo-points are very useful, not only in areas with recreational or resource extraction activities, but also in more pristine areas where the consequences of natural disturbances such as erosion, landslides, and local soil disturbance can be evaluated. The monitoring scheme should address the patchy and possibly dynamic nature of some of these occurrences. Problems associated with spatial auto-correlation can occur when using permanent plots to monitor a dynamic population. If the size of the plot is too small or the establishment of new plots is not part of the original scheme, when plants die and no replacement occurs it is impossible to know the significance of the change without studying a very large number of similar plots. Permanent transects may be the most accurate way to study long-term trends. Goldsmith (1991) and Elzinga et al. (1998) have discussed using a rectangular quadrant frame along transect lines to effectively monitor the "clumped-gradient nature" of populations.

Habitat monitoring

The relative lack of information on habitat requirements makes it premature to consider habitat monitoring in the absence of plants. Habitat monitoring should be associated with population monitoring protocols. Descriptions of habitat should be recorded during population monitoring activities in order to correlate environmental conditions with abundance over the long-term. Conditions several years prior to the onset of a decrease or increase in population size may be more important than conditions existing during the year the change is observed. Current land use designation and land use activities are important to include with monitoring data. For example, where possible, it should be noted if populations are on an active grazing allotment even though no use by livestock may be observed.

Population or habitat management approaches

There have been no systematic monitoring programs for the populations in protected areas and therefore the benefits cannot be evaluated. Beneficial management practices within national forests include restricting recreational vehicle traffic to designated trails, routing hikers to designated trails when they pass through known populations, and enforcing re-vegetation policies that restrict persistent introduced species and emphasize local germplasm of native plants (Austin personal communication 2001, Johnston personal communication 2002). All these policies are relatively recently initiated, and their consequences have not been documented.

Information Needs

The most pressing need is more information on the numbers, distribution, and range of this species. Although it is locally abundant in some places, the extent of its range and abundance within that range are not well defined. Current evidence suggests that potential habitat includes any outcrop of limestone or calcareous soils in the alpine tundra zone in central Colorado. Therefore, there is potential for more populations to be located during appropriate surveys. Its perceived rarity may be due to a lack of surveys. However, it may be a naturally uncommon species or one that has experienced a decline in the last century.

Inventory may be the most important need, but monitoring activities are essential to understand the implications of new management practices. Where management practices are likely to change, inventory should be taken to collect baseline data and periodic monitoring should be conducted after the new policy is initiated. Establishing exclosures, with photo points, is always valuable, but they should be sufficiently large to avoid suffering from impacts initiated outside the exclosure. For example, if an exclosure is downslope of a trail it will be directly impacted by sediment run-off that is entirely dependent on the conditions upslope of the exclosure. Similarly, if an exclosure is located within 50 feet of a snowmobile trail, plants within the exclosure may be impacted by pollution directly associated with activity outside of the exclosure. It is vital that accurate records of initial population size and demographic structure be collected.

Habitat requirements need to be more rigorously defined. The ability to tolerate competition is speculated as low. However, the observation that a turf community was invading *Astragalus molybdenus* (see Community Ecology section) needs further evaluation of natural spatial and temporal dynamics, that is succession, of the communities. In this case monitoring the area to determine the cause of the "invasion" is valuable in assessing potential threat.

The ecology, reproductive biology, and relative importance of different stages of its life cycle are largely assessed in this document by comparison to other species rather than through direct studies on *Astragalus molybdenus*. The factors that limit population size and abundance and that contribute to the variable sized occurrences are not known. As mentioned in the Habitat section, it is unclear what constitutes sustainable habitat. *Astragalus molybdenus* has an extensive rhizome system and, potentially, rhizobial associations. These characteristics permit it to colonize large tracts of land, stabilizing otherwise highly erosive soils, and potentially contributing to soil building. Therefore, this rhizomatous perennial may be a particularly important component of the alpine tundra ecosystem of which it is part.

Information needs can be summarized as follows:

- ❖ More information is required on the numbers, distribution, and range of this species.

- ❖ More monitoring of known populations is required to determine the impact of management actions, human-caused disturbance, invasive species, and natural perturbation, such as pika herbivory and land slides.

- ❖ More information on sustainable habitat conditions would facilitate the development of bio-rational management plans.

- ❖ Studies on the reproductive biology and demography of the taxon need to be made. Specific questions could include:
  - ♦ Is it predominately self-pollinating or cross-pollinating?
  - ♦ If cross-pollinating, what are the pollinators?
  - ♦ What is (are) the most critical part(s) of its life cycle?

DEFINITIONS

Allopatry - Applied to the geographical relationship of different species or sub-species that do not occur together, i.e. having different areas of distribution. Compare "sympatric" (Abercrombie et al. 1973)

Aneuploid - Applied to a cell or an organism whose chromosome number is greater by a small number than the normal chromosome number for that species (Allaby 1992).

Appressed - Lying flat or close against something.

Autogamous or Autogamy - Self-fertilized, self-fertilization.

Calyx - Outermost part of a flower, consisting usually of green, leaf-like members known as sepals (Abercrombie et al. 1973).

Caudex - The perennial region between the base of the stem and the top of the roots that is slowly elongating and commonly branched.

Clade - A clade is a group of all the organisms that share a particular common ancestor and therefore have similar features. The members of a clade are closely related to each other.

COLO - Abbreviation for the herbarium at the University of Colorado at Boulder, Colorado.

Euploid - A cell or organism that has any number of complete chromosome sets (Allaby 1992).

Keel - In the context of this report a keel is the name for the two anterior united petals of the *Astragalus* flower.

KHD - Abbreviation for the Kathryn Kalmbach Herbarium at the Denver Botanical Garden, Denver, Colorado.

Mucroniform - Having a short, abrupt, small tooth-like tip.

Phalanx - In North America, the species in the genus *Astragalus* are divided into "phalanxes" (which can be thought of as "sub-genera") that in turn are divided into sections and sometimes further into sub-sections (Barneby 1964).

Rank - NatureServe and the Heritage Programs Ranking system (Internet site: http://www.natureserve.org/explorer/granks.htm). G3 indicates *Astragalus molybdenus* is "vulnerable globally either because it is very rare and local throughout its range, found only in a restricted range (even if abundant at some locations), or because of other factors making it vulnerable to extinction or elimination". S2 indicates it is "imperiled in the nation or subnation because of rarity or because of some factor(s) making it very vulnerable to extirpation from the nation or subnation".

Retorse - Directed backward or downward.

Section - In North America the species in the genus *Astragalus* are divided into "phalanxes" (which can be thought of as "sub-genera") that in turn are divided into sections and sometimes further into sub-sections (Barneby 1964).

Sympatric - Species or sub-species that occur together, that is, with areas of distribution that coincide or overlap (Abercrombie et al. 1973).

Commonly Used Synonyms of Plant Species

The commonly used synonyms of plant species (Kartesz 1994) mentioned in the Habitat section of this report. The reference in parentheses refers to a flora in Region 2 in which the synonym is used:

Sedum lanceolatum	*Amerosedum lanceolatum* (Weber 1987)
Zigadenus elegans	*Anticlea elegans* (Weber 1987)
Eritrichium aretioides	*Eritrichum aretioides* (Weber 1987)
Eutrema penlandii	*Eutrema edwardsii* ssp. *penlandii* (Weber 1987)
Senecio amplectens var. *holmii*	*Ligularia holmii* (Weber 1987)
Senecio wernerifolia	*Packera wernerifolia* (Weber 1987)
Centaurea biebersteinii	*Acosta maculosa* (Weber 1987)
Centaurea biebersteinii	*Centaurea maculosa* (Dorn 2001)

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