Astragalus wetherillii Jones (Wetherill's milkvetch): A Technical Conservation Assessment

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Astragalus wetherillii (Wetherill's milkvetch). Photograph by William Jennings, used with permission.

Summary of Key Components for Conservation of *Astragalus wetherillii*

Status

Astragalus wetherillii (Wetherill's milkvetch) is a local endemic whose global distribution is limited to Colorado west of the Continental Divide. Occurrences have been reported from approximately 50 sites in the Yampa, Colorado, Gunnison, Uncompahgre, and San Miguel river drainages. Documented occurrences include one site on the Rifle Ranger District of the White River National Forest and one on the Norwood Ranger District of the Grand Mesa, Uncompahgre, and Gunnison National Forests. Occurrences are also known from Bureau of Land Management lands, State of Colorado land, and private property. *Astragalus wetherillii* is considered a sensitive species in Region 2 of the USDA Forest Service. Due to its small global distribution, it is ranked G3S3 (vulnerable both globally and in the state, because of rarity or other factors) by NatureServe and the Colorado Natural Heritage Program. It is not listed as threatened or endangered under the Federal Endangered Species Act (1973, U.S.C. 1531-1536, 1538-1540).

Primary Threats

Although *Astragalus wetherillii* is locally common in parts of its range and does not appear to be in significant decline, its entire global range is contained within the five river drainages mentioned above. Widespread threats in these drainages will affect the entire species. Based on the available information, there are several probable threats to *A. wetherillii*. In order of decreasing priority, these are road building and maintenance, off-road vehicle use, oil and gas development, livestock trailing, residential development, exotic species invasion, and global climate change. Without systematic tracking of population trends and conditions, and without a better understanding of the species' life cycle, there is the possibility that one or more of these factors will threaten the long-term persistence of the species without anyone being aware of it.

Primary Conservation Elements, Management Implications and Considerations

Factors controlling the distribution and abundance of *Astragalus wetherillii* are largely unknown. The broad range and sporadic distribution pattern makes it likely that all threats will not be operating at the same intensity in every occurrence. Surface-disturbing activities such as road building and energy resource development are the primary source of habitat alteration; minimizing the impacts of these activities will have the greatest effect on protecting the species.

The majority of known occurrences (28 of 50) occur at least in part on Bureau of Land Management lands, and two are on National Forest System lands. Interagency cooperation in tracking the status of known *Astragalus wetherillii* occurrences would greatly facilitate conservation of the species. Current understanding of the distribution and abundance of *A. wetherillii* suggests that it should remain a species of concern, even though it is clearly not among the most imperiled Colorado's endemic species.

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INTRODUCTION

This assessment is one of many being produced to support the Species Conservation Project for the Rocky Mountain Region (Region 2), USDA Forest Service (USFS). *Astragalus wetherillii* (Wetherill's milkvetch) is the focus of an assessment because it is a sensitive species in Region 2 (USDA Forest Service Rocky Mountain Region 2005). Within the National Forest System, a sensitive species is a plant or animal whose population viability is identified as a concern by a Regional Forester because of significant current or predicted downward trends in abundance and/or habitat capability that would reduce its distribution (FSM 2670.5(19)). A sensitive species requires special management, so understanding of its biology and ecology is critical.

This assessment addresses the biology of *Astragalus wetherillii* 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 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, and conservation status of certain species based on available scientific knowledge. The assessment goals limit the scope of the document to summaries of scientific knowledge, discussion of broad implications of that knowledge, and outlines of information needs. The assessment does not seek to develop specific management recommendations. Rather, it provides the ecological background upon which management must be based by focusing on the consequences of changes in the environment that result from management (i.e., management implications). Furthermore, this assessment cites management recommendations proposed elsewhere and examines the success of those recommendations that have been implemented.

Scope of Assessment

This conservation assessment examines the biology, ecology, conservation, and management of *Astragalus wetherillii*, whose current range is contained entirely within Region 2. This document is concerned with reproductive behavior, population dynamics, and other characteristics of this species in the context of the current environment rather than under historical conditions. The evolutionary environment of the species is considered in conducting the synthesis, but placed in a current context.

In producing the assessment, I reviewed refereed literature, non-refereed publications, research reports, and data accumulated by resource management agencies. While no refereed publications are devoted entirely to *Astragalus wetherillii*, it is mentioned in a variety of sources. Because research has not been conducted on many facets of the biology of *A. wetherillii*, literature on its congeners was used to make inferences. The refereed and non-refereed literature on the genus *Astragalus* and its included species is more extensive and includes many endemic or rare species. Not all publications that include information on *A. wetherillii* or other *Astragalus* species are referenced in the assessment, nor were all published materials considered equally reliable. Material treating common or non-native species of *Astragalus* was generally omitted, as was material that included only brief mention of *A. wetherillii* without providing new information. This assessment emphasizes refereed literature because this is the accepted standard in science. However, due to the lack of refereed material directly pertaining to this species, non-refereed publications and reports were used, but these must be regarded with greater skepticism.

In this document, the term "occurrence" is used to refer to a discrete group of *Astragalus proximus* plants that are physically separated from the next nearest known group of *A. proximus* plants by at least one kilometer. Within an occurrence, individual plants may be distributed in a patchy pattern, but all are within the minimum separation distance. This usage is synonymous with "occurrence" as used by NatureServe and state Heritage Programs. In NatureServe's lexicon, "occurrence" implies that members of such a group are much more likely to interbreed with one another than with members of another occurrence, and thus an occurrence may also constitute a genetic population. I also sometimes use the term "location" or "station" to refer to a physically discrete occurrence. In this document, the term "population" is not used to refer to the entire complement of *A. proximus* individuals present in Region 2 (the meta-population).

Treatment of Uncertainty in Assessment

Science represents a rigorous, systematic approach to obtaining knowledge. Competing ideas regarding how the world works are measured against observations. Because our descriptions of the world are incomplete and our observations are limited, science focuses on approaches for dealing with uncertainty. A commonly accepted approach to science is based on a progression of critical experiments to develop strong inference (Platt 1964). However, it is difficult to conduct experiments that produce clean results in the ecological sciences. Observations, inference, critical thinking, and models must instead be relied on to guide our understanding of ecological relations. Confronting uncertainty, then, is not prescriptive. In this assessment, the strength of evidence for particular ideas is noted, and alternative explanations are described when appropriate.

Treatment of This Document as a Web Publication

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 reports. More importantly, Web publication facilitates revision of the assessments, which will be accomplished based on guidelines established by Region 2.

Peer Review of This Document

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 two recognized experts in this or related taxa. Peer review was designed to improve the quality of communication and to increase the rigor of the assessment.

MANAGEMENT STATUS AND NATURAL HISTORY

Management Status

The U.S. Fish and Wildlife Service included *Astragalus wetherillii* on the first candidate Notice of Review list in 1975 (Federal Register 40(127)), at which time it was known from only six or seven locations. It was originally listed as a Category 2 candidate species; the Category 2 list includes taxa for which a proposal to list as endangered or threatened is possibly appropriate, but for which there is insufficient data on biological vulnerability and threat (Federal Register 45(82491)). The species was subsequently downlisted to Category 3C, which includes taxa that have proven to be more abundant or widespread than previously believed as well as taxa that are not subject to any identifiable threat (Federal Register 48(53662) and 50(39526)). *Astragalus wetherillii* was removed from consideration altogether in 1996 when the U.S. Fish and Wildlife Service eliminated the Category 2 and Category 3 lists (Federal Register 61(64481)).

USDA Forest Service Rocky Mountain Region (2005) currently considers *Astragalus wetherillii* to be a sensitive species. The Region 2 sensitive species list revision process completed in 2003 retained *A. wetherillii* on the sensitive list "due to its rarity, narrow distribution, documented threats, and downward population trends" (USDA Forest Service Rocky Mountain Region 2003). Documented occurrences on National Forest System lands include one site on the Rifle Ranger District of the White River National Forest, and one on the Norwood Ranger District of the Grand Mesa, Uncompahgre, and Gunnison National Forests. At least 48 additional occurrences are known from Bureau of Land Management (BLM) lands, State of Colorado lands, and private property (**Figure 1**, **Table 1**). The species is not currently on the Colorado BLM State Director's Sensitive Species List, but it has been in the past (Bunin 1992). *Astragalus wetherillii* historically occurred within USDA Forest Service Region 4 (Utah), but it is not included on that region's sensitive species list.

Based on the status of the taxon throughout its range, the global NatureServe rank for *Astragalus wetherillii* is G3, defined as "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. A G3 taxon typically has 21 to 100 occurrences or between 3,000 and 10,000 individuals" (NatureServe 2004). The Colorado Natural Heritage Program ranks this species S3, indicating that its rarity (21 to 100 occurrences) or other factors render it vulnerable to extinction or elimination in the state. In Utah, *A. wetherillii* is ranked SH, which indicates that the species was known historically from the state but is possibly extirpated.

Existing Regulatory Mechanisms, Management Plans, and Conservation Strategies

Astragalus wetherillii is no longer a candidate for Threatened or Endangered status under the

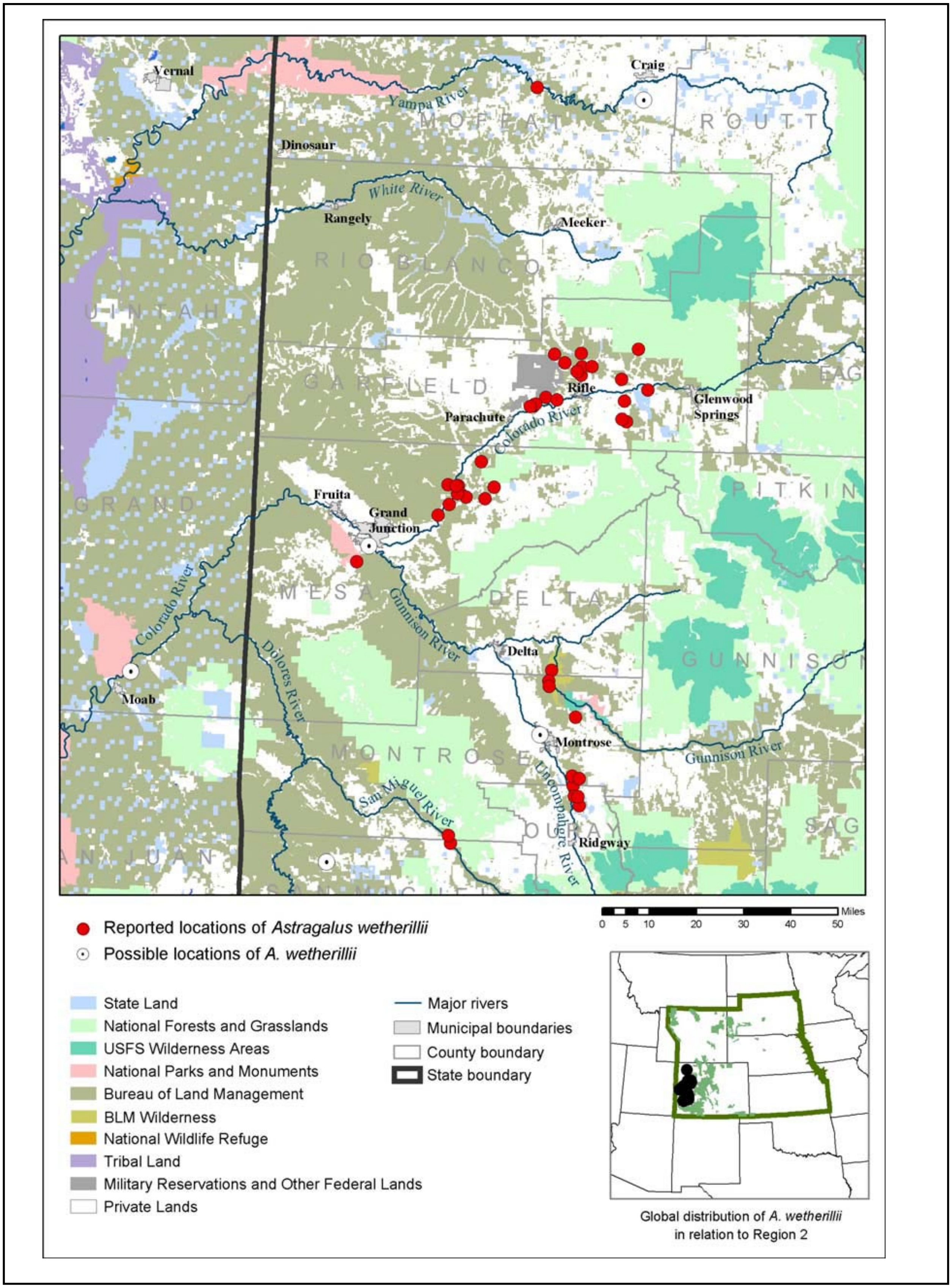


Figure 1. Land ownership throughout the range of *Astragalus wetherillii*.

Table 1. Documented occurrences of *Astragalus wetherillii* within USDA Forest Service Region 2.

Arbitrary occurrence number	County	Site	Ownership[1]	Date of last observation	Elevation (ft.)	Habitat[2]	Last known population size	Source[3]
1	Moffat	Little Juniper Mountain	BLM	14 June 1979	6,040	Streamside; pinyon-juniper community; slope 30º, aspect west.	unknown	CNHP (EOR-1)
2	Moffat	South of Craig	unknown	12 June 1953	6,600	Open ground among sagebrush.	unknown	CNHP (EOR-21)
3	Garfield	Coal Ridge, Garfield State Wildlife Area	State/Private	2 May 2000	6,100 to 6,600	Hillside with exposed rock and eroded soil; pinyon-juniper woodland; aspect southwest; top of Mesa Verde Fm.	33	CNHP (EOR-47)
4	Garfield	Joe Hill Road	USFS White River National Forest Rifle Ranger District	23 May 1990	7,400	Steep talus slopes and outcrops; Gambel oak-pinyon pine community; aspect south, slope 60+%; limestone.	unknown	CNHP (EOR-15)
5	Garfield	Lewellen Mine/ Burning Mountain	BLM	26 May 1991	6,500	Pinyon-juniper/Gambel oak community; aspect south; Grand Hogback.	1000+	CNHP (EOR-13)
6	Garfield	Divide Creek	BLM	1 June 1991	5,700 to 6,000	Pinyon-juniper community; aspect south; clay and sand soil; Wasatch Fm.	50	CNHP (EOR-28)
7	Garfield	Divide Creek East	BLM	1 June 1991	6,200 to 6,400	Pinyon-juniper community; aspect southwest; silty soil.	10	CNHP (EOR-29)
8	Garfield	East Divide Creek	BLM	2 May 2000	6,600 to 7,000	Rocky hillside with bare, eroded soil; pinyon-juniper community; aspect south-southwest, slopes steep.	99	CNHP (EOR-34)
9	Garfield	Willard Nathanial Beane Gravesite	Private	25 May 1991	6,480 to 6,600	Scattered in Gambel oak-sagebrush community; aspect west; sandy soil; Shale at base of Grand Hogback.	50	CNHP (EOR-2)
10	Garfield	Government Creek	BLM	20 June 1994	5,800	Pinyon-juniper-sagebrush community; aspect southwest, slope 40%; dry clay soil; Wasatch Fm., sandstone.	600	CNHP (EOR-4)
11	Garfield	Estes Gulch	BLM/Private	17 May 2000	5,580 to 6,100	Gullies in dry wash on bare, eroded soil; pinyon-juniper/mixed shrub community; aspect south-southeast, moderate to steep slopes.	119	CNHP (EOR-32)
12	Garfield	Rifle Hogback	BLM/Private	16 May 2000	5,720	Dry washes, rocky and barren shale outcrops; pinyon-juniper and saltbush communities; aspect south, slope 20-60%; clay soil; Wasatch Fm.	17	CNHP (EOR-7)
13	Garfield	Grand Hogback	BLM?	19 June 1991	6,200	Steep, eroding slope; sandstone and clay soil; Wasatch Fm.	unknown	CNHP (EOR-16)
14	Garfield	Ripple Mine/Grand Hogback	BLM/Private	28 May 1990	7,000	Pinyon-juniper community; sandy soil; Grand Hogback.	unknown	CNHP (EOR-14)

Table 1 (cont.).

Arbitrary occurrence number	County	Site	Ownership[1]	Date of last observation	Elevation (ft.)	Habitat[2]	Last known population size	Source[3]
15	Garfield	Middle Rifle Creek	BLM	20 June 1994	6,180 to 6,260	Steep washes of white/light sandstone. pinyon-juniper/mixed shrub community.	200+	CNHP (EOR-35)
16	Garfield	Northwest of Rifle	unknown	2 May 1982	5,280	Clay slope; atriplex-juniper community; aspect south.	unknown	CNHP (EOR-5)
17	Garfield	North of Garfield County Landfill	BLM	28 Oct 1995	5,600 to 5,800	Open lower slopes; juniper-atriplex badlands; aspect all, slope 40-60º; Small shale stones on soil surface; Wasatch Fm.	930	CNHP (EOR-38)
18	Garfield	Naval Oil Shale Reserve	BLM - NOSR	16 July 1998	5,280 to 5,560	Juniper/saltbush-snakeweed community; Wasatch Fm.	unknown	CNHP (EOR-23)
19	Garfield	Lower Cottonwood Gulch	BLM - NOSR	12 May 1998	5,360	Along edge of intermittent drainage in barren soil; juniper/sagebrush-atriplex-greasewood community; clay and gravel soil; Wasatch Fm.	unknown	CNHP (EOR-43)
20	Garfield	Naval Oil Shale Reserve	BLM - NOSR	13 May 1998	5,280 to 5,320	Barren rocky toe slopes; juniper woodland community; sandy clay loam soil; Wasatch Fm.	30	CNHP (EOR-44)
21	Garfield	Balzac Gulch	BLM - NOSR	13 May 1998	5,400	Mostly bare ground in intermittent drainage, incised wash; scattered juniper; Atwell Gulch Fm.	9	CNHP (EOR-45)
22	Garfield	Balzac Gulch	BLM - NOSR	16 July 1998	5,280 to 5,560	Sparsely vegetated slopes and drainage bottom; saltbush community; aspect south, east, west, slope 0-30º; rocky clay soil; Wasatch Fm.	42	CNHP (EOR-46)
23	Mesa	Horsethief Creek	unknown	16 May 1984	5,250	Greasewood-sagebrush community; slope 0-5º; sandy soil; Wasatch Fm., sandstone member.	100	CNHP (EOR-6)
24	Mesa	7 miles below Debeque	unknown	17 May 1955	4,800	unknown	unknown	Herbarium label, Barneby 12741
25	Mesa	Atwell Gulch	Private	29 May 1991	5,280	Hillside of clay and large sandstone boulders; pinyon-juniper, sagebrush, and saltbush communities; Wasatch Fm.	5	CNHP (EOR-33)
26	Mesa	Atwell Gulch	BLM	23 May 1996	5,880 to 5,960	Low bench above floor of wash, open bare ground; juniper community. Aspect west, slope 20º; dry sandy clay soil; Atwell Gulch Fm.	23	CNHP (EOR-39)
27	Mesa	Long Point	Private	11 May 1985	5,600	Sagebrush-juniper community; sandstone.	unknown	CNHP (EOR-9)
28	Mesa	Little Park Road	unknown	14 May 1980	6,500	Clay soil.	unknown	CNHP (EOR-12)
29	Mesa	Eddington	BLM	25 June 1996	5,300 to 5,600	In dry washes, barren eroded areas; juniper/mixed shrub community; aspect south, slope 45º; sandy soil; Mesa Verde sandstone.	500	CNHP (EOR-40)

Table 1 (cont.).

Arbitrary occurrence number	County	Site	Ownership[1]	Date of last observation	Elevation (ft.)	Habitat[2]	Last known population size	Source[3]
30	Mesa	Monument Canyon	BLM	16 May 1997	5,000	Canyonside in washes and rocky areas; juniper/ sagebrush-atriplex-greasewood community; aspect north.	unknown	CNHP (EOR-48)
31	Mesa	West Monument	unknown	18 May 1997	5,600	Dry wash above canyon; juniper community; aspect west; Mesa Verde sandstone.	10	CNHP (RDB2056)
32	Mesa	Jackson Canyon	BLM	6 June 1997	5,600	Canyon rim, above rimrock; pinyon-juniper/ mountain mahogany community; Mesa Verde Fm.	6	CNHP (RDB2057)
33	Mesa	Debeque Canyon-Plateau Creek Confluence	unknown	17 May 1997	5,000	Dry rocky wash and adjacent sandy areas on side of mesa; sagebrush-saltbush-greasewood community; aspect west, steep slopes.	15	CNHP (RDB2055)
34	Mesa	Cameo, E of Grand Junction	unknown	25 May 1943	4,800	unknown	unknown	Herbarium label, Ripley and Barneby 5427
35	Mesa	Near Grand Junction	unknown	May 1892	unknown	unknown	unknown	CNHP (EOR-10)
36	Delta	Ute Trail	BLM Gunnison Gorge NCA	21 June 1997	5,600 to 5,900	Low gradient sites in schistose gravel and scree.	32	CNHP (EOR-26)
37	Montrose	Duncan Trail	BLM Gunnison Gorge NCA	30 Apr 1998	5,800 to 6,300	Dry draws and washes; pinyon-juniper community; aspect north to east, slopes level to moderately steep; alluvial soils.	1 or 2	CNHP (EOR-24)
38	Montrose	Bobcat Trail	BLM Gunnison Gorge NCA	30 May 1991	5,600 to 6,200	Dry sandy wash; pinyon-juniper community; aspect north, east and south; level to moderately steep slopes.	2	CNHP (EOR-25)
39	Montrose	Bostwick Park	unknown	15 June 1915	5,800	Sandy hillside among junipers.	unknown	CNHP (EOR-8)
40	Montrose	Beaton Creek	BLM	2 June 1991	6,800 to 7,100	Pinyon-juniper community; rocky, sandy clay soils; Mancos shale.	200+	CNHP (EOR-30)
41	Montrose	Beaton Creek West	BLM	2 June 1991	6,600 to 6,700	Pinyon-juniper community; rocky, sandy clay soils; Mancos shale.	150+	CNHP (EOR-31)
42	Montrose	Intersection of Wheeler Gulch and Parachute Creek	USFS Uncompahgre National Forest Norwood Ranger District	10 Apr 1999	6,950 to 7,150	Midslope disturbed washes and scree slopes; pinyon-juniper/mixed shrub community; gravelly clay soil.	49	CNHP (EOR-37)
43	Montrose	Montrose	unknown	11 May 1913	5,740	unknown	unknown	CNHP (EOR-22)

Table 1 (concluded).

Arbitrary occurrence number	County	Site	Ownership[1]	Date of last observation	Elevation (ft.)	Habitat[2]	Last known population size	Source[3]
44	Ouray	Colona Mtn.	Private	27 Apr 1998	6,900	Barren shale slopes below pinyon-juniper-sagebrush community.	1000	CNHP (EOR-41)
45	Ouray	Billy Creek West	BLM	9 June 1998	6,740 to 7,200	Open slopes and gullies on adobe hills; pinyon-juniper community; aspect south, gentle to steep slopes; rocky clay soil; Mancos shale.	800-1000	CNHP (EOR-36)
46	Ouray	Billy Creek North	BLM	29 May 1991	7,000 to 7,700	Moderately steep slopes; pinyon-juniper community; aspect south; rocky clay soil; Mancos shale.	1000+	CNHP (EOR-27)
47	Ouray	Chaffee Gulch	unknown	5 June 1987	7,000	Scattered in sagebrush park at base of Mancos shale hills.	unknown	CNHP (EOR-17)
48	San Miguel	Sanborn Park Road, Ravine above San Miguel River	BLM	6 May 1999	6,500 to 7,220	Open areas on small level benches or next to boulders in steep ravine; pinyon-juniper/mixed shrub community; sandy clay soil; Morrison Fm.	12	CNHP (EOR-42)
49	San Miguel	unknown	unknown	unknown	unknown	unknown	unknown	CNHP (EOR-3)
50	Grand (Utah)	Colorado River, east of Moab	unknown	unknown	unknown	unknown	unknown	None

[1]Ownership/Management: BLM = Bureau of Land Management, BLM-NOSR = former Naval Oil Shale Reserve, now managed by BLM, NCA=National Conservation Area (BLM)

[2]Habitat type names are given as in the original source, using either scientific or common names. Population sizes are numbers of individual plants.

[3]Sources include Colorado Natural Heritage Program data (CNHP) and herbarium labels. CNHP ID's are Element Occurrence Records (of the format EO-00), or unentered data (RDB0000). Herbarium label ID's are collector name and collection number.

Endangered Species Act, and there are no federal or state laws concerned specifically with its conservation. Because it is included on the Region 2 sensitive species list, USFS personnel are required to "develop and implement management practices to ensure that [*Astragalus wetherillii* does] not become threatened or endangered because of Forest Service activities" (USDA Forest Service Manual, Region 2 supplement, 2670.22). As of this writing, neither the USFS nor any other federal agency has written a conservation strategy for this species at a national or regional level. Almost all *A. wetherillii* occurrences are on lands administered by the BLM or the USFS. In general, these lands are managed for multiple uses, including livestock grazing, recreation, and mineral or energy resource exploration and extraction. Exceptions are occurrences within the BLM Gunnison Gorge National Conservation Area. There are no known occurrences in a BLM-designated Area of Critical Environmental Concern, Wilderness, or Wilderness Study Area. Because *A. wetherillii* is no longer on the BLM sensitive species list, BLM public lands managers are not required to consider potential impacts to the species in analyzing the environmental consequences of any management actions.

Adequacy of current laws and regulations

Data that would allow an evaluation of the conservation status of *Astragalus wetherillii* are generally not available. Moreover, in the absence of formal laws, regulations, or a detailed conservation strategy, assessing the adequacy of current management practices is difficult due to the lack of quantitative information on population trends for *A. wetherillii*. There is no way to know whether current management practices on lands supporting *A. wetherillii* occurrences are effective in protecting the species in the long term. The occurrences in the Gunnison Gorge National Conservation Area (numbers 36-38 in **Table 1**) are likely to be better protected than occurrences on lands where more uses are permitted. The dispersed nature of *A. wetherillii* occurrences makes it unlikely that the species could be suddenly decimated by anthropogenic activities, but without range-wide monitoring of the species, individual occurrences could decline and disappear unnoticed.

Adequacy of current enforcement of laws and regulations

There is at least one documented instance in which a portion of an *Astragalus wetherillii* occurrence was destroyed by human activities. Approximately 460 plants in a larger occurrence (number 20 in **Table 1**) were destroyed during the construction of a well pad on Naval Oil Shale Reserve land near Rifle (Colorado Natural Heritage Program 2005). An occurrence in San Miguel County (number 48 in **Table 1**) occurs partly on private land that is undergoing residential development (Lyon personal communication 2004). It is possible that other occurrences have been similarly affected. In addition, historical occurrences that have never been relocated during subsequent survey efforts may have been extirpated by unknown causes. For known locations, isolated incidents of extirpation do not appear to have threatened the persistence of the species.

Biology and Ecology

Classification and description

Astragalus wetherillii is a member of the Pea Family (Fabaceae, sometimes known as Leguminosae). This family is a member of the Class Angiospermae (flowering plants), Subclass Dicotyledoneae (dicots), Superorder Rosidae, Order Fabales (formerly Order Leguminales; Heywood 1993). The Fabaceae is among the largest of the plant families, containing 600 to 700 genera and 13,000 to 18,000 species (Smith 1977, Heywood 1993, Zomlefer 1994). The genus *Astragalus* falls under the subfamily Papilionoideae (also known as Lotoideae or Faboideae). Species in the Papilionoideae are characterized by having papilionaceous or butterfly-like flowers. More than two thirds of the Fabaceae are in this group, including many of the most common species (Zomlefer 1994). Within the subfamily Papilionoideae, Heywood (1993) recognizes 10 to 11 tribes. The genus *Astragalus* is the largest member of the tribe Galegeae (characterized by pinnate leaves with five or more leaflets), comprising some 1,600 to 2,000 species worldwide (Smith 1987, Zomlefer 1994).

The worldwide distribution of *Astragalus* is cosmopolitan outside the tropics and Australia (Allen and Allen 1981); the largest center of distribution for *Astragalus* is southwestern Asia. *Astragalus* species commonly occur in prairies, steppes, and semi-desert areas (Allen and Allen 1981). Western North America is a center of *Astragalus* diversity in the western hemisphere, and many of our species are endemic to some degree (Barneby 1964).

In the late 1800s and early 1900s, the two most important students of North American *Astragalus* were Marcus Eugene Jones and Per Axel Rydberg. Jones lived and worked in Salt Lake City for many years, in one of the centers of *Astragalus* speciation. He explored the Colorado Plateau and Great Basin, collecting and describing many of our species, including *A. wetherillii*. His self-published revision of the genus (Jones 1923) draws on materials from his own work as well as specimens from the California Academy of Sciences and other historical collections. Jones proposed 30 sections of *Astragalus* with 273 species and 144 subordinate varieties (Barneby 1964). Working at about the same time as Jones, Per Axel Rydberg produced a monograph of the genus *Astragalus* for the North American Flora (1929). Rydberg breaks *Astragalus* into 28 genera and 564 species. Rydberg had an aversion to the use of varieties and subspecies, always "preferring a binomial name to a trinomial for the sake of convenience" (Rydberg 1923). Later authors (Barneby 1964) pointed out that as a consequence, his treatment falls apart due to a rigid adherence to a system of fruiting characters without any recognition of the dynamic evolutionary processes operating on such characters.

The monumental revision of Barneby (1964) presents one genus with 368 species and 184 varieties for a total of 552 taxa and supersedes the treatments of Jones and Rydberg. Isely's treatments (1984, 1985, 1986) largely follow Barneby, adding new information as appropriate and presenting entirely new keys. His 1998 synopsis includes 375 species, and with varieties, about 570 taxa.

There are more than 150 species of *Astragalus* in the Intermountain Region of the western United States, including *A. wetherillii* (Barneby 1989). The Astragali are remarkable in our region for their proliferation by adaptive radiation into arid and otherwise hostile microhabitats (Barneby 1989). This phenomenon has produced numerous, well-differentiated but geographically restricted species, including *A. wetherillii*.

History of knowledge

Astragalus wetherillii was first described by Jones (1893), from a specimen collected "at Grand Junction, Colorado, May 1892, by Miss Alice Eastwood." Miss Eastwood requested that the species name be dedicated to her traveling companion, the archeological/botanical explorer Benjamin Alfred Wetherill (Jones 1893). Jones (1923) placed *A. wetherillii* in his Inflati group. Rydberg (1929) treated this species as *Phaca wetherillii* in his treatment of Leguminosae for the North American Flora, but this name was never widely adopted. Barneby (1964) places *A. wetherillii* in the Piptoloboid Phalanx (small-flowered Piptolobi), under section Inflati, subsection Sparsiflori, together with *A. sparsiflorus* (var. *majusculus* and var. *sparsiflorus*), and *A. diaphanus*. *Astragalus wetherillii* is not sympatric with either of these related species.

The holotype was originally housed at Pomona College, now merged with Rancho Santa Ana (RSA-POM), as accession number POM-26002. Duplicates of this collection (isotypes) are housed at Harvard University Gray Herbarium (GH), Missouri Botanical Garden (MO), University of Notre Dame (ND), New York Botanical Garden (NY), Rocky Mountain Herbarium (RM), and the Smithsonian Institution (US). In addition to the type specimens listed above, specimens from other locations are also housed at the Stanley L. Welsh Herbarium at Brigham Young University (BRY), University of Colorado (COLO), Colorado State University (CS), Mesa State College (MESA), Rocky Mountain Herbarium (RM), and possibly at other locations.

Prior to 1990, *Astragalus wetherillii* was collected sporadically in Colorado, and at the time the species was proposed for federal listing in 1975, there were six or seven known localities. A few additional locations were documented in the 1980s, and survey work in the early 1990s (Bunin 1991, 1992) documented 31 occurrences. Recent surveys by Colorado Natural Heritage Program botanists and others have continued to add to the number of occurrences for a current total of 50.

Description

As described by Barneby (1964) and Welsh et al. (1993), *Astragalus wetherillii* is a low-growing, short-lived perennial with a slender taproot and up to 10 stems arising from a superficial root-crown. Isely (1986, 1998) indicates that *A. wetherillii* may sometimes be so short-lived as to qualify as an annual, but no studies have been done to quantify variation in the lifespan of the species. The stems are usually purple or reddish, at least at the base, and sparsely hairy with fine, straight hairs lying flat on the stem. The foliage appears green, as the leaves are not hairy on the upper surface. The pinnately compound leaves are 3.5 to 10 cm length, with 7 to 15 broadly obovate or oval leaflets. The flat, thin-textured leaflets are 5 to 14 mm long. Sparsely flowered racemes typically hold 2 to 9 flowers with white or lavender-tinged petals. Flower corollas are 7.5 to 11 mm in length. Flowers are initially ascending, but become less so with age. The greenish, often purple-speckled pods are inflated but not strongly bladdery, with a single chamber and a prominent beak. Pods of early flowers are often mature or even dried while newer growth continues to produce flowers. Pods contain 9 to 13 ovules, and seeds are small (2.4 to 2.7 mm long) and dark colored. Seeds usually disperse from the pod after it has fallen from the plant.

Astragalus wetherillii is not likely to be mistaken for any other *Astragalus* species within its range. The purple-reddish stems and almost round leaves make it easy to identify in the field (**Figure 2**; Lyon personal communication 2004). It differs from the closely related, but not sympatric, *A. sparsiflorus* in having an inflated pod and slightly larger flower (Barneby 1964). The range of *A. sparsiflorus* is restricted to the eastern slope of the Colorado Front Range and does not overlap that of *A. wetherillii* on Colorado's western slope. Barneby (1989) notes that *A. wetherillii* also has a superficial resemblance to *A. sabulonum*, whose range is to the south and west of that of *A. wetherillii*, in the lowlands of the Colorado River Plateau.

Published descriptions and other sources

Complete technical descriptions are available in Jones (1923), Rydberg (1929), Barneby (1964, 1989), Welsh et al. (1993), and Isely (1986, 1998). Of these, Barneby's are the most complete, and his Atlas (1964) and Volume 3B of the Intermountain Flora (1989) are available in most herbaria and university libraries. Although more recent, Isely's (1998) description is much abridged, and the longer version published in the Iowa State Journal of Research (Isely 1986) is not widely available. Brief descriptions are found in Rydberg (1906), Porter (1951), Harrington (1954), and Weber and Wittmann (2001).

A drawing and a photograph of the plant and its habitat are readily available in the *Colorado Rare*

Figure 2. Photograph of *Astragalus wetherillii* in flower. By Susan Spackman-Panjabi, used with permission.

Plant Field Guide, in both online and print versions (**Figure 3**; Spackman et al. 1997). Additional drawings are available in Volume 3B of the Intermountain Flora (Barneby 1989), and in the *Utah Endangered, Threatened, and Sensitive Plant Field Guide* (Atwood et al. 1991).

Distribution and abundance

Documented occurrences of *Astragalus wetherillii* are shown in **Figure 1** and are detailed in **Table 1**. Some of this information was compiled from herbarium labels of unverified specimens; therefore it is possible that a few locations are not in fact occurrences of *A. wetherillii*. Other collections have practically no location information and have never been relocated. The species is documented from about 50 locations in western Colorado, depending on whether some reports in fact constitute separate occurrences. The species has been collected in the Yampa, Colorado, Gunnison, Uncompahgre, and San Miguel river drainages. As far as is known, the current range of this species is similar to its historic distribution. The species was collected once by Alice Eastwood in the canyon of the Colorado River above Moab, Utah more than a century ago (Barneby 1989, Welsh et al. 1993), but it has not since been reported from that state. The Utah specimen has apparently been lost, and Barneby (1987) speculates that it may have been destroyed in the 1906 San Francisco earthquake and ensuing fire,

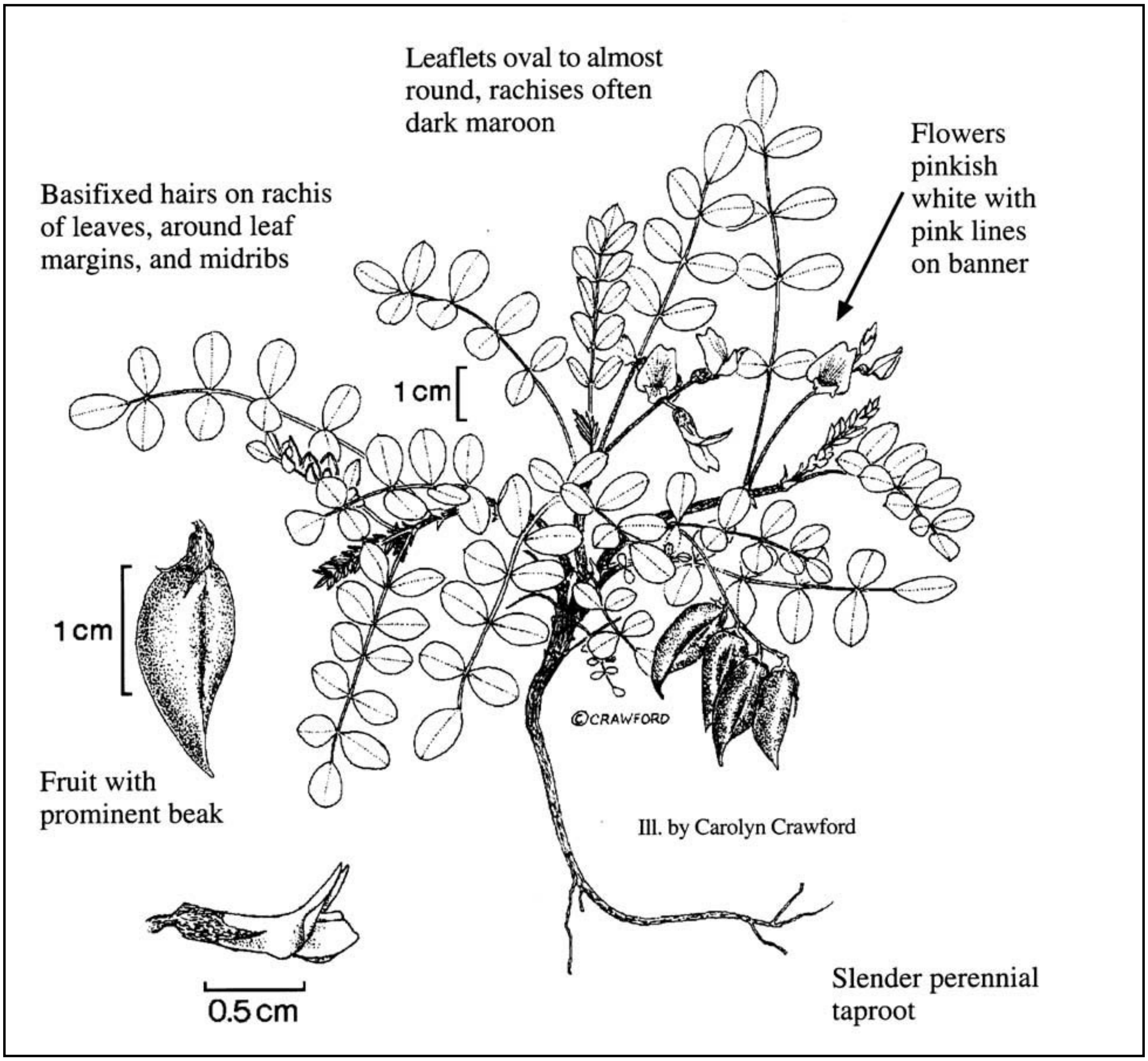


Figure 3. Drawing of *Astragalus wetherillii* from Spackman et al 1997.

which burned the California Academy of Sciences to the ground. In Colorado, the species is known from Moffat, Garfield, Mesa, Delta, Montrose, Ouray, and San Miguel counties.

Due to the lack of precise location information for many herbarium specimens, ownership for some occurrences is unknown. At least two of the Colorado occurrences are on National Forest System lands. One is on the Rifle Ranger District of the White River National Forest, and one is on the Norwood Ranger District of the Grand Mesa, Uncompahgre, and Gunnison National Forests. More than half (28 of 50) of the known occurrences are at least partly on BLM-administered public lands. BLM occurrences are primarily in the Glenwood Springs, Grand Junction, and Uncompahgre Basin Resource Areas. Other landowners include the State of Colorado and private individuals (**Figure 1**).

Collection locations of *Astragalus wetherillii* are scattered over an area of 9600 square miles, measuring 160 miles between the Yampa River in the north and the San Miguel River in the south and 60 miles east to west, not including the historic Utah collection. *Astragalus wetherillii* has an unusually large range for an endemic species, but it is not known to occur continuously throughout this range. Occurrences are found at lower to middle elevations in the river valleys of western Colorado, where they are separated by high plateaus or mountain ranges. Distribution patterns are disjunct at both broad and fine scales, with occurrences grouping into four or five population centers. Most occurrences are clustered near Debeque Canyon and near the town of Rifle along the main stem of the Colorado River.

It is not known if *Astragalus wetherillii* is more continuous in its distribution than it presently appears. There are large areas of apparently suitable habitat in the lands separating documented occurrences. If it is not continuously distributed, the present distribution could be explained either as relictual occurrences from a once-continuous distribution, or as disjunct colonies arising from rare long-distance dispersal events. Additional surveys would clarify the question of the species' distribution.

Data (estimates and counts) from the most recent observations indicate that the total number of *Astragalus wetherillii* individuals is approximately 7,300. True numbers are probably much higher at a few sites. However, most of these occurrences have not been observed within the last five years. Only four occurrences have numbers of individuals documented in three or more years (**Table 2**).

Population trend

Population trends for *Astragalus wetherillii* are unquantified. There has been no rigorous repeated population census that would allow an accurate description of trends. Counts at individual locations appear to fluctuate substantially between observations (**Table 2**), and reported numbers vary from a few plants to several thousand individuals in a population. During some years populations appear to be in severe decline (Bunin 1991) or chronically small (O'Kane 1988), and in other years observers report or estimate numbers in the thousands.

Surveys in 1990 were unable to locate *Astragalus wetherillii* occurrences in eight of 10 sites where it had been previously reported (Bunin 1991, 1992), but in the mid-1990s several large new occurrences were identified (Colorado Natural Heritage Program 2005). Population numbers may have declined prior to 1991 in response to drought conditions that began in 1987. A similar pattern may be occurring in response to recent drought conditions (1999 – 2003). The limited data available from sporadic observations indicate that population numbers are highly variable. There is not enough information to determine if this pattern is true for the species across its entire range.

Habitat

Most documented occurrences of *Astragalus wetherillii* fall near the western edge of the Southern Rocky Mountain ecoregion as defined by The Nature Conservancy (2001). A few occurrences fall into either the Colorado Plateau, Utah High Plateau, or Wyoming Basins ecoregions where they abut the Southern Rocky Mountains. Within its range, *A. wetherillii* is broadly associated with the Southern Rocky Mountain Pinyon-Juniper Woodland, Colorado Plateau Pinyon-juniper Woodland, Intermountain Basins Big Sagebrush Shrubland, and Intermountain Basins Mixed Salt Desert Scrub ecological system types (Rondeau 2001, NatureServe 2003). The first three ecological systems are described as "matrix forming" communities that may cover areas of hundreds to millions of acres in their various successional stages. Matrix communities occur across a broad range of environmental conditions in an area and are shaped by regional-scale processes (Anderson et al. 1999). The Intermountain Basins Mixed Salt Desert Scrub ecological system is defined as a "large patch" community that may form extensive cover over some areas but is usually influenced primarily by local processes (Anderson et al. 1999). Characteristics of these ecological systems are summarized in **Table 3**.

Table 2. Population variability in *Astragalus wetherillii* occurrences with repeated observations. Refer to **Table 1** for complete descriptions of each occurrence.

Arbitrary occurrence number	Source	Year Count				
8	**CNHP (EOR-34)**	**1992**	**2000**			
		190	99			
10	**CNHP (EOR-04)**	**1986**	**1986**	**1990**	**1991**	**2004**
		801	600	67	20	600
11	**CNHP (EOR-32)**	**1991**	**1992**	**2000**		
		30	592-3000	119		
12	**CNHP (EOR-07)**	**1990**	**1991**	**1992**	**2000**	
		1	20	93	17	
13	**CNHP (EOR-16)**	**1990**	**1991**	**1992**		
		95	350+	750-1000		
20	**CNHP (EOR-44)**		**1993**	**1998**		
			2700	30		
23	**CNHP (EOR-06)**		**1984**	**1988**	**1990**	
			40-100	12	not found	
37	**CNHP (EOR-24)**		**1990**	**1991**	**1998**	
			not found	2	1	
42	**CNHP (EOR-37) (USFS)**		**1998**	**1999**		
			25-100	49		
45	**CNHP (EOR-36)**		**1991**	**1999**		
			800	1000+		

Within these ecological systems, *Astragalus wetherillii* is consistently associated with a few widespread vegetation associations characteristic of lower elevations in western Colorado. Occurrences are most frequently reported from pinyon-juniper or juniper woodlands with a sparse to shrubby understory, and occasionally from sagebrush or saltbush-greasewood shrublands. Plants are generally restricted to sparsely vegetated openings within these associations. Data from specimen labels and element occurrence records show *A. wetherillii* occurring with the associated species shown in **Table 4**.

The characteristic habitat of *Astragalus wetherillii* is open sites on eroding slopes and washes in middle-elevation pinyon-juniper woodlands or shrublands (**Figure 4**). Substrates are generally well-drained sandy or rocky clay soils derived from shales and sandstones, and the plants are often found in areas subject to high erosion (e.g., gullies, dry washes, barren slopes). Although *A. wetherillii* does not appear to be restricted to a particular geologic substrate, occurrences are primarily associated with the Wasatch, Mancos, Morrison, and similar shale formations, or with sandstones and interbedded shales of the Mesa Verde Formation. Substrates vary from Wasatch in the north to Mancos and Morrison in the southern part of the range.

Elevations of reported occurrences range from 4,800 to 7,700 ft. (1,460 to 2,350 m). The type location near Grand Junction is probably below this range, but this is impossible to verify. Barneby (1987) queried Miss Eastwood about the location of the type specimen, but she was unable to pinpoint it as other than "above Grand Junction." The lost Utah specimen was also presumably lower than the documented range, but not lower than 4,000 ft. (1,219 m), which is the elevation of Moab. Aspects vary but are most often south to west facing, and slopes range from flat to steep.

The lower valleys of western Colorado are protected from more extreme climatic conditions by surrounding high plateaus and mountains. In comparison with similar elevations on Colorado's eastern slope, these valleys have higher summer temperatures and lower winter temperatures. Low precipitation and a wide range of daily and annual temperatures are characteristic of the western valleys (Western Regional Climate Center 2004). Annual precipitation within the range of *Astragalus wetherillii*

Table 3. Characteristics of ecological systems associated with *Astragalus wetherillii*.

Ecological System	Characteristics
Southern Rocky Mountain Pinyon-Juniper Woodland	Occurs on warm, dry sites on mountain slopes, mesas, plateaus, and ridges. Severe climatic events occurring during the growing season, such as frosts and drought, are thought to limit the distribution of pinyon-juniper woodlands to relatively narrow altitudinal belts on mountainsides. Soils supporting this system vary in texture ranging from stony, cobbly, gravelly sandy loams to clay loam or clay. *Pinus edulis* and/or *Juniperus monosperma* dominate the tree canopy. *Juniperus scopulorum* may codominate or replace *J. monosperma* at higher elevations. Understory layers are variable and may be dominated by shrubs, graminoids, or be absent.
Colorado Plateau Pinyon-juniper Woodland	Found on warm, dry sites on mountain slopes, mesas, plateaus, and ridges. Severe climatic events occurring during the growing season, such as frosts and drought, are thought to limit the distribution of pinyon-juniper woodlands to relatively narrow altitudinal belts on mountainsides. The tree canopy is dominated by *Pinus edulis* and/or *Juniperus osteosperma*. Understory layers are variable and may be dominated by shrubs, graminoids, or be absent.
Intermountain Basins Big Sagebrush Shrubland	Occurs throughout the much of western United States typically in broad basins between mountain ranges, plains and foothills between 1,500 and 2,300 m elevation. These shrublands are dominated by *Artemisia tridentata* ssp. *tridentata* and/or *A. tridentata* ssp. *wyomingensis*. *Ericameria nauseosa* or *Chrysothamnus viscidiflorus* may codominate disturbed stands. Perennial herbaceous components typically contribute less than 25 percent vegetative cover.
Intermountain Basins Mixed Salt Desert Scrub	Open-canopied shrublands of typically saline desert basins, alluvial slopes and plains across the Intermountain West. The vegetation is characterized by a typically open to moderately dense shrubland composed of one or more *Atriplex* species such as *A. confertifolia*, *A. canescens*, *A. polycarpa*, or *A. spinifera*. The herbaceous layer varies from sparse to moderately dense and is dominated by perennial graminoids. Various forbs are also present.

ranges from about 11 to 19 inches. Occurrences at higher elevations receive more precipitation than those at lower elevations. Precipitation amounts are evenly distributed throughout the seasons, with more moisture being received during the fall and winter (Western Regional Climate Center 2004).

Habitat meeting the description given above is common in western Colorado, but *Astragalus wetherillii* appears to be much less abundant than habitat availability would indicate. It is likely that the species has additional habitat requirements or restrictions that are not yet understood.

Reproductive biology and autecology

Life history and strategy

Astragalus wetherillii is generally a short-lived perennial, perhaps occasionally annual (Isely 1998), and it often flowers in its first year. Until more is known about the life history of the species, it is not appropriate to assume that *A. wetherillii* is a typical annual or ruderal species. Although individual reproductive rates are probably not high in comparison with some species, the quick flowering and short life-span make *A. wetherillii* more of an r-selected species than a k-selected one (*sensu* MacArthur and Wilson 1967).

On a fine scale, the typical habitat of *Astragalus wetherillii* is unstable and changing; the loose shale slopes on which it is found are easily eroded by the action of wind, water, gravity, livestock trailing, or vehicle use. *Astragalus wetherillii* appears to specialize on the sparsely vegetated, easily eroded areas of pinyon-juniper that are not successfully colonized by most other species. Grime (2001) points out that in terrestrial habitats with both severe disturbance and severe stress, vegetation is often completely lacking. A slight mitigation of either of these factors enables a few specialized species to survive. *Astragalus wetherillii* is clearly well adapted to a habitat that few other plants can tolerate, and its habit is probably best described as a Stress-tolerant Ruderal in Grime's classification scheme. It is not clear exactly which environmental characters are acting as stressors, but low moisture, nutrient deficiency, and soil chemistry are likely factors for any species of the sparsely vegetated, arid, low soil moisture habitats characteristic of the intermountain west.

Reproduction

Astragalus wetherillii reproduces only by seed, not by vegetative reproduction or clonal growth. As with all *Astragalus* species, flowers of *A. wetherillii* contain both male and female parts. *Astragalus wetherillii*'s

Table 4. Species reported as associated with *Astragalus wetherillii*. Most commonly reported species are in bold type.

TREE	**FORBS**
Juniperus monosperma	*Arabis selbyi*
Juniperus osteosperma	*Arenaria* spp.
***Juniperus* spp.**	Astragalus flavus
Pinus edulis	*Astragalus lonchocarpus*
Pseudotsuga menziesii	*Chaetopappa ericoides*
	Cirsium spp.
SHRUBS	*Cryptantha flavoculata*
Amelanchier utahensis	*Cryptantha* spp.
Artemisia tridentata	*Cymopterus* spp.
***Artemisia* spp.**	*Descurainia incana*
Atriplex brandegei	*Echinocereus triglochidiatus*
Atriplex canescens	*Erigeron pumilus*
Atriplex confertifolia	*Eriogonum ovalifolium*
***Atriplex* spp.**	*Hedysarum boreale*
Cercocarpus montanus	*Lesquerella* spp.
Chrysothamnus nauseosus	*Lomatium eastwoodiae*
Chrysothamnus viscidiflorus	*Melilotus officinale*
Chrysothamnus spp.	*Opuntia erinacea*
Ephedra torreyana	*Opuntia fragilis*
Ephedra viridis	*Opuntia phaeacantha*
Forsellesia meionandra	*Opuntia polyacantha*
Gutierrezia sarothrae	*Opuntia* spp.
Peraphyllum ramosissimum	*Pediomelum megalanthum*
Philadelphus microphyllus	*Penstemon moffatii*
Picrothamnus desertorum	*Penstemon osterhoutii*
Purshia tridentata	*Phlox hoodii*
Quercus gambelii	*Phlox longifolia*
Rhus trilobata	*Physaria* spp.
Ribes spp.	*Physaria acutifolia*
Sarcobatus vermiculatus	*Platyschkuhria integrifolia.*
	Schoenocrambe linifolia
GRAMINOIDS	*Scutellaria brittonii*
Bromus tectorum	*Senecio multilobatus*
Elymus salina	*Tetraneuris ivesiana*
Hilaria jamesii	*Teucrium canadense*
Oryzopsis hymenoides	*Tithymalus brachyceras* (*Euphorbia*)
Pascopyrum smithii	

mating system and degree of self-compatibility have not been investigated; geographically restricted species are predicted to be more self-compatible than widely distributed species (Stebbins 1957). This prediction was partly supported by the work of Karron (1989), who reported that two restricted (*A. linifolius* and *A. osterhoutii*) and one widespread *Astragalus* (*A. lonchocarpus*) species were self-compatible and capable of setting as many fruits by selfing as by outcrossing. The two restricted species experienced lower overall levels of embryo abortion in self-pollinated ovules compared to the one widespread species. In one restricted and one

Figure 4. Examples of *Astragalus wetherillii* habitat (arrow). Photographs by Susan Spackman-Panjabi, used with permission.

widespread species, selfed seeds were more likely to germinate although the selfed seedlings of the restricted species showed evidence of inbreeding depression.

Although none of the above-mentioned species is closely related to *Astragalus wetherillii*, it may show the same degree of self-compatibility and effects as the two restricted species. Future research could investigate the possibility of selfing in *A. wetherillii*, and whether selfing produces high levels of inbreeding depression.

Pollinators and pollination ecology

Astragalus wetherillii possesses papilionaceous flowers, as do all members of the subfamily Papilionoideae. The papilionaceous flower is the characteristic "pea" flower with a zygomorphic corolla consisting of a large posterior and upright standard (banner), a lateral pair of long-clawed wings, and an innermost boat-shaped keel (see drawing in Definitions section). Flowers of this type typically share the pollination syndrome of *melittophily* or bee pollination (Faegri and van der Pijl 1979).

The "trip mechanism" of papilionaceous flowers means that large bees of the family Apidae and Anthophoridae (Green and Bohart 1975) and Megachilidae (Rittenhouse and Rosentreter 1994) are likely to be the primary pollinators. The bees typically alight on the landing platform provided by the flower's wings, and push their head between the banner and keel petals. The weight of the bee depresses the wings and keel, exposing the stamens and depositing pollen on the underside of the bee's head, thorax, and abdomen (Green and Bohart 1975).

Pollinators of *Astragalus wetherillii* have not been identified. Potential pollinators reported for some *Astragalus* species of the western United States include native bumblebees (*Bombus* spp.), native digger bees (*Anthophora* spp.), native mason bees (*Osmia* spp.), and the introduced honeybee (*Apis mellifera*) (Green and Bohart 1975, Sugden 1985, Karron 1987, Geer et al. 1995). Geer et al. (1995) reported more than 27 species of bees visiting flowers of *Astragalus montii*, *A. kentrophyta*, and *A. miser*. *Osmia* species were the most frequent visitors to all three species of *Astragalus*. Green and Bohart (1975) concluded that pollen quantity and distribution on flies (Diptera) and beetles (Coleoptera) indicated that they were not likely to be successful pollinators of *Astragalus* species.

Phenology

Flowering typically begins in early May and continues into late June in most years (Bunin 1992). Plants often bear flowers and mature fruits simultaneously, but it is not clear when seeds are fully mature. The best time to find the species is from the third week of May to the third week of June. Plants senesce rapidly after fruiting and are difficult to identify by mid-July (Bunin 1992).

There is no information about germination site requirements for *Astragalus wetherillii*. Many individuals are found on bare, loose soil in areas where soil movement due to the action of wind, water, and gravity is high. In some locations, plants are reported as growing on small soil terraces that collect behind rocks and boulders (Colorado Natural Heritage Program 2005). Dispersed pods are probably more likely to come to rest in these slightly more stable areas, but seeds are probably able to germinate in less protected conditions.

Fertility and propagule viability

There are no data available with which to assess the fertility and propagule viability of *Astragalus wetherillii*. Field observers report that larger plants are often covered with flowers and fruits (Lyon personal communication 2004). There have been occasional reports of numerous seedlings in some sites (numbers 6, 17, and 20 in **Table 1**; Colorado Natural Heritage Program 2005). A large individual of *A. wetherillii* with ten stems, each with eight or nine fully fertilized flowers producing a dozen or so seeds per pod might produce as many as a thousand seeds in a single season if not limited by pollinator or resource availability. Plants under natural conditions probably produce fewer viable seeds, perhaps several hundred for a larger individual in an average year.

Dispersal mechanisms

Pods of *Astragalus wetherillii* typically fall from the plant before they dehisce. Pods rolling or washing down slope or blowing across the ground may disperse some distance before seeds escape the pod. Rittenhouse and Rosentreter (1994) observed pods of *A. amblytropis* rolling down slope under very light wind conditions, and occasionally up slope under very windy conditions.

Seed predation has been reported for a variety of *Astragalus* species (Friedlander 1980, Clement and

Miller 1982, Nelson and Johnson 1983, Rittenhouse and Rosentreter 1994, Lesica 1995, Decker and Anderson 2004). No instances of insect damage on fruits of *A. wetherillii* have been reported by field observers, and no herbarium specimens examined for this assessment showed any obvious damage to fruits. Seed predation does not appear to be a significant source of mortality for *A. wetherillii*.

Cryptic phases

Seed bank dynamics and seed longevity for *Astragalus wetherillii* are unknown. Bowles et al. (1993) successfully germinated seeds from herbarium specimens of two rare *Astragalus* species (*neglectus* and *tennesseensis*) that were at least four years old. Successful germination of *A. neglectus* seeds included some specimens that were 97 years old. Although these seeds had been stored under herbarium conditions, the results indicate the possibility that *A. wetherillii* seeds under natural conditions may remain viable for many years.

The abundance of *Astragalus wetherillii* seeds in the soil is unknown. Anecdotal evidence suggests that substantial numbers of *A. wetherillii* seeds may be present in the seed bank in some locations. Open areas created in pinyon-juniper to mitigate the construction of a uranium tailings disposal site resulted in the appearance of numerous seedlings of *A. wetherillii* in an area where it was not previously observed (Scheck personal communication 2004). Some other *Astragalus* species are able to maintain variable potentially large seed banks. Ralphs and Cronin (1987) reported a mean density of 394 seeds per m^2 of soil for *A. lentiginosus* var. *salinas* (salt milkvetch) in Utah. They found that seed density was not necessarily correlated with foliar cover of the species. Ralphs and Bagley (1988) reported seed density ranging from 20 to 4,346 seeds per m^2 for *A. lentiginosus* var. *wahweepensis* in Utah, and they hypothesize that the seed bank is sufficient to allow "population outbreaks" (undefined) in years with favorable environmental conditions. Morris et al. (2002) reported densities from 24 to 753 seeds per m^2 for *A. bibullatus* in the Central Basin of Tennessee. The tendency for populations of *A. wetherillii* to appear and disappear from one year to the next may indicate that the seed bank is a significant part of the species' life-cycle.

Astragalus wetherillii may make use of a dormant stage in which an individual plant does not produce aboveground vegetation for one or more years and then "reappears." Lesica (1995) reported this type of dormant phase in *A. scaphoides*. Observations of some *A. wetherillii* occurrences suggest that plants can appear one year where none were seen in the previous year, so the possibility should be investigated for *A. wetherillii*, although its short-lived habit suggests that this is not as likely as for some other species. This type of sudden appearance could also indicate the presence of a seed bank that responds to favorable conditions with a significant recruitment event.

Mycorrhizal relationships

Endomycorrhizal fungi belonging to the taxonomic order Glomales are a key component of symbioses involving the roots of plants. These endomycorrhizae are characterized by inter-and intracellular fungal growth in the root cortex where they form structures known as vesicles and arbuscles (Quilambo 2003). Vesicular-arbuscular mycorrhizae (VAM) occur in about 80 percent of all vascular plants (Raven et al. 1986), and the association is geographically widespread. VAM associations are documented from habitats occupied by *Astragalus wetherillii*, including pinyon-juniper (Klopatek and Klopatek 1987), and sagebrush-steppe (Wicklow-Howard 1994).

Roots of *Astragalus wetherillii* have not been assayed for the presence of VA mycorrhizal symbionts. Both presence (Zhao et al. 1997, Barroetavena et al. 1998) and absence (Treu et al. 1995) of VAM have been reported in the genus *Astragalus*. In the endangered species *A. applegatei*, Barroetavena et al. (1998) reported that colonization by VAM fungi from native soil was crucial to the survival of plants grown in a greenhouse.

Members of the pea family are well known for forming symbiotic relationships with *Rhizobium* bacteria that invade the cortical root swellings or nodules of root hairs. Through this mutually beneficial association, free air nitrogen is converted to fixed nitrogen that can be used by the plant. The ability to form nodules appears to be reasonably consistent within phylogenetic groups of Fabaceae. *Astragalus* species with nodules occur in almost all habitats, and nodules have been reported for at least 80 species (Allen and Allen 1981). *Astragalus wetherillii* has not been investigated for nodulization, but the phenomenon has been reported for at least two other members of Section Inflati (Allen and Allen 1981).

Hybridization

There is no evidence of hybridization in *Astragalus wetherillii*. Although other genera in the Fabaceae (e.g., *Oxytropis* and *Lathyrus*) have been reported to exhibit hybridization, the phenomenon is not prevalent in *Astragalus*. Karron (1987) and Geer et al. (1995) report that sympatric *Astragalus* species can share pollinators. At least one other species of *Astragalus* (*A. lonchocarpus*) has been reported to occur with *A. wetherillii*. If these two species share pollinators, then a mechanism to facilitate hybridization is available, but it is not known if that is actually occurring.

Demography

Little is known about the population genetics of *Astragalus wetherillii*. The degree of connectedness among occurrences, either within or between the various river drainages, is not known, and it is probable that individual occurrences have varying degrees of contact, from frequent genetic interchange to no exchange. Our current knowledge of the distribution of *A. wetherillii* indicates that some occurrences may be genetically isolated from each other. Unless *A. wetherillii* is more continuously distributed within its range than it currently appears, it is likely that gene flow between northern, central, and southern occurrences is not occurring. Studies of allele frequencies in the different population centers could clarify the degree of population connectivity and help to facilitate prioritization of protection efforts.

It is not known whether the species is capable of self-pollination. Some species of *Astragalus* are self-compatible while others are obligate outcrossers (Karron et al. 1988). Efforts to quantify genetic variability in *A. wetherillii* would be of interest in relation to the facet of evolutionary theory that predicts that species with small ranges and few individuals will exhibit low levels of genetic polymorphism (Hartl and Clark 1989). Some *A. wetherillii* occurrences have fewer than 100 individuals; these might be susceptible to the erosion of genetic variation over time if they remain small and isolated.

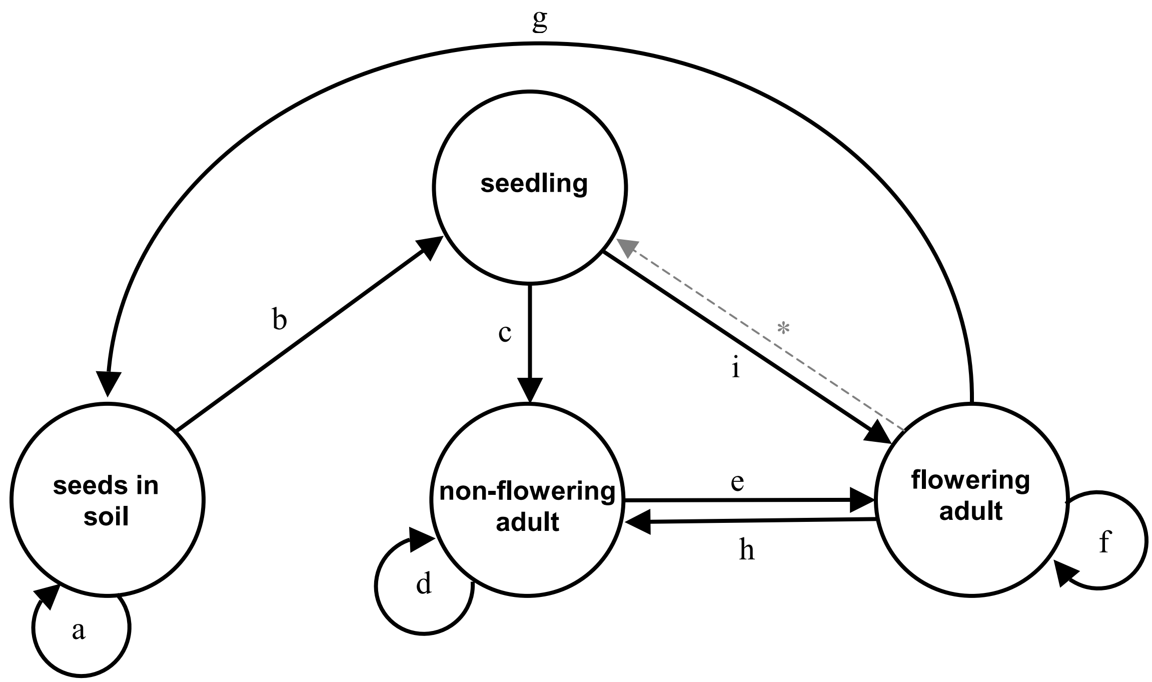
As a short-lived but polycarpic herbaceous perennial, *Astragalus wetherillii* exhibits overlapping generations. This characteristic is potentially important in that individuals of different ages are exposed to slightly different selective pressures (Harper 1977). Such selection can lead to temporal variation in population genetic structure, allowing seed banks to serve as reservoirs of genetic variation (Templeton and Levin 1979). Morris et al. (2002) found higher levels of genetic variation in the seed bank than in vegetative populations of the cedar glade endemic *A. bibullatus*. They suggest that the ability of the seed bank to preserve genetic diversity may depend on seed dormancy characters and on the relative size of the seed bank compared to the vegetative population. The investigation of these two factors could help clarify genetic diversity issues for *A. wetherillii*.

Figure 5 shows a hypothetical life cycle diagram for *Astragalus wetherillii*. Because there are no multi-year studies of this species, transition probabilities are left unquantified. Under the basic scenario shown, flowering plants produce seeds in mid- to late summer. The seeds over winter and germinate in the spring or remain dormant. Seedlings may flower in their first year, or require additional seasons to reach reproductive size/age. Reproductive adults flower every year as conditions and lifespan permit. The model assumes a transition interval of t = one year, and plants do not move between stages in intervals less than t. Although some *Astragalus* species appear to maintain a portion of the population in a dormant phase (Lesica 1995), the annual or short-lived perennial physical structure of *A. wetherillii* makes this less likely in this case.

Until better demographic data are available for *Astragalus wetherillii*, it is impossible to determine which demographic transitions are making the greatest contribution to population growth. An elasticity analysis of *A. cremnophylax* var. *cremnophylax* (Maschinski et al. 1997), a narrow endemic restricted to the Grand Canyon, indicated that reproductive plants remaining within the same reproductive-size stage had the greatest influence on population growth. The size class making the largest contribution changed when the occurrence was protected from trampling. Lesica (1995) found that although relative contributions of stages varied between years and sites, growth and survival of non-reproductive individuals of *A. scaphoides* were consistently important. As a short-lived perennial, *A. wetherillii* may have fewer size classes and less complex demographics than other *Astragalus* species.

There are no Population Viability Analysis (PVA) models available for *Astragalus wetherillii*. Morris et al. (1999) discuss general classes of data sets and methods suitable for PVA, including:

- ❖ count based extinction analysis, which requires counts of individuals in a single population from a minimum of 10 years of annual censuses (preferably more).



a. survival of dormant seeds in the seed bank
b. probability of seed becoming a seedling
c. survival of seedling to adult but non-reproductive stage
d. probability of non-flowering adult remaining non-reproductive
e. probability of non-reproductive plant becoming reproductive
f. probability of flowering adult flowering again next year
g. seed production of flowering plants
h. probability of flowering adult not flowering next year
i. probability of seedling flowering

* when do seeds germinate, i.e., are seedlings produced the same year?

Figure 5. Life cycle diagram for *Astragalus wetherillii* (after Caswell 2001).

❖ multi-site extinction analysis, which requires counts from multiple populations, including a multi-year census from at least one of those populations.

❖ projection matrix modeling, which requires detailed demographic information on individuals collected over three or more years (typically at only one or two sites).

There is clearly a trade-off in the years required versus intensity of data collection. There are no data sets available that could be used for PVA of *Astragalus wetherillii*. Although population levels appear to be stable and the species is not in obvious danger of extinction, the identification of a minimum viable population could assist in the formation of quantitative management objectives (Brackley 1989).

Community ecology

The community ecology of *Astragalus wetherillii* is poorly understood. Although the species is primarily found in openings in pinyon-juniper woodlands, it does not appear to be interacting strongly with other community members, and it is not strictly restricted to a particular community type within its range. The sparse vegetation that is typical of *A. wetherillii* habitat limits the number of potential competitors. Rare plants, in particular those that are characteristic of sparsely vegetated habitat types, are commonly thought to be poor competitors, and *A. wetherillii* may follow this pattern. Studies investigating the relative competitive abilities of rare and common congeners have shown mixed results (Lloyd et al. 2002).

Herbivores

Astragalus species are often poisonous to livestock, primarily due to the sequestration of selenium in plant tissues, or to the production of nitro-toxins such as miserotoxin (Stermitz et al. 1969), cibarian, karakin, and hiptagin (Williams et al. 1975). These compounds are catabolized in the digestive tracts of ruminants and disrupt the central nervous system. *Astragalus* species containing nitro-toxins kill or permanently cripple thousands of sheep and cattle every year. Williams and Barneby (1977) analyzed leaflets of 505 *Astragalus* species for the presence of nitro-toxins. They found varying levels of nitro-toxin in about 52 percent of the species they examined. Presence and levels of nitro-toxins were consistent among species belonging to the same taxonomic group. Although *A. wetherillii* was not among the species tested, all other members of the section Inflati tested exhibited only trace concentrations of 2 to 3 mg of nitro-toxin per gram of plant. These results indicate that *A. wetherillii* also probably contains low amounts of nitro-toxin.

Some species of *Astragalus* appear to be resistant to herbivory (Rittenhouse and Rosentreter 1994), but the mechanisms of resistance are not known. Other species are subject to a variety of impacts from invertebrate herbivores. Anderson (2001) reported severe defoliation of *A. schmolliae* by larvae of the clouded sulfur butterfly (*Colias philodice*). Aphids also appeared to have an impact on reproductive output for this species (Anderson 2001). Lesica (1995) reported increased predation on inflorescences of *A. scaphoides* when livestock were present. Field observers report little sign of use by either vertebrate or invertebrate herbivores on *A. wetherillii*.

Competitors

Community relationships of *Astragalus wetherillii* have not been investigated. This species is usually found growing in sparsely vegetated areas where it avoids competition from most other plants. Intraspecific competition may be more important than interspecific competition since plants often grow in loose clumps. The primary invasive species reported to co-occur with *A. wetherillii* is cheatgrass (*Bromus tectorum*). The potential for cheatgrass to become a serious competitor of *A. wetherillii* in the future is unknown.

Parasites and disease

There are no reports of disease in *Astragalus wetherillii*. Field observers have not reported any obvious damage to foliage or fruits. Plants and populations are often reported as appearing "healthy" (Lyon personal communication 2004).

Symbioses

With the exception of possible mycorrhizal relationships described above, there are no reports of symbiotic or mutualistic interactions between *Astragalus wetherillii* and other species. Barneby (1964) notes that some xerophytic *Astragalus* species of the Intermountain West grow in close association with sagebrush species (*Artemisia arbuscula* or *A. tridentata*) that provide shelter for seedlings and protect the foliage from grazing animals. This interaction has been referred to in the literature as the "nurse plant syndrome" and has been well studied in the saguaro cactus (*Cereus gigantea*; Niering et al. 1963). Although *A. wetherillii* is sometimes found in sagebrush-dominated habitats, this type of relationship has not been noted by collectors or observers.

CONSERVATION

Threats

A primary consideration in evaluating threats to the long-term persistence of *Astragalus wetherillii* is the fact that very little is known about the species. This lack of knowledge is compounded by the reluctance of agency and other personnel to spend time on a species that is perceived to be stable and reasonably common, when there are much rarer and more imperiled species. Although it is apparently locally common in parts of its range, factors controlling its distribution and abundance are relatively unknown. Its broad, but sporadic distribution pattern makes it likely that all threats will not be operating at the same intensity for every occurrence or area. Based on the available information, there are several probable threats to *A. wetherillii*. In order of decreasing priority, these are road building and maintenance, off-road vehicle use, oil and gas development, livestock movement (trailing), residential development, non-native species invasion, and global climate change. The two occurrences on National Forest System lands are not currently known to be affected by any of these threats (Colorado Natural Heritage Program 2005). However, with the exception of residential development, all threats may become pertinent to occurrences on the Uncompahgre and White River national forests in the future.

Lands managed by the White River and Uncompahgre national forests, as well as other federal, state, and private lands in the region, have not been surveyed exhaustively for *Astragalus wetherillii* occurrences. It is impossible to assess the extent of impacts from the above threats for any undocumented occurrences on USFS or other lands. In the absence of a coordinated effort to monitor and maintain known occurrences and potential habitat, ignorance of potential impacts could lead to a gradual erosion of habitat availability and increasing impacts from energy resource development, as well as other forms of disturbance. Increased disturbance from human activity on Colorado's western slope is likely to have a gradual but cumulative effect on habitats, occurrences, and individuals of *A. wetherillii* and its pollinators. Without systematic monitoring of the species throughout its limited range, population levels could be severely reduced before anyone realizes the extent of the losses.

Road construction and maintenance directly threaten some occurrences and are likely to destroy habitat in others. Colorado Natural Heritage Program records indicate that several occurrences are growing on or near roads (numbers 3, 5, 9, 11, and 19 in **Table 1**), and that several of these were likely to be disturbed by activities associated with well pad construction or road construction. The proliferation of roads and trails often degrades habitat connectivity, increases the opportunity for weed invasion, and has the potential for detrimental effects on pollinators. Although *Astragalus wetherillii* appears to thrive in naturally disturbed habitats, in the balance, disturbances from roads and trails are likely to weigh more heavily on the negative side for the species as a whole.

Motorized recreation, especially when it results in the creation of social trails, has the potential to affect occurrences of *Astragalus wetherillii* negatively. Although many *A. wetherillii* occurrences are on steep slopes that are generally unsuitable for motorized travel, the general increase in recreational off-highway vehicle (OHV) use throughout western Colorado may threaten some occurrences. The White River National Forest reported a 74 percent increase in OHV use between 1986 and 1996 (USDA Forest Service White River National Forest 2002). The Uncompahgre National Forest also noted an increase in the recreational use of OHVs from 1985 to 2000 (USDA Forest Service Grand Mesa, Uncompahgre, Gunnison National Forest 2000a). It is likely that use has increased since then, on USFS and on other federal lands. Except for the Uncompahgre Plateau, National Forest System lands in western Colorado are generally under travel management guidelines that restrict OHV and motorcycle use to designated routes. On the Uncompahgre National Forest, the area where *A. wetherillii* has been documented is open to off-road travel except during the winter (USDA Forest Service Grand Mesa, Uncompahgre, Gunnison National Forest 2000b). BLM holdings are evenly divided between designations of open use and travel limited to existing routes. In areas where travel is restricted, impacts to individuals of *A. wetherillii* are likely to be minimal.

In Region 2, oil and gas development is concentrated on BLM and private land, and has been minimal on National Forest System land (**Figure 6**). Occurrences of *Astragalus wetherillii* impacted by energy development are primarily in the Colorado River drainage. The disturbance from well pad, road, pipeline, and transmission line construction is estimated at 3.4 acres per drill site (Bureau of Land Management 1998). In areas where drilling occurs, the potential for habitat disturbance and fragmentation is high. Through its effects on plant-insect interactions, habitat fragmentation tends to decrease the effective population size (Holsinger and Gottlieb 1991), affects the foraging behavior of pollinators (Goverde et al. 2002), and potentially reduces seed set (Steffan-Dewenter and Tscharntke 1999). Fragmentation may also enhance the potential for spread of invasive species (With 2002). Seismic analysis exploratory activities, such as the use of explosives or vibroseis trucks, can also disturb habitat.

Much of the public land in western Colorado is grazed by livestock, and *Astragalus wetherillii* is exposed to grazing on both USFS and BLM lands. Livestock are unlikely to congregate in *A. wetherillii* habitat due to its sparse vegetation and steep, unstable slopes. Movement of livestock from one area to another (trailing) can cause heavy local erosion and affect both individuals and habitat of *A. wetherillii* (Scheck personal communication 2004). Trampling by concentrations of livestock could be detrimental to pollinators as well as to some individual plants (Sugden 1985).

The bulk of the species' habitat falls on public lands, where the possibility of direct impacts from residential development is small. One occurrence

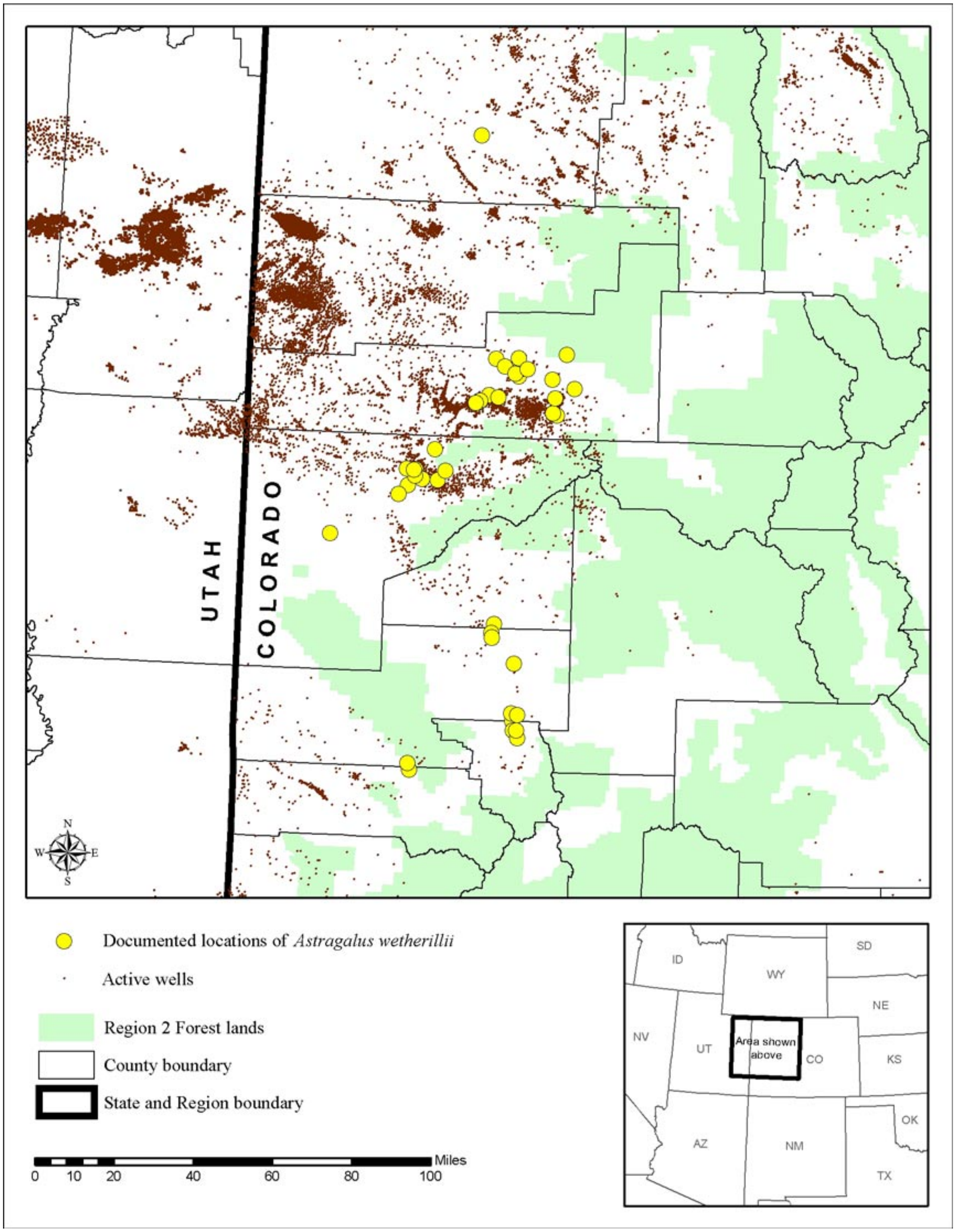


Figure 6. Energy resource development (gas well location) in the range of *Astragalus wetherillii*.

(number 12 in **Table 1**) is located in drainages below a housing development (Lyon personal communication 2004). Human populations continue to increase in western Colorado, at or above the rate for the state as a whole (U.S. Census Bureau 2004), and this is likely to lead to an increase in anthropogenic effects to the environment. When development does occur, it can increase habitat fragmentation and edge effects.

The mechanisms by which invasive or non-native species threaten rare plants or other native vegetation are not well understood. The replacement of native vegetation by non-native species is often observed, but documentation of direct competitive interactions with non-natives that are detrimental to rare species is sparse. Studies that have investigated these interactions indicate that negative effects of invasive species are often better explained by changes in disturbance regime or other habitat variables associated with invasive species presence rather than solely by the presence of invasive species (Gould and Gorchov 2000, Farnsworth 2004, Thomson 2005).

As of this writing, *Astragalus wetherillii* habitat is largely free of invasive non-native plant species. The only two non-native species reported to co-occur with *A. wetherillii* are cheatgrass and yellow sweetclover (*Melilotus officinalis*). Both of these species are listed as invasives by the BLM (2004). Cheatgrass is a Colorado state-listed noxious weed and is regarded as noxious by the USFS.

Cheatgrass is widespread in western Colorado. In the Grand Junction and Montrose areas, it dominates some rangelands and has replaced native grasses and shrubs within the last 50 years (Hayes and Scott 2001). Cheatgrass can establish quickly where the soil surface has been disturbed and often first appears along roadsides. Extensive invasion by cheatgrass can alter the natural fire dynamics of the native vegetation (Zouhar 2003). Cheatgrass has been reported in eight of the occurrences of *Astragalus wetherillii* on BLM land listed in **Table 1** (numbers 3, 15, 17, 19, 20, 21, 22, and 29). Because cover of cheatgrass can vary substantially from year to year, it may be present in other locations as well.

The long-term survival of the species could be affected by habitat expansion or contraction induced by global climate change. Under two widely-used climate change models, as levels of atmospheric CO_2 increase, the predicted scenario for much of western Colorado is an increase in both temperature and precipitation (National Assessment Synthesis Team, Climate Change Impacts on the United States 2000). Locally, this change is likely to drive an increase of vegetation biomass as grasslands shift to woodlands and forests. This change may be detrimental to *Astragalus wetherillii* if it results in a decrease in the sparsely vegetated habitat favored by the species, but with the current level of knowledge of this species' habitat requirements, it is difficult to predict the outcome.

Astragalus wetherillii presumably evolved under natural cycles of fire and regrowth, at least where it occurs in woodland settings. Much of its habitat is very sparsely vegetated, and fine fuels are often lacking in the understory. The effect of fire suppression on habitat dynamics is unknown, but it is potentially important in the persistence of suitable habitat and in the potential for increased erosion. This threat may also interact with the effects of global warming on dominant vegetation. For instance, if fire-prone vegetation types increase in extent, then the frequency and intensity of fire in the range of *A. wetherillii* may also increase. Effects of changes in fire regime on the survival of *A. wetherillii*, whether beneficial or detrimental, are unknown.

It is unlikely that any single threat is sufficient to eliminate the species from its entire range. For species with small global ranges such as *Astragalus wetherillii*, there is a smaller margin for error in protection. Land managers faced with repeated decisions must be aware of the cumulative effects of their decisions. The combination of several smaller actions that do not individually cause a loss of viability may have a significant impact on population trends that is not quickly apparent. In general, the most effective strategy is to avoid impacts to sensitive species whenever possible, and to preserve the largest population numbers possible.

Influence of management activities or natural disturbances on habitat quality

The effects of management activities or natural disturbances on *Astragalus wetherillii* habitat quality have not been studied. Some inferences can be drawn from the knowledge of its preferred niche within the pinyon-juniper woodland habitat. *Astragalus wetherillii* is clearly specialized to grow on sparsely vegetated, easily eroded shale slopes. Any management activities or natural disturbances that alter this particular niche are likely to have an effect on habitat quality for *A. wetherillii*. The species appears to be well adapted to natural levels of disturbance, but it may not be able to tolerate either the increased erosion that results from road building, livestock trailing, or recreational impacts to friable soil, or an increase of vegetative cover that results from fire suppression or invasive species. Activities that have a sudden and severe impact on local erosion and drainage patterns of *A. wetherillii* habitat may also result in a loss of safe sites for germination. Activities or disturbances that result in habitat fragmentation or soil disturbance outside of occurrence boundaries (e.g., road construction, energy and mineral exploration, development) are likely to impact local pollinators negatively, as well as increase the potential for local extinction.

Influence of management activities or natural disturbances on individuals

In general, management activities or natural disturbances that affect habitats are likely to have similar or parallel effects on individuals or occurrences. In particular, surface disturbance associated with road construction, livestock trailing, and off-road vehicle use is likely to impact *Astragalus wetherillii* directly. Plants may be killed or damaged as a result of these activities, and population remnants may be unable to recolonize disturbed areas. Surface disturbance may also affect the survival and reproductive success of individuals by altering local patterns of erosion and drainage, promoting weed invasion, and eliminating germination safe sites.

Maschinski et al. (1997) found that population levels of *Astragalus cremnophylax* var. *cremnophylax* at Grand Canyon National Park fluctuated after protection from trampling, and modeling suggested that the post-protection occurrence would stabilize, in contrast to the declining unprotected occurrence. Although plants were able to tolerate some trampling, disturbance increased the vulnerability of individuals to poor climatic conditions. Seedlings were able to reach reproductive stage more quickly after protection from trampling. Sugden (1985) found that sheep grazing endangered ground-nesting bees that are responsible for pollinating *A. monoensis* in California. These results tend to suggest that occurrences of *Astragalus* species are more stable under conditions where disturbance is limited, or is of a type under which the species has evolved.

Threats from over-utilization

There are no known commercial uses for *Astragalus wetherillii*. Although *Astragalus* is a very large genus, comparatively few species are of agricultural significance (Allen and Allen 1981). The prevalence of toxic compounds in the genus greatly reduces their utility as forage. A variety of *Astragalus* species are a source of gum tragacanth, an insoluble carbohydrate gum that has been used in manufacturing and the pharmaceutical industry for centuries (Allen and Allen 1981). At least one species of *Astragalus* (*A. membranaceous* [Huang-qi]) is widely used in Chinese medicine, where it is often listed merely as "Astragalus". It is generally described as an immune system booster and is recommended for a variety of uses. There is no indication that *A. wetherillii* is likely to become a target of either of these types of commercial use.

Selenium-absorbing species of *Astragalus* have been used in the detection and mapping of seleniferous and uranium-bearing areas, and they are a major source of livestock poisoning. *Astragalus wetherillii* is not a selenium-absorbing species, but its potential unpalatability due to other toxins has not been investigated.

Astragalus wetherillii is regularly collected in botanical surveys, but it has never been the subject of formal scientific investigation. Available evidence indicates that populations are sufficient to support collecting and research at similar levels in the future.

Conservation Status of __Astragalus wetherillii__ in Region 2

As with many species perceived as moderately rare, our knowledge of *Astragalus wetherillii* is imprecise and largely undocumented. The species is an endemic whose entire range consists of portions of a few major river drainages in western Colorado. Although *A. wetherillii* has multiple population centers and is not a narrow habitat specialist, its limited global distribution makes it a species of interest to plant conservationists. Because of the variable quality of past reports for this species, it is unwise to rely solely on the undocumented opinions of a few observers to determine the conservation status of *A. wetherillii*. Although the observations of agency personnel or contractors with many years experience in the field are valuable, they are also easily lost over time as people retire, records are lost or never created, and information technology changes. There is no substitute for vouchered plant locations with precise coordinates, good estimates of total numbers, and repeat observations.

Currently there is no evidence that the distribution or abundance of *Astragalus wetherillii* is severely declining in Region 2. The numbers of plants in some occurrences have been observed to fluctuate dramatically between years (Lyon personal communication 2004, Colorado Natural Heritage Program 2005). Some of these observations show a downward trend. Many occurrences have not been visited more than once, or population numbers were not recorded in each visit. Multi-year observations of *A. wetherillii* occurrences are insufficient for analysis of distribution and abundance trends. Reported population sizes are quite variable, and much of the potential range has not been surveyed for *A. wetherillii*. This lack of quantitative information makes it difficult to assign the species a conservation status with any degree of confidence. In addition, few of the known occurrences are in protected areas.

Our knowledge of habitat quality for *Astragalus wetherillii* is also limited. Current knowledge suggests that there is substantial potential suitable habitat in western Colorado and adjacent eastern Utah. As far as is known, much of this potential habitat is unoccupied, and there is no information on whether this is due to a lower capacity to support the species, lack of colonization opportunities, or other reasons. It is also possible that *A. wetherillii* is more widely distributed than thought, but largely undocumented.

There are no obvious risks to *Astragalus wetherillii* arising from its life history and ecological characteristics, but these factors have never been investigated. Population sizes appear sufficient to mitigate against demographic or genetic stochasticity. Until more is known about population trends and the dispersal capabilities and pollination dynamics of the species, the possibility that the species is vulnerable to environmental stochasticity should not be dismissed.

Although there is no strong evidence of occurrences at risk in Region 2, evidence presented in the previous sections indicates that surface disturbing activities are likely to have a detrimental effect on *Astragalus wetherillii* in some parts of its range. This potential should be weighed against the knowledge that there are a number of *A. wetherillii* occurrences, some of which appear to be fairly large; that these occur in multiple population centers; and that recent discoveries of occurrences may indicate that there are additional, as yet undiscovered occurrences. Overall, our current understanding of the distribution and abundance of *A. wetherillii* suggests that it should remain a species of concern, even though it is clearly not among the most imperiled Colorado endemic species. Benign neglect has apparently been a reasonable strategy to this point, but it will be impossible to detect a change of status without at least minimal monitoring.

Management of Astragalus wetherillii in Region 2

Implications and potential conservation elements

Until more is known about the distribution, habitat requirements, and population dynamics of *Astragalus wetherillii*, our knowledge of the effects of management activities on the species must be generalized. *Astragalus wetherillii* is primarily found in sparsely vegetated areas in pinyon-juniper associations where shale soils form steep, eroding slopes. Management activities that alter the normal processes of this widespread environment may threaten the persistence of the species.

Desired environmental conditions for *Astragalus wetherillii* include undisturbed and unfragmented tracts of habitat that are large enough to sustain natural ecosystem processes for both the plant and its pollinators. Micro- and meso-scale erosion dynamics that maintain sparsely vegetated areas appear to be an important factor. Landscape connectivity should be sufficient to allow dispersal and colonization. From a functional standpoint, the ecosystem processes on which *A. wetherillii* depends appear to be largely intact at this time, at least in areas that have not been severely altered by construction. Whether this will remain true with increasing energy resource development and recreational use is uncertain. Targeted research on the ecology and distribution of *A. wetherillii* could help to develop effective approaches to management and conservation.

The apparently disjunct nature of occurrences within the known range of *Astragalus wetherillii* may allow some occurrences to escape the effects of environmental change or management that may eliminate other occurrences. It is important to preserve disjunct occurrences as reservoirs of local variation and adaptation. The generally arid and uninviting habitat of *A. wetherillii* habitat has probably contributed to its escape from anthropogenic impacts.

The majority of known occurrences of this species are on BLM lands; two are on USFS lands. Interagency cooperation in tracking the status of known occurrences and impacts on *Astragalus wetherillii* habitat would facilitate the conservation of the species. It is likely that a careful analysis of current practices on lands occupied by *A. wetherillii* would identify opportunities for management that would be inexpensive and have minimal impacts on the livelihood and routines of local residents, ranchers, managers and recreationists while conferring benefits to *A. wetherillii*.

Tools available to the USFS for conservation of *Astragalus wetherillii* in Region 2 include continued listing as a sensitive species, regulating the use of land where *A. wetherillii* occurs, and increasing the protective level of management area designations for *A. wetherillii* occurrences. In some instances, it may be possible for the USFS to contribute to the conservation of *A. wetherillii* by identifying and proposing land exchanges or purchases that will lead to the protection of additional occurrences. The USFS can also provide opportunities for the collection of *A. wetherillii* material for storage or propagation of off-site occurrences. Implementation of these and other tools largely depends on the acquisition of better information on known or suspected occurrences on USFS lands.

Tools and practices

As with many species that are not in immediate danger of extirpation, it is difficult to identify priorities for inventory and monitoring. For instance, if comprehensive inventory work were to determine that the species is more common and widespread than currently known, monitoring might not be necessary. Likewise, if regular population monitoring established that known occurrences were stable or increasing over an extended period, additional inventory may not be needed. The prioritization of inventory and monitoring efforts for both occurrences and habitat will depend on the results of initial investigations, and these are likely to be determined by the interests, funding, and availability of agency personnel.

There have been numerous reports of *Astragalus wetherillii* occurrences, as well as survey work in the early 1990s. These observations have not completely clarified the status of the species. Total population numbers and temporal patterns of abundance remain unquantified. Two issues that need additional research are 1) searching potential habitat between known occurrences, and 2) the natural range of variation in population numbers. In some years, the species is reported as being in decline while in others it is perceived as healthy and stable.

Species and habitat inventory

The ideal inventory would thoroughly search all potential habitat, locate and map all occurrences, and accurately census each occurrence. Because such efforts are usually prohibitively expensive and time consuming, inventory work normally concentrates on obtaining reasonable estimates of population numbers and species distribution.

Methods should be based on a standard protocol suitable for the scale and purpose of the inventory. Most vascular plant inventories produce a species list rather than documenting the distribution of a single species. Consequently, methods of species inventory for plants are poorly standardized in some aspects although they usually adhere to the same fundamental methodology. The National Park Service Guidelines for Biological Inventories (National Park Service 1999) is an excellent protocol for both species and habitat monitoring, and it is available online at http://science.nature.nps.gov/im/inventory/biology/.

Efficient species inventory depends on the identification of suitable habitat to be searched. Search areas should be closely linked to digital, geo-referenced data, especially aerial photographs, soil maps, and vegetation maps. Locations of known occurrences overlaid on aerial imagery would provide a quick method of identifying the extent of similar habitat in the areas where *Astragalus wetherillii* has been documented. Validation by ground surveys would provide information on soil types, microhabitat requirements, disturbance tolerance, and other factors, and it would allow additional potential habitat to be mapped from aerial photos for further surveys. If these methods establish the presence of potentially suitable habitat in the Yampa and White river drainages, a search of these areas could clarify the persistence of the species north of the Colorado River. Better definition of important habitat characteristics would also be helpful for attempts to relocate the Eastwood collection location in Utah.

Once the appropriate habitat parameters have been established, the second phase of inventory should focus on obtaining a reasonable estimate of abundance throughout the species' range, as well as establishing the boundaries of that range. The results of this phase will determine the need for further inventory.

Inventories will be most successful if they take place during the flowering and fruiting season (i.e., the last week of May through the first half of June). Initial surveys may include intensive soil sampling, habitat characterization, and careful estimation of population numbers. The initial survey should concentrate more on collecting a variety of data rather than visiting every known occurrence.

Although there may be many more *Astragalus wetherillii* occurrences not yet undiscovered, known locations provide sufficient opportunity to detect important changes in the species' response to management. It is probably more important to focus on year-to-year population fluctuations than to discover new occurrences. Future species inventory work should focus on obtaining better and more frequent population size data. Rough population estimates, using size categories such as 1 to 10, 10 to 100, 100 to 1000, etc., would be adequate if they are repeated more often using a consistent methodology. Past inventory work has reported estimates in the thousands for an occurrence that later was estimated to contain fewer than 100 individuals. Since observations have been sporadic, it is impossible to determine if this is due to real population fluctuations or observer error.

Habitat inventory techniques are similar to those for species inventory. The use of aerial photography, topographic maps, soil maps, and geology maps to identify search areas is a widely used technique. This technique is most effective when basic knowledge of a species' substrate and habitat specificity is available. Important factors to quantify during habitat inventory for *Astragalus wetherillii* will include the proximity of habitat to roads, energy development, the degree and type of disturbance in the area, variation in local topography and habitat structure.

Ideally, surveys should be conducted by trained professionals who are familiar with *Astragalus wetherillii*. Voucher specimens are necessary to ensure proper identification. Personnel should be familiar with methods of soil and habitat characterization. Surveyors should use Global Positioning System equipment for rapid and accurate data collection of location and occurrence extent. Preparatory work should take into account the fact that although much of the habitat to be searched is federal land, access through private land is often required. Determination of the need for further inventory, the extent of occurrences, and critical habitat characteristics should be shared among state and federal agencies, natural heritage programs, local and regional experts, and interested members of the public.

In the absence of funding for formal survey work, agency personnel and contractors should be encouraged to document new occurrences located during the performance of other work by collecting a specimen, estimating the population size and extent, and obtaining exact geospatial location information. Whenever possible, this information should be submitted to the Colorado Natural Heritage Program. Even minimal documented observations could greatly increase our knowledge of the species.

Population monitoring

Our limited knowledge of temporal patterns of abundance for *Astragalus wetherillii* makes population monitoring a high priority for clarifying population trends, identifying risks to occurrence survival, and characterizing potential threats. Repeat observations are critical, since previous infrequent observations suggest that numbers vary widely. A small, long-term monitoring program could establish population abundance patterns over several generations under varying environmental conditions. Monitoring one or two of the known occurrences in each of the major population centers would probably be sufficient to determine broad trends, especially if sites known to be impacted by management activities are included.

Ideally, monitoring stations would coincide with locations already visited by agency personnel in the course of other duties. With a little additional effort, broad population estimates could be made at each station (Elzinga et al. 1998), and photographs could provide an idea of habitat condition. Initially, monitoring would need to be sufficiently frequent to determine the appropriate time to measure growth and reproduction. Natural variability in growth, flowering, and seed set means that observations that are too infrequent can result in data that is difficult to interpret (e.g., plants that had no flowers at observation time 1 have abundant fruit at observation time 2). The first year of monitoring should concentrate on establishing the timing of critical seasonal elements such as flowering and fruit set, and determining the most useful and practical data collection protocols. Subsequent years of monitoring should concentrate on collecting data at these established times.

If monitoring determines that all occurrences are experiencing population fluctuations in concert, it may indicate that the species is vulnerable to environmental stochasticity on a broad scale. In this case, more detailed monitoring may be required to clarify the life history and population dynamics of the species in order to guide conservation efforts. If population fluctuations are not coordinated between occurrences, then this may be a sign that metapopulation dynamics will allow for persistence of the species even when local extinction events occur. In this case, additional research should concentrate on establishing rates of colonization and extinction, and clarifying the interconnectivity of subpopulations.

Quantitative studies are time-consuming and expensive. Although *Astragalus wetherillii* does not appear to merit such intensive study at this time, it should be kept in mind as a potential research subject for other investigators. Efforts to enlist the help of researchers in studying *A. wetherillii* could greatly enhance our knowledge of this species. *Astragalus wetherillii* is an ideal subject because it is both endemic and plentiful enough in its restricted range to allow for the collection/manipulation of individuals.

Habitat monitoring

The decision to undertake habitat monitoring will be driven by the results of species inventory and monitoring, and by the habitat characteristics identified during inventory. Efficient monitoring must wait until we have better information on the habitat requirements of the species. Once habitat extent is known, even on a broad scale, basic monitoring could be done by overlaying known impacts from energy development, recreation, weeds, fire, residential development, etc. on known locations. Geographic Information System (GIS) technology can provide a powerful tool in the analysis of the scope and severity of habitat impacts. Alternatively, the use of photopoints for habitat monitoring is a powerful technique that can be accomplished quickly in the field. Monitoring techniques are described in Elzinga et al. (1998). Practical details of photographic monitoring are covered exhaustively in Hall (2001).

If habitat monitoring is not possible, then documenting habitat characteristics, associated species, evidence of current land use and management, disturbance and so forth for inventoried occurrences would contribute to our knowledge of the species. Until more is known about the species' habitat requirements, it is possible that only monitoring the habitat of a few known occurrences will risk missing important trends.

Beneficial management actions

The establishment of an interagency awareness of *Astragalus wetherillii* locations and trends is perhaps the most useful conservation strategy. The fact that more than 60 percent of the known occurrences are on federal land puts federal land managers in a position to carry out such a strategy. Management actions that minimize the impacts of surface disturbance and that promote natural levels of connectivity between subpopulations will benefit occurrences of *A. wetherillii*. Managers need to be aware that fluctuations in population numbers from year to year are a potential source of difficulty in project clearance work; surveys in poor growth years may not detect the species where it is in fact present. Wherever possible, road, well pad, and pipeline construction should avoid *A. wetherillii* occurrences and habitat. Monitoring and control of construction activities, off-road vehicle travel, and livestock trailing should be combined with practices that prevent the spread of weeds into *A. wetherillii* habitat. These practices include public educational outreach about the problem, periodic monitoring of areas most at risk for travel violations and weed infestation, efforts to minimize disturbance and limit dispersal, and the maintenance of healthy native vegetation (see Colorado Natural Areas Program 2000 for additional information). If infestation by noxious weeds cannot be prevented, then control efforts should focus on methods that will have the least impact *A. wetherillii* individuals growing in the area.

Seed banking

Astragalus wetherillii is included in the BLM's Seeds of Success program (http://www.nps.gov/plants/sos/index.htm). This interagency program is run through the Plant Conservation Alliance and coordinates seed native plant seed collections in the United States. No seeds or genetic material are currently in storage for *A. wetherillii* at the National Center for Genetic Resource Preservation (Miller personal communication 2003). Nor is *A. wetherillii* among the National Collection of Endangered Plants maintained by the Center for Plant Conservation (Center for Plant Conservation 2002).

Information Needs

Distribution

At this time, our knowledge regarding the extent of *Astragalus wetherillii* distribution is incomplete, even on a broad scale. It would be useful to know if the distribution is as intermittent as current knowledge indicates. Is *A. wetherillii* still present in the Yampa River watershed? Is the White River watershed really lacking the species? Is the species still present in Utah? Accurate information on the abundance of the species is needed. It will be difficult to formulate conservation strategies for Region 2 without clarifying these types of questions. More complete information on the environmental characters influencing distribution patterns would also be invaluable in formulating management strategies.

Life cycle, habitat, and population trend

The dynamics of pinyon-juniper habitats where *Astragalus wetherillii* is found are reasonably well documented, even though the specific position of *A. wetherillii* within these ecological systems is not well studied. Furthermore, although the species has been casually observed in the field for many years, there are no detailed multi-year observations that would contribute to an understanding of the species' life cycle and population trends. Some inferences can be made from other *Astragalus* species, but members of this genus often exhibit restricted ranges, which may indicate local adaptation and differentiation.

Repeated observations of marked individuals in multiple wild occurrences, or even in an artificial population under natural conditions, would greatly clarify the population dynamics of *Astragalus wetherillii*. In particular, it would be useful to identify the timing of germination, germination requirements, life expectancy, seed bank dynamics, and transition probabilities for different life-cycle stages. This type of information could help to determine whether fluctuating population numbers are due to dormancy of mature plants or to recruitment from the seed bank. The development of an elasticity analysis could identify critical stages of the life cycle and aid in identifying threats to *A. wetherillii*. Similarly, multi-year census or tracking efforts for some occurrences would facilitate the quantification of population trends for the species as a whole.

Response to change

The effects of environmental variation on the reproductive rates, dispersal mechanisms, and establishment success of *Astragalus wetherillii* are unknown. The same is true for its relationship with herbivores, pollinators, and exotic species. Therefore, the effects of both fine- and broad-scale habitat change in response to management or disturbance are difficult to evaluate. Detailed information on the habitat requirements of *A. wetherillii* would enable better understanding of the potential effects of disturbance and management actions in these habitats. In particular, the response of the species to soil disturbances produced by livestock trailing, off-road vehicle use, and road construction should be investigated. Because these disturbances can easily be followed by an increase in invasive species, additional information on the effects of these invaders on the habitat and life cycle of *A. wetherillii* is also needed. The effects of grazing on the habitat and pollination ecology of *A. wetherillii* are also of interest.

Metapopulation dynamics

The apparent tendency of *Astragalus wetherillii* to occur in scattered small occurrences and for some occurrences to appear and disappear from one year to the next may mean that metapopulation dynamics are especially important to the survival of the species. However, virtually nothing is known about the metapopulation structure and processes of *A. wetherillii*. It is not clear if occurrences in separate drainages can act as a metapopulation. Baseline studies are needed to collect data on migration, colonization and extinction rates, as well as environmental factors contributing to the maintenance of inter-population connectivity. Until this information is available, we cannot realistically predict the likelihood of *A. wetherillii* persisting at either the local or the regional scale.

Demography

As with metapopulation dynamics, current demographic information is also not sufficient to enable an analysis of the persistence of *Astragalus wetherillii* at either the local or the regional scale. The demographic information that is lacking includes:

- ❖ whether individual and population numbers are declining, stable, or increasing
- ❖ which life cycle stages have the greatest influence on population trends
- ❖ what are the biological factors influencing the important stages (Schemske et al. 1994).

Lesica's (1995) long-term study of *A. scaphoides* provides a good model for similar work on *A. wetherillii*. Collection of demographic data will require the investment of two to three years at a minimum (depending on weather patterns), ideally more. While they provide useful data, short-term studies can miss important demographic events that occur irregularly or at intervals longer than the study period (Coles and Naumann 2000). Please see the Population monitoring section under Tools and practices above for more detailed information on demographic monitoring.

Population trend monitoring methods

A variety of population monitoring methods could be easily adapted to the tracking of *Astragalus wetherillii*. Pilot studies may be required to adapt some methods to the particular growth and distribution patterns of *A. wetherillii*. Please see the Population monitoring section under Tools and practices for details.

Restoration methods

Restoration methods have not been developed for this species. Existing reclamation and restoration guidelines for road building or resource extraction activities do not have specific provisions for the restoration of *Astragalus wetherillii* occurrences. The tendency for *A. wetherillii* to occur on open, eroding areas, and its quick growing habit indicate that it is likely to be easily re-established in suitable areas.

Research priorities for *Astragalus wetherillii* in Region 2

Research priorities for *Astragalus wetherillii* in Region 2 are, in order of priority:

- population monitoring
- population inventory
- identification of critical habitat factors
- quantification of the effects of management practices on the species
- demographic studies sufficient to perform elasticity analyses
- pollination dynamics and possible impacts on pollinators.

Additional research and data resources

Some additional information on occurrence locations and habitats may be available from herbarium specimens not consulted for this document. In addition, Volume 10/11 (Magnoliophyta: Rosidae, part 3 & 4) of the Flora of North America, which will contain the treatment of *Astragalus*, has not yet been released.

Definitions

Ascending – growing obliquely upward, usually curved (Harris and Harris 1994).

Compound leaf – a leaf separated into two or more distinct leaflets. A pinnately compound leaf has leaflets arranged on opposite sides of an elongated axis (Harris and Harris 1994).

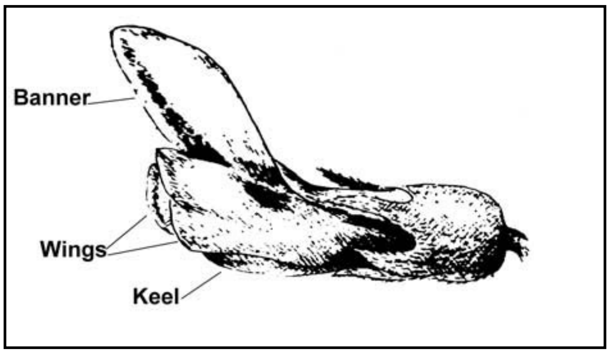
Dehiscence – the opening at maturity of fruits and anthers (Harris and Harris 1994).

Glabrous – smooth, without hairs.

Melittophily – pollination by bees.

Monoecious – a plant that bears male and female reproductive structures in the same flower, or separate male and female flowers on the same plant (Allaby 1998).

Papilionaceous – of flowers, butterfly-like, with a banner petal, two wing petals, and a keel petal (Harris and Harris 1994).



Adapted from Faegri and van der Pijl 1979

Perfect – flowers that include both male and female structures; bisexual (Weber and Wittmann 2001).

Polycarpic – a plant capable of repeated flowering.

Pubescent – hairy.

Raceme – an elongated inflorescence with a single main axis along which single, stalked flowers are arranged (Weber and Wittmann 2001).

Rank – used by Natural Heritage Programs, Natural Heritage Inventories, Natural Diversity Databases, and NatureServe. Global imperilment (G) ranks are based on the range-wide status of a species. State-province imperilment (S) ranks are based on the status of a species in an individual state or province. State-province and Global ranks are denoted, respectively, with an "S" or a "G" followed by a character (NatureServe 2003a). These ranks should not be interpreted as legal designations.

Sympatric – applied to species whose habitats (ranges) overlap (Allaby 1998).

Trailing – concentrated movement of large groups of domestic livestock, as when animals are herded from one location to another.

Vesture (also vestiture) – the epidermal coverings of a plant (Harris and Harris 1994).

Zygomorphic – having bilateral symmetry; a line through the middle of the structure will produce a mirror image on only one plane (Harris and Harris 1994).

References

Allaby, M. 1998. A Dictionary of Plant Sciences. Oxford University Press, New York, NY.

Allen, O.N. and E.K. Allen. 1981. The Leguminosae: A Source Book of Characteristics, Uses, and Nodulation. The University of Wisconsin Press, Madison, WI.

Anderson, D.G. 2001. Population Status Survey of Schmoll's Milkvetch (*Astragalus schmolliae* C.L. Porter). Summary of Year 1 Results. Prepared for National Park Service, Mesa Verde National Park.

Anderson, M., P. Comer, D. Grossman, C. Groves, K. Poiani, M. Reid, R. Schneider, B. Vickery, and A. Weakly. 1999. Guidelines for Representing Ecological Communities in Ecoregional Conservation Plans. The Nature Conservancy.

Atwood, D., J. Holland, R. Bolander, B. Franklin, D.E. House, L. Armstrong, K. Thorne, and L. England. 1991. Utah Threatened, Endangered and Sensitive Plant Field Guide. U.S. Forest Service Intermountain Region, National Park Service, Bureau of Land Management, Utah Natural Heritage Program, U.S. Fish and Wildlife Service, Environmental Protection Agency, Navajo Nation and Skull Valley Goshute Tribe.

Barneby, R.C. 1964. Atlas of North American *Astragalus*. Memoirs of the New York Botanical Garden Vol 13. New York, NY.

Barneby, R.C. 1987. Letter of November 30, 1987 to John L. Anderson.

Barneby, R.C. 1989. Fabales. *In*: A. Cronquist, A.H. Holmgren, N.H. Holmgren, J.L. Reveal, and P.K. Holmgren. Volume Three, Part B of Intermountain Flora, Vascular Plants of the Intermountain West, U.S.A. New York Botanical Garden, New York, NY.

Barroetavena, C., S.D. Gisler, D.L. Luoma, and R.J. Meinke. 1998. Mycorrhizal status of the endangered species *Astragalus applegatei* Peck as determined from a soil bioassay. Mycorrhiza 8:117-119.

Bowles, M.L., R.F. Betz, and M.M. DeMauro. 1993. Propagation of rare plants from historic seed collections: implications for species restoration and herbarium management. Restoration Ecology 1:101-106.

Brackley, F.E. 1989. Jesup's milkvetch recovery plan. U.S. Fish and Wildlife Service, New England Field Office. Concord, NH.

Bunin, J.E. 1991. 1990 Interim status report for *Astragalus wetherillii* M.E. Jones.

Bunin, J.E. 1992. Status Report for *Astragalus wetherillii* M.E. Jones.

Bureau of Land Management. 1998. Glenwood Springs Resource Area Oil & Gas Leasing & Development Draft Supplemental Environmental Impact Statement. Glenwood Springs, CO.

Bureau of Land Management. 2004. National List of Invasive Weed Species of Concern. Available online at: http://www.co.blm.gov/botany/invasiweed.htm.

Caswell, H. 2001. Matrix Population Models. Second Edition. Sinauer Associates, Inc. Sunderland, MA.

Center for Plant Conservation. 2002. National Collection of Endangered Plants. Database available online at: http://www.mobot.org/CPC/NC_choice.html.

Clement, S.L. and D.H. Miller. 1982. Insect seed predation on *Astragalus bisulcatus* (Hook.) Gray (Leguminosae). Pan-Pacific Entomologist 58:38-41.

Coles, J.J. and T.S Naumann.2001. Long-term demographic monitoring of the Mesa Verde cactus in Colorado. *In*: J. Maschinski and L. Holter, editors. Southwest Rare and Endangered Plants: Proceedings of Third Conference. RMRS-P-23. USDA Forest Service, Rocky Mountain Research Station, Fort Collins, CO.

Colorado Natural Areas Program. 2000. Creating an Integrated Weed Management Plan: A Handbook for Owners and Managers of Lands with Natural Values. Colorado Natural Areas Program, Colorado State Parks, Colorado Department of Natural Resources and Division of Plant Industry, Colorado Department of Agriculture. Denver, CO.

Colorado Natural Heritage Program. 2005. Biodiversity Tracking and Conservation System (BIOTICS). Colorado Natural Heritage Program, Colorado State University, Fort Collins, CO.

Colorado Oil and Gas Conservation Commission. 2004. Well locations. Digital Data. Available online at http://oil-gas.state.co.us/.

Decker, K. and D.G. Anderson. 2004. *Astragalus anisus* Jones (Gunnison milkvetch): A Technical Conservation Assessment. Prepared for the USDA Forest Service, Rocky Mountain Region, Species Conservation Project.

Elzinga, C.L., D.W. Salzer, and J.W. Willoughby. 1998. Measuring and Monitoring Plant Populations. BLM Technical Reference 1730-1.

Faegri, K. and L. van der Pijl. 1979. The Principles of Pollination Ecology. Pergamon Press, Oxford.

Farnsworth, E.J. 2004. Patterns of plant invasions at sites with rare plant species throughout New England. Rhodora 106:97-117.

Friedlander, J.D. 1980. The Status of Rare and Endangered Plant Species in Mesa Verde National Park, Colorado. M.S. Thesis. Colorado State University.

Geer, S.M., V.J. Tepedino, T.L. Griswold, and V.R. Bowlin. 1995. Pollinator sharing by 3 sympatric milkvetches, including the endangered species *Astragalus montii*. Great Basin Naturalist 55:19-28.

Gould, A.M.A. and D.L. Gorchov. 2000. Effects of the exotic invasive shrub *Lonicera maackii* on the survival and fecundity of three species of native annuals. American Midland Naturalist 144:36-50.

Goverde M., K. Schweizer, B. Baur, and A. Erhardt. 2002. Small-scale habitat fragmentation effects on pollinator behaviour: experimental evidence from the bumblebee *Bombus veteranus* on calcareous grasslands. Biological Conservation 104:293-299.

Green, T.W. and G.E. Bohart. 1975. Pollination ecology of *Astragalus cibarius* and *Astragalus utahensis* (Leguminosae). American Journal of Botany 62:379-386.

Green, T.W. and I.G. Palmbald. 1975. Effects of insect seed predators on *Astragalus cibarius* and *Astragalus utahensis* (Leguminosae). Ecology 56:1435-1440.

Grime, J.P. 2001. Plant Strategies, Vegetation Processes, and Ecosystem Properties. John Wiley & Sons, Chichester, West Sussex, England.

Hall, F.C. 2001. Ground-Based Photographic Monitoring. General Technical Report PNW-GTR-503 USDA Forest Service Pacific Northwest Research Station.

Harper, J.L. 1977. Population Biology of Plants. Academic Press, New York, NY.

Harrington, H.D. 1954. Manual of the Plants of Colorado. Sage Books, Denver, CO.

Harris, J.G. and M.W. Harris. 1994. Plant Identification Terminology: An Illustrated Glossary. Spring Lake Publishing, Spring Lake, UT.

Hartl, D.L. and A.G. Clark. 1989. Principles of Population Genetics. Sinauer Associates, Inc., Sunderland, MA.

Hayes, A. and J. Scott. 2001. Fact Sheet: Cheatgrass Invasion in the Gunnison Basin. Available online at: http://www.gunnisonbiodiversity.org/cheatgrs_facts.html.

Heywood, V.H. 1993. Flowering Plants of the World. Oxford University Press, New York, NY.

Holsinger, K.E. and L.D. Gottlieb. 1991. Conservation of Rare and Endangered plants: Principles and Prospects. *In*: D.A. Falk and K.E. Holsinger, editors. Genetics and Conservation of Rare Plants. Oxford University Press, New York, NY.

Isely, D. 1984. *Astragalus* L. (Leguminosae: Papilionoideae) II: Species summary A-E. Iowa State J. Res. 59:97-216.

Isely, D. 1985. Leguminosae of the United States. *Astragalus* L. species summary F-M. Iowa State J. Res. 60:183-320.

Isely, D. 1986. Leguminosae of the United States. *Astragalus* L. species summary N-Z. Iowa State J. Res. 61:157-289.

Isely, D. 1998. Native and Naturalized Leguminosae (Fabaceae) of the United States. Monte L. Bean Life Science Museum, Provo, UT.

Jones, M.E. 1893. Contributions to Western Botany, *Astragalus wetherillii*. Zoe 4:34.

Jones, M.E. 1923. *Revision of North-American Species of Astragalus*. Salt Lake City, UT.

Karron, J.D. 1987. The pollination ecology of co-occurring geographically restricted and widespread species of *Astragalus* (Fabaceae). Biological Conservation 39:179-193.

Karron, J.D. 1989. Breeding systems and levels of inbreeding depression in geographically restricted and widespread species of *Astragalus* (Fabaceae). American Journal of Botany 76:331-340.

Karron, J.D., Y.B. Linhart, C.A. Chaulk, and C.A. Robertson. 1988. Genetic structure of populations of geographically restricted and widespread species of *Astragalus* (Fabaceae). American Journal of Botany 75:1114-1119.

Klopatek, C.C. and J.M. Klopatek. 1987. Mycorrhizae, microbes and nutrient cycling processes in pinyon-juniper ecosystems. In Proceedings-Pinyon-Juniper Conference. USDA Forest Service, Intermountain Research Station, General Technical Report INT-215.

Lesica, P. 1995. Demography of *Astragalus scaphoides* and effects of herbivory on population growth. Great Basin Naturalist 55:142-150.

Lloyd, K.M., W.G. Lee, and J.B. Wilson. 2002. Competitive abilities of rare and common plants: comparisons using *Acaena* (Rosaceae) and *Chionochloa* (Poaceae) from New Zealand. Conservation Biology 16:975-985.

Lyon, P. 2004. Personal communication with Colorado Natural Heritage Program botanist regarding *Astragalus wetherillii*.

Lyon, P., J. Sovell, and J. Rocchio. 2001. Survey of Critical Biological Resources, Garfield County, Colorado, Volume 1. Colorado Natural Heritage Program, Fort Collins, CO.

MacArthur, R.H. and E.O. Wilson. 1967. The Theory of Island Biogeography. Princeton University Press, Princeton, NJ.

Maschinski, J., R. Frye, and S. Rutman. 1997. Demography and population viability of an endangered plant species before and after protection from trampling. Conservation Biology 11:990-999.

Miller, A. 2003. Personal communication with National Center for Genetic Resource Preservation Seed Analyst regarding *Astragalus wetherillii*.

Morris, A.B., R.S. Baucom, and M.B. Cruzan. 2002. Stratified analysis of the soil seed bank in the cedar glade endemic *Astragalus bibullatus*: evidence for historical changes in genetic structure. American Journal of Botany 89:29-36.

Morris, W., D. Doak, M. Groom, P. Kareiva, J. Fieberg, L. Gerber, P. Murphy, and D. Thomson. 1999. A Practical Handbook for Population Viability Analysis. The Nature Conservancy.

National Assessment Synthesis Team, Climate Change Impacts on the United States. 2000. The Potential Consequences of Climate Variability and Change. U.S. Global Change Research Program, Washington D.C.

National Park Service. 1999. Guidelines for Biological Inventories. National Park Service Inventory and Monitoring Program. Available online at: http://science.nature.nps.gov/im/inventory/biology/.

NatureServe. 2003. Ecological Systems Database, version 1.02. NatureServe, Arlington, VA.

NatureServe. 2004. NatureServe Explorer: An online encyclopedia of life, version 3.1. NatureServe, Arlington, VA. Available online at: http://www.natureserve.org/explorer.

Nelson, D.M. and C.D. Johnson. 1983. Stabilizing selection on seed size in *Astragalus* (Leguminosae) due to differential predation and differential germination. Journal of the Kansas Entomological Society 56:169-174.

Niering, W.A., R.H. Whittaker, and C.H. Lowe. 1963. The saguaro: a population in relation to its environment. Science 142: 15-23.

O'Kane, S.L. 1988. Colorado's rare flora. Great Basin Naturalist 48:434-484.

Platt, J.R. 1964. Strong inference. Science 146:347-353.

Porter, C.L. 1951. *Astragalus* and *Oxytropis* in Colorado. University of Wyoming Publications, Volume XVI, No I, pp.1-49.

Quilambo, O.A. 2003. The vesicular-arbuscular mycorrhizal symbiosis. African Journal of Biotechnology 2:539-546.

Ralphs, M.H. and V.L. Bagley. 1988. Population cycles of Wahweap milkvetch on the Henry Mountains and seed reserve in the soil. Great Basin Naturalist 48:541-547.

Ralphs, M.H. and E.H. Cronin. 1987. Locoweed seed in soil: density, longevity, germination, and viability. Weed Science 35:792-795.

Raven, P.H., R.F. Evert, and S.E. Eichhorn. 1986. Biology of Plants, Fourth Edition. Worth Publishers, Inc., New York, NY.

Rittenhouse, B. and R. Rosentreter. 1994. The autecology of Challis-milkvetch, an endemic of east-central Idaho. Natural Areas Journal 14:22-30.

Rondeau, R. 2001. Ecological Systems Viability Specifications for Southern Rocky Mountains Ecoregion. Colorado Natural Heritage Program, Fort Collins, CO.

Rydberg, P.A. 1906. Flora of Colorado. Agricultural Experiment Station, Fort Collins, CO.

Rydberg, P.A. 1923. Notes on Fabaceae I. Bulletin of the Torrey Botanical Club. 50:177-187.

Rydberg, P.A. 1929. *Astragalanae*, in North American Flora 24: parts 5, 6, and 7. pp. 251-426.

Scheck, C. 2004. Personal communication with Bureau of Land Management ecologist regarding *Astragalus wetherillii*.

Schemske, D.W., B.C. Husband, M.H. Ruckelshaus, C. Goodwillie, I.M. Parker, and J.G. Bishop. 1994. Evaluating approaches to the conservation of rare and endangered plants. Ecology 75:584-606.

Smith, Jr., J.P. 1977. Vascular Plant Families. Mad River Press, Inc., Eureka, CA.

Spackman, S., B. Jennings, J. Coles, C. Dawson, M. Minton, A. Kratz, and C. Spurrier. 1997. Colorado rare plant field guide. Prepared for the Bureau of Land Management, the USDA Forest Service and the U.S. Fish and Wildlife Service by the Colorado Natural Heritage Program.

Stebbins, G.L. 1957. Self-fertilization and population variability in higher plants. American Naturalist 91:337-354.

Steffan-Dewenter, I. and T. Tscharntke. 1999. Effects of habitat isolation on pollinator communities and seed set. Oecologia 121:432-440.

Stermitz, F.R., F.A. Norris, and M.C. Williams. 1969. Miserotoxin, a new naturally occurring nitro compound. J. Amer. Chem. Soc. 91:4599-4600.

Sugden, E.A. 1985. Pollinators of *Astragalus monoensis* Barneby (Fabaceae) - new host records - potential impact of sheep grazing. Great Basin Naturalist 45:299-312.

Templeton, A.R. and D.A. Levin. 1979. Evolutionary consequences of seed pools. American Naturalist 114:232-249.

The Nature Conservancy. 2001. Ecoregions of the United States of America. Vector digital data. The Nature Conservancy - Conservation Science Division. Western Conservation Science Center, Boulder, CO.

Thomson, D. 2005. Measuring the effects of invasive species on the demography of a rare endemic plant. Biological Invasions 7:615-624.

Treu, R., G.A. Laursen, S.L. Stephenson, J.C. Landolt, and R. Densmore. 1995. Mycorrhizae from Denali National Park and Preserve, Alaska. Mycorrhiza 6:21-29.

U.S. Census Bureau. 2004. Census 2000 data, State and County quick facts. Available online at: http://www,census.gov/main/www/cen2000.html.

USDA Forest Service Grand Mesa, Uncompahgre and Gunnison National Forests. 2000a. Final environmental impact statement: Uncompahgre National Forest travel plan. USDA Forest Service, Delta, CO.

USDA Forest Service Grand Mesa, Uncompahgre and Gunnison National Forests. 2000b. Uncompahgre National Forest travel plan: record of decision. USDA Forest Service, Delta, CO.

USDA Forest Service Rocky Mountain Region. 2003. Rationale statement for *Astragalus wetherillii*. Available online at: http://www.fs.fed.us/r2/projects/scp/evalrationale/rationales/dicots/index.shtml.

USDA Forest Service Rocky Mountain Region. 2005. Region 2 Regional Forester's Sensitive Species List. Available online at: http://www.fs.fed.us/r2/projects/scp/sensitivespecies/index.shtml.

USDA Forest Service White River National Forest. 2002. Final Environmental Impact Statement Volume 1 for the White River National Forest Land and Resource Plan 2002 Revision. Glenwood Springs, CO.

Utah Division of Oil, Gas, and Mining. 2004. Well locations. Digital Data. Available online at http://ogm.utah.gov/oilgas/default.htm.

Weber, W.A. and R.C. Wittmann. 2001. Colorado Flora: Western Slope. University Press of Colorado, Niwot, CO.

Welsh, S.L., N.D. Atwood, S. Goodrich, and L.C. Higgins. 1993. A Utah Flora. Brigham Young University Print Services, Provo, UT.

Western Regional Climate Center. 2004. Historical Climate Information. Available online at: http://www.wrcc.dri.edu.

Wicklow-Howard, M.C. 1994. Vesicular-Arbuscular Mycorrhizae from sagebrush steppe habitat in western Idaho and parts of eastern and central Oregon. Report prepared for Eastside Ecosystem Management Project. Boise State University Boise, ID.

Williams, M.C. and R.C. Barneby. 1977. Occurrence of nitro-toxins in North American *Astragalus* (Fabaceae). Brittonia 29:310-326.

Williams, M.C., F.R. Stermitz, and R.D. Thomas. 1975. Nitro compounds in *Astragalus* species. Phytochemistry 14: 2306-2308.

With, K.A. 2002. The landscape ecology of invasive spread. Conservation Biology 16:1192-1203.

Wooton, E.O. and P.C. Standley. 1915. Flora of New Mexico. Contr. U.S. Natl. Herb. 19:1-794.

Zhao, B., A. Trouvelot, S. Gianinazzi, and V. Pearson. 1997. Influence of two legume species on hyphal production and activity of two arbuscular mycorrhizal fungi. Mycorrhiza 7:179-185.

Zomlefer, W. 1994. Guide to Flowering Plant Families. University of North Carolina Press, Chapel Hill, NC.

Zouhar, K. 2003. *Bromus tectorum*. *In*: USDA Forest Service Rocky Mountain Research Station Fire Sciences Laboratory, producer. Fire Effects Information System. Available online at http://www.fs.fed.us/database/feis/.