Astragalus proximus (Rydberg) Wooton & Standley (Aztec milkvetch): A Technical Conservation Assessment

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COVER PHOTO CREDIT

Astragalus proximus (Aztec Milkvetch). Photograph by William Jennings, used with permission.

SUMMARY OF KEY COMPONENTS FOR CONSERVATION OF THE *ASTRAGALUS PROXIMUS*

Status

Astragalus proximus (Aztec milkvetch) is a local endemic whose global distribution is limited to the San Juan Basin in southwestern Colorado and northwestern New Mexico. It is considered fairly common within the New Mexico part of the basin, but much rarer in the Colorado portion of its range. Documented locations include five sites on the Pagosa and Columbine Ranger Districts of the San Juan National Forest in Region 2, and three on the Jicarilla Ranger District of the Carson National Forest in Region 3. The species is also known from lands managed by the Bureau of Land Management and National Park Service, Southern Ute and Jicarilla Apache tribal lands, State of Colorado and State of New Mexico lands, and private property. Although data are lacking, population numbers are assumed to be stable. *Astragalus proximus* is considered a sensitive species in Region 2 of the USDA Forest Service. It is ranked G4S2 (globally vulnerable, and imperiled in state because of rarity or other factors) within Region 2 by NatureServe and the Colorado Natural Heritage Program due to its small global distribution. It is not listed as threatened or endangered on the Federal Endangered Species List (ESA of 1973, U.S.C. 1531-1536, 1538-1540).

Primary Threats

Although *Astragalus proximus* is locally common in parts of its range and appears to have a stable population, its entire global range is contained within the northeastern San Juan Basin. Threats that are basin-wide will affect the entire species. Based on the available information, there are several threats to *A. proximus*. In approximate order of decreasing priority, these are oil and gas development, road building and maintenance (including attendant sand and gravel mining), off-road vehicle use, grazing, fire, air pollution, and global climate change. A lack of systematic tracking of population trends and conditions, and the lack of knowledge about its basic life cycle also contribute to the possibility that one or more of these factors will threaten the long-term persistence of the species.

Primary Conservation Elements, Management Implications and Considerations

Current evidence suggests that *Astragalus proximus* populations are small and scattered, but that the species occurs more or less continuously in suitable habitat throughout its range. The dispersed nature of these populations may render them especially susceptible to environmental changes or management policies that introduce fragmentation into once continuous habitat. Surface disturbing activities such as road building and energy resource development are the primary source of habitat change in the area. The patchwork of ownership patterns in the range of *A. proximus* means that cooperation among federal land managers and with a variety of state, tribal, and local entities is needed to ensure the persistence of the 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 proximus* (Aztec milkvetch) is the focus of an assessment because it has been designated a sensitive species in Region 2 (USDA Forest Service 2005). Within the USFS, 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 or significant current or predicted downward trends in habitat capability that would reduce its distribution (FSM 2670.5(19)). A sensitive species may require special management and, therefore, knowledge of its biology and ecology is critical. This assessment addresses the biology of *A. proximus* throughout its range in Region 2 and in areas of Region 3 immediately adjacent to Region 2. This introduction defines the goal of the assessment, outlines its scope, and describes the process used in its production.

Goal of Assessment

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

Scope of Assessment

This assessment examines the biology, ecology, and management of *Astragalus proximus* with specific reference to the geographic and ecological characteristics of the USFS Rocky Mountain Region. Although much of the literature on this species and its congeners is derived from field investigations outside the region, this document places that literature in the ecological context of the central and southern Rocky Mountains. Similarly, this assessment is concerned with reproductive behavior, population dynamics, and other characteristics of *A. proximus* 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, refereed literature, non-refereed publications, research reports, and data accumulated by resource management agencies were reviewed. While there are no refereed publications devoted entirely to *Astragalus proximus*, it is mentioned in a variety of sources. The refereed and non-refereed literature on the genus *Astragalus* and its included species is somewhat more extensive, and includes many endemic or rare species. Because basic research has not been conducted on many facets of the biology of *Astragalus proximus*, literature on its congeners was used to make inferences. For reference, Barneby's (1964) classification of each conspecific mentioned is given in **Table 1**. Not all publications that include information on *A. proximus* 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. proximus* without providing new information. The assessment emphasizes refereed literature because this is the accepted standard in science. Non-refereed publications or reports were used in the assessment, due to the lack of refereed material directly pertaining to *A. proximus*, but these were regarded with greater skepticism.

In this document, the term population or populations is used to refer to discrete groups of *Astragalus proximus* individuals that are separated from the next nearest known group of *A. proximus* individuals by at least 1 km (0.62 miles). Within a population, individual plants may be distributed in a more-or-less patchy fashion, but all are within the minimum separation distance. This usage is synonymous with "occurrence" as used by NatureServe and state Heritage Programs. In this usage, population/occurrence implies that members of such a group are much more likely to interbreed with one another than with members of another group. To lessen confusion, this assessment uses the term "location" or "station" to refer to such a discrete group. In this document, the term population is not used to refer to the entire complement of *A. proximus* individuals present in Region 2 or worldwide (the meta-population).

Table 1. Barneby's (1964) classification of Astragalus species mentioned in this document.

Astragalus species	"Phalanx"	"Series"	Section	Subsection
proximus	**B. Homaloboid**	***Genuine Homalobi**	**X. *Scytocarpi***	***Scytocarpi***
miser	B. Homaloboid	*Genuine Homalobi	XI. *Genistoidei*	—
lonchocarpus	B. Homaloboid	*Genuine Homalobi	XII. *Lonchocarpi*	*Lonchocarpi*
applegatei	B. Homaloboid	*Genuine Homalobi	XIV. *Solitarii*	—
kentrophyta	B. Homaloboid	*Genuine Homalobi	XX. *Ervoidei*	*Submonospermi*
montii (*limnocharis* var. *montii*)	B. Homaloboid	**Piptoloboid Homalobi	XXIII. *Jejuni*	—
linifolius	B. Homaloboid	***seleniferous Homalobi	XXIX. *Pectinati*	*Pectinati*
osterhoutii	B. Homaloboid	***seleniferous Homalobi	XXIX. *Pectinati*	*Osterhoutiani*
oocalycis	B. Homaloboid	***seleniferous Homalobi	XXVIII. *Oocalyces*	—
neglectus	B. Homaloboid	*****Arrect Homalobi	LII. *Neglecti*	—
scaphoides	B. Homaloboid	*****Arrect Homalobi	XLII. *Reventi-arrecti*	*Eremitichi*
bibullatus	E. Piptoloboid	*large-flowered Piptolobi	LXI. *Sarcocarpi*	*Sarcocarpi*
tennesseensis	E. Piptoloboid	*large-flowered Piptolobi	LXII. *Tennesseenses*	—
lentiginosus var. *salinas*	E. Piptoloboid	***Small-flowered Piptolobi	LXX. *Diphysi*	—
lentiginosus var. *wahweepensis*	E. Piptoloboid	***Small-flowered Piptolobi	LXX. *Diphysi*	—
amblytropis	E. Piptoloboid	***Small-flowered Piptolobi	LXXIV. *Platytropides*	—
cremnophylax var. *cremnophylax*	E. Piptoloboid	***Small-flowered Piptolobi	LXXVII. *Humillimi*	*Humillimi*

Outline designations (letters, asterisks, roman numerals) given as in the original source.

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. However, because our descriptions of the world are always incomplete and our observations are limited, science focuses on approaches for dealing with uncertainty. A commonly accepted approach to science is based on a progression of critical experiments to develop strong inference (Platt 1964). However, in the ecological sciences, it is difficult to conduct experiments that produce clean results. Often, observations, inference, critical thinking, and models must 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

Species assessments developed for the species Conservation Project have been peer reviewed prior to their release on the Web. This assessment was reviewed through a process administered by the Center for Plant Conservation, employing at least 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

Astragalus proximus has been designated a sensitive species in Region 2 of the USDA Forest

Service (USDA Forest Service 2005). Documented locations include five sites on the Pagosa and Columbine Ranger Districts of the San Juan National Forest in Region 2, and three on the Jicarilla Ranger District of the Carson National Forest in Region 3. The species is also known from lands managed by the Bureau of Land Management (BLM) and National Park Service (NPS), Southern Ute and Jicarilla Apache tribal lands, State of Colorado and State of New Mexico lands, and private property (**Figure 1**). Although at least one herbarium specimen is labeled as having been collected at Chaco Canyon (Chaco Culture National Historical Park), an unofficial database of species occurring on national parks does not show *A. proximus* at this site (Information Center for the Environment 2002). Only 15 percent of locations are on National Forest System (NFS) lands.

Astragalus proximus is not included on BLM Sensitive Species Lists for Colorado or New Mexico. While it is considered a USFS sensitive species in Region 2, the species is not included on the sensitive species list for Region 3 (USDA Forest Service 2000). Of the five locations on NFS lands in Region 2 and the three in Region 3, none are in designated wilderness areas. Two locations are within the boundaries of the Chimney Rock Archaeological Area on the Pagosa Ranger District of the San Juan National Forest in Region 2. This special management area is managed to emphasize wildlife protection, recreation, and archaeological research. Although none of these lands is specifically managed for the conservation of *A. proximus*, Forest Service Manual directions regarding sensitive species require that management actions be reviewed for potential effects on these species, and that impacts be minimized or avoided. Any impact allowed must not result in loss of species viability or create significant trends toward Federal listing. (USDA Forest Service Manual 2670.32).

The current global NatureServe rank for *Astragalus proximus* is G4 (NatureServe 2003a). The global (G) rank is based on the status of a taxon throughout its range. A G4 ranking is defined as "Apparently Secure - Uncommon but not rare (although it may be rare in parts of its range, particularly on the periphery), and usually widespread. Apparently not vulnerable in most of its range, but possibly cause for long-term concern. Typically more than 100 occurrences and more than 10,000 individuals" (NatureServe 2003a). State Natural Heritage Program rankings are S2 for Colorado and S3 for New Mexico. The state (S) rank is based on the status of a taxon in an individual state. In Colorado, this species is ranked S2, "imperiled in the state because of rarity (6 to 20 occurrences), or because of other factors demonstrably making it very vulnerable to extirpation from the state" (NatureServe 2003a). The S3 state ranking for New Mexico indicates that the species is considered very rare or local throughout its range or found locally in a restricted range (21 to 100 occurrences); however, the New Mexico Natural Heritage Program does not track this species. Although the species is described as common within its range (New Mexico Rare Plant Technical Council 1999), reported population sizes are small, and there are fewer than 100 documented occurrences. These factors, together with its restricted global distribution and higher state rankings, indicate that the global rank should probably be revised to G3: Vulnerable – "Vulnerable globally either because 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, typically 21 to 100 occurrences or between 3,000 and 10,000 individuals" (NatureServe 2003a).

Existing Regulatory Mechanisms, Management Plans, and Conservation Strategies

Astragalus proximus is not listed as threatened or endangered in accordance with the Endangered Species Act, and therefore there are no laws concerned specifically with its conservation. Because it is included on the Regional Forester's sensitive species list in Region 2, USFS personnel are required to "develop and implement management practices to ensure that species do not become threatened or endangered because of Forest service activities" (USDA Forest Service Manual, Region 2 supplement, 2670.22). As of this writing, a conservation strategy has not been written for this species at a national or regional level by the USFS or any other federal agency. Almost all occurrences of *A. proximus* on NFS lands and BLM managed lands in the San Juan Basin are on lands managed for multiple uses.

Adequacy of current laws and regulations

Although USFS policy requires the maintenance of viable populations within the planning area, data that would allow an evaluation of the conservation status of *Astragalus proximus* are generally not available. In the absence of population and habitat monitoring regulations, assessing the adequacy of current management practices is difficult due to the lack of quantitative information on population trends for *A.*

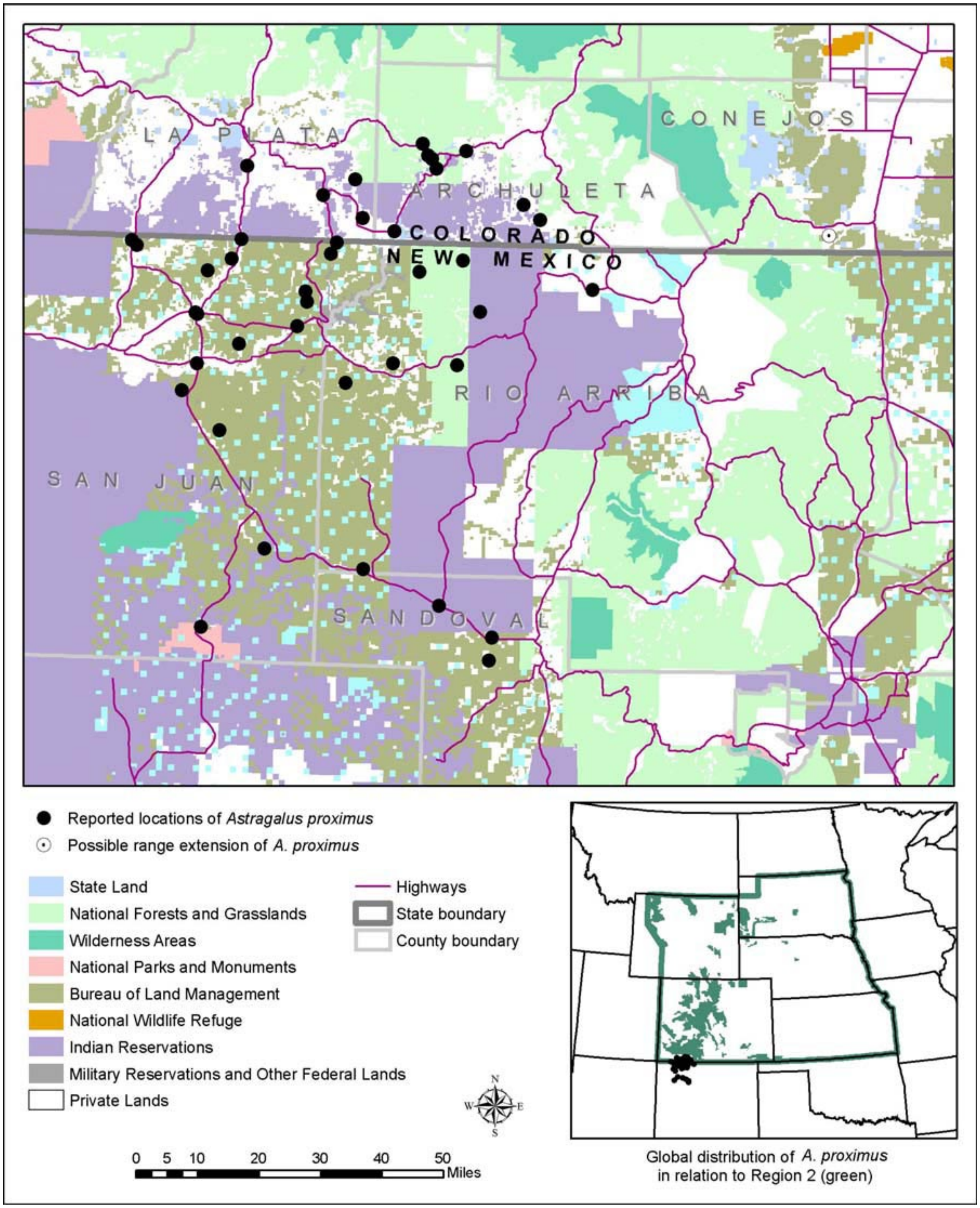


Figure 1. Land ownership in the distribution of *Astragalus proximus*. Land ownership data: USDI Bureau of Land Management 1993, 2003b.

proximus. There is no way to know whether current management practices on lands supporting *A. proximus* populations are effective in protecting the species in the long term. The plants at Chimney Rock Archaeological Area are likely to be somewhat better protected than those on lands where more use is permitted. It is unlikely that the species could be suddenly decimated by anthropogenic activities, but without range-wide monitoring, individual populations could decline and disappear without much notice.

Adequacy of current enforcement of laws and regulations

There are no documented instances in which populations of *Astragalus proximus* have been extirpated by human activities although it is probable that a few such occurrences have gone unrecorded. Some individuals in the populations at Chimney Rock Archaeological Area have probably been destroyed or damaged by road maintenance activities, despite special efforts by USFS personnel to direct such work away from extant plants (Brinton personal communication 2004). It is likely that populations have been affected by construction associated with oil and gas development, and some populations may have been extirpated or reduced by the filling of Navajo Lake beginning in 1962. These isolated incidents do not appear to have affected the persistence of the species. However, a steady but gradual loss of individual populations over time through a variety of causes could go largely unnoticed for many years.

Biology and Ecology

Classification and description

Astragalus proximus 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 (including the subfamilies Caesalpinaceae and Mimosaceae) is among the largest of the plant families, containing something on the order of 600 to 700 genera and 13,000 to 18,000 species (Smith 1977, Heywood 1993, Zomlefer 1994). Within this large family, the genus *Astragalus* falls under the subfamily Papilionoideae (also known as Lotoideae or Faboideae). The Papilionoideae are characterized by having papilionaceous or butterfly-like flowers. More than two thirds of the Fabaceae are in this group, including most of the commonest species (Zomlefer 1994).

Within the subfamily Papilionoideae, Heywood (1993) recognizes 10 or 11 tribes. The genus *Astragalus* is part of the tribe Galegeae (characterized by pinnate leaves, with five or more leaflets), of which it is the largest member, comprising some 1,600 to 2,000 species worldwide (Smith 1977, Zomlefer 1994). The worldwide distribution of *Astragalus* is cosmopolitan outside the tropics and Australia (Allen and Allen 1981) and the greatest concentration of *Astragalus* species is in southwestern Asia (Isely 1983). Species commonly occur in prairies, steppes, and semi-desert areas (Allen and Allen 1981). Western North America is a center of *Astragalus* diversity for the western hemisphere, and many of our species are broadly to narrowly endemic (Barneby 1964).

Beginning with Torrey and Gray's (1838) Flora of North America, North American *Astragalus* have largely been considered separately from the Old World species. North American treatments have tended to focus on characters of the fruit while European and Asian species have historically been differentiated by characters involving the stipules, leaves, vesture, calyx, and petals (Barneby 1964). Barneby (1964) notes that "Perhaps the most remarkable single characteristic of the genus *Astragalus* as a whole, and it is especially marked in North America, is that there are hardly two species, even very closely related, which do not differ one from another in form or structure of the fruit". This characteristic allows for easy description of individual species, but is at the same time consequently less valuable as an indicator of phylogeny (Barneby 1964).

During the century between Torrey and Gray (1838) and Barneby (1964), the two most important and disputatious monographers 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. His self-published revision of the genus (Jones 1923), drawing on materials from his own work as well as from the California Academy of Sciences, Brandegee collections and others, presents 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 for North American Flora (Rydberg 1929). Rydberg breaks *Astragalus* into 28 genera and 564 species. Rydberg had a perhaps unreasonable aversion to the use of variety and subspecies, always "preferring a binomial name to a trinomial for the sake of convenience" (Rydberg 1923), and later critics (Barneby 1964) have 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. Barneby's treatment is still widely accepted and used, due to its broad scope, thorough assessment of variation, and attention to detail. Isely's (1983, 1984, 1985, 1986) treatments 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.

History of knowledge

Astragalus proximus was first described by Rydberg (1905) under the name *Homalobus proximus*, from a specimen collected at Arboles, Colorado by Charles Fuller Baker (collection 421) in June of 1899. Rydberg (1929) later revised this species to *Pisophaca proxima* in his treatment of Leguminoseae for the North American Flora, but this revision was never widely adopted. Wooton and Standley (1915) rejected the segregation of *Astragalus* into several genera and recombined the name to *A. proximus*, where it has since remained without controversy. Jones (1923) treated *A. proximus* as a synonym of *A. wingatensis* var. *dodgeanus* but gave a range for this species that is clearly not the same as that of *A. proximus* as currently understood (Jones' misspelling of "*wingatanus*" was later corrected).

The holotype of this species is housed at the New York Botanical Garden (NY) as NY specimen 11993. Duplicates of this collection (isotypes) are housed at Conservatoire et Jardin Botaniques de la Ville de Genève (G), Harvard University Gray Herbarium (GH), Royal Botanic Gardens, Kew (K), Missouri Botanical Garden (MO), Pomona College, now merged with Rancho Santa Ana (RSA-POM), and the Smithsonian Institution (US). In addition to the type specimens listed above, specimens are also housed at the University of Colorado (COLO), Colorado State University (CS), Rocky Mountain Herbarium (RM), Fort Lewis College (FLD), Denver Botanic Gardens (KHD), San Juan College (SJNM), University of New Mexico (UNM), New Mexico State University (NMC), and other locations.

Barneby (1964) places *Astragalus proximus* in the Homaloboid Phalanx, genuine Homalobi, under section Scytocarpi (a large and taxonomically rather difficult group of species), subsection Scytocarpi, together with *A. flexuosus*, *A. pictiformis*, *A. fucatus*, and *A. subcinereus*. *Astragalus proximus* is sympatric with and closely related to *A. flexuosus*, described by Barneby (1964) as a polymorphic aggregate of many small races whose characteristics are fully intergradient and not definable in mutually exclusive terms. Physical descriptions of *A. proximus* in Barneby (1964) and Isely (1986, 1998) also intergrade slightly with *A. flexuosus* for key distinguishing characters. Although the validity of *A. proximus* as a species has not been questioned, neither has it been examined in the light of modern systematic techniques.

Recent knowledge of *Astragalus proximus* has been augmented by informal monitoring of Colorado populations, and by occasional collections in New Mexico by Bob Sivinski (Rare and Endangered Plants Specialist, State of New Mexico), Ken Heil (San Juan College Herbarium), Richard Spellenberg (New Mexico State University), and others. Site visits to several Colorado populations have been carried out by a number of people, including the late Mary Edwards (Colorado Native Plant Society), Peggy Lyon (Colorado Natural Heritage Program), and Sara Brinton (Pagosa Springs Ranger District, San Juan National Forest).

Description

As described by Barneby (1964) and Isely (1986, 1998), *Astragalus proximus* is a perennial with clustered stems arising from a subterranean caudex (stem base). The slender stems are erect or ascending, sparsely leafy, up to 15 to 50 cm (6 to 20 inches) long, and often branched at the first few nodes. The plant appears pale gray-green, due to the sparse presence of minute straight, appressed hairs. Stipules (scale-like appendages) are present at the base of the leaf stalk, and on the lower nodes often form a papery-membranous sheath around the leaf stalk. The pinnately compound leaves are 2 to 8 cm (0.75 to 3.1 inches) in length and possess 7 to 11 narrow linear-oblanceolate leaflets. *Astragalus proximus* flowers from late April to July. The sparsely flowered racemes typically hold 12 to 40 flowers with white or lavender-tinged petals. Flower corollas are 6 to 7.5 mm (0.24 to 0.30 inches) long, and the calyx tube at the base of the flower has black or mixed white and black hairs. Flowers are initially ascending, but become less so with age. The legumes (pods) are pendulous, with short (1 to 2 mm [0.04 to 0.08 inches]) stipes or stalks, are unilocular (one chambered), and remain on the plant after seeds have dispersed. The pods are oblong-ellipsoid in shape, 1 to 1.5 cm (0.4 to 0.6 inches) long and 2.3 to 3.2 mm (0.09 to 0.13 inches) in diameter, thin-walled, green and without hairs (glabrous). Pods contain 6 to 10 ovules, and seeds are small (about 2 mm [0.078 inches]) long.

Astragalus proximus can easily be confused with the closely related *A. flexuosus*. In overall appearance, *A. proximus* may be described as a smaller, more delicate version of *A. flexuosus*. The uniformly small flowers widely separated along the raceme, and the stipitate cylindrical pods distinguish *A. proximus* from other members of the Sytocarpi (Welsh personal communication 2004). Distinguishing features between *A. proximus* and *A. flexuosus* are the number of leaflets (7 to 11 for *A. proximus*, 11 to 25 for *A. flexuosus*) and the pods, which are glabrous in *A. proximus* and almost always pubescent in *A. flexuosus*. Although *A. flexuosus* only rarely has glabrous pods, there is some potential for confusion between specimens of the two species if collected material is not adequate for positive identification.

Published descriptions and other sources

Complete technical descriptions are available in Rydberg (1929), Barneby (1964), and Isely (1986, 1998). Of these, Barneby is the most complete, and his Atlas is available in most herbaria and university libraries. Isely's (1998) description, although more recent, is much abridged, and his longer version published in the Iowa State Journal of Research (of which the 1986 issue, containing *Astragalus proximus*, is a portion) is not widely available. Brief descriptions are found in Harrington (1954), Martin and Hutchins (1980), and Weber and Wittmann (2001).

A drawing (**Figure 2**) and photograph of the plant and its habitat are readily available in the *Colorado Rare Plant Field Guide*, in both online and print versions (Spackman et al. 1997). Photographs of the plant in flower and in fruit are shown in **Figure 3**. An image of the holotype specimen as *Homalobus proximus* is available on the website of the New York Botanic Garden (http://www.nybg.org/bsci/hcol/vasc/Fabaceae.html).

Distribution and abundance

Documented locations of *Astragalus proximus* are shown in **Figure 1** and listed in detail in **Table 2**. Much of this information was compiled from herbarium

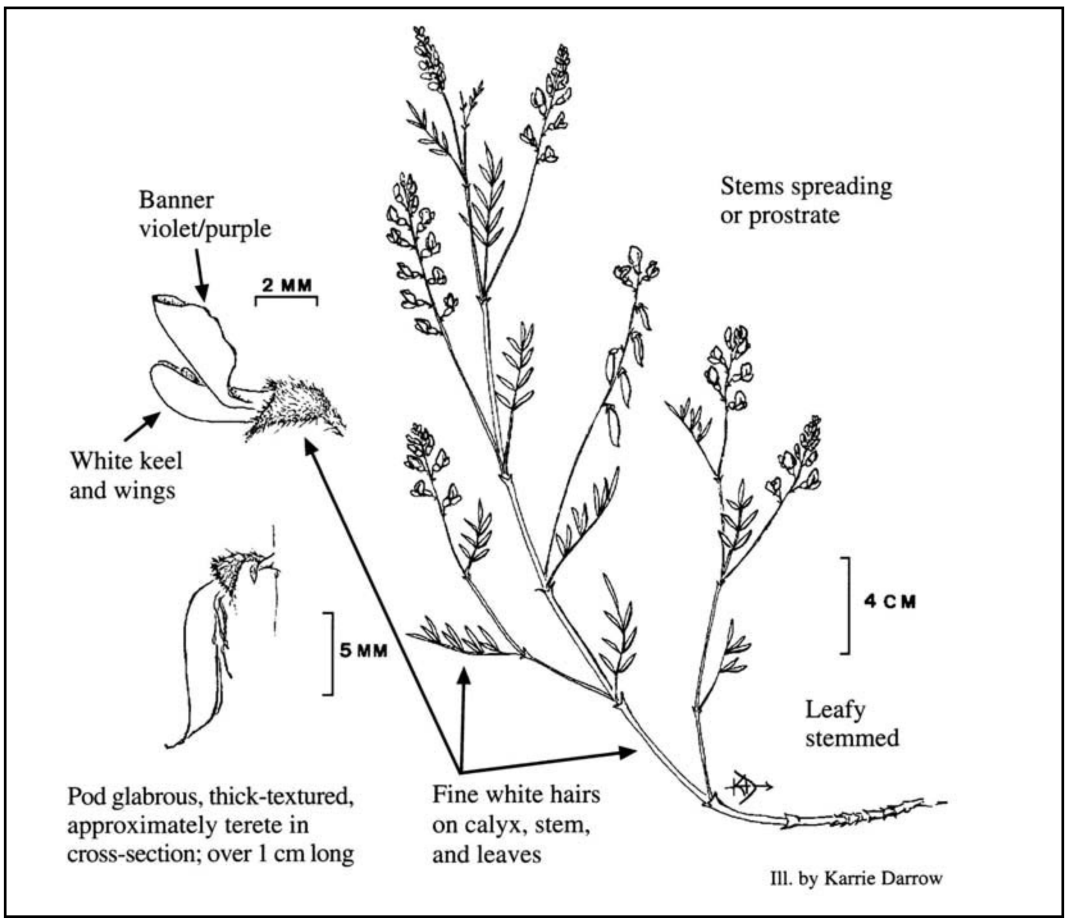


Figure 2. Drawing of *Astragalus proximus* from Spackman et al. 1997. Illustration by K. Darrow, used with permission.

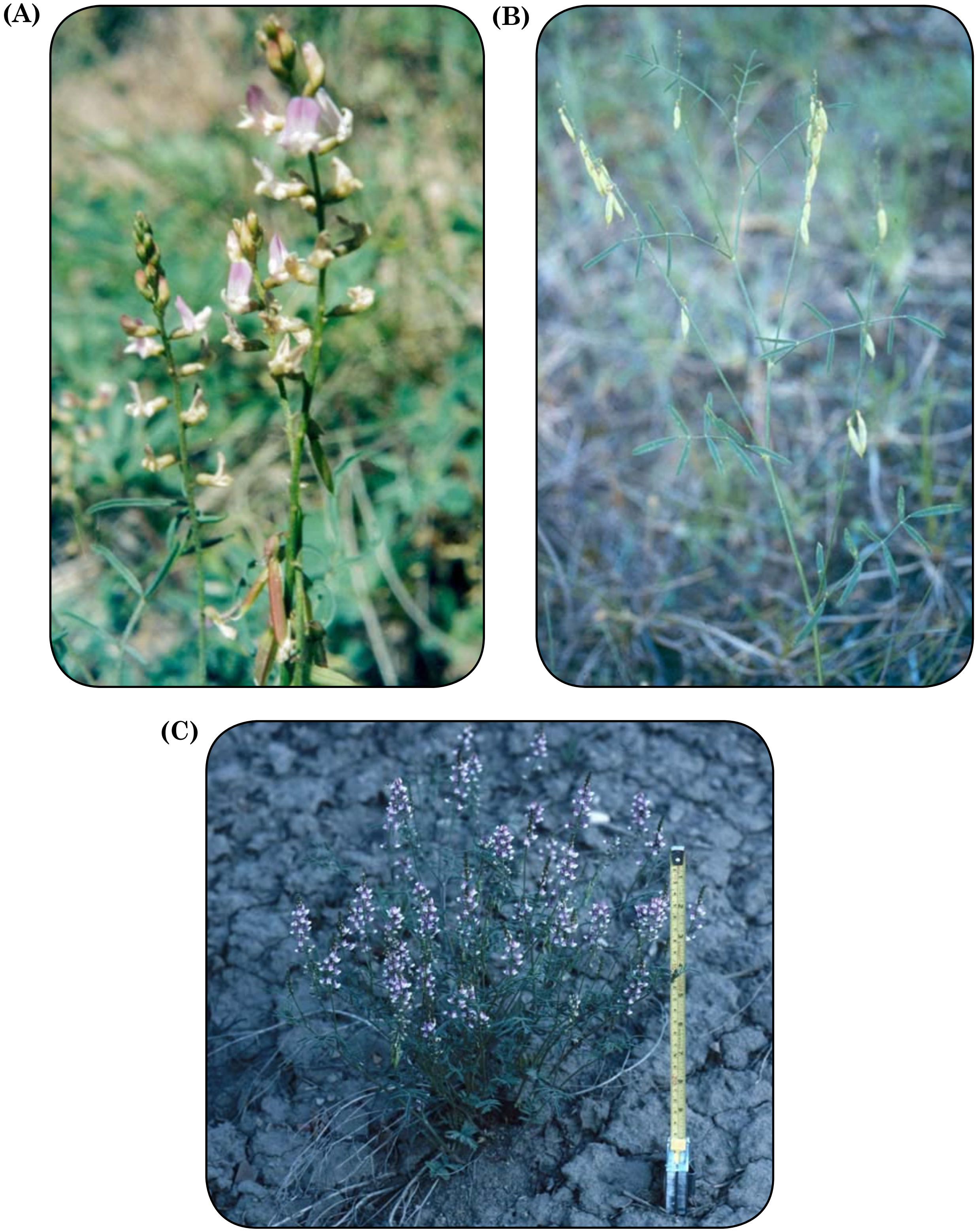


Figure 3. Photographs of *Astragalus proximus* in flower and fruit. (A) and (B) photographs by Bob Clearwater, used with permission and (C) photograph by William Jennings, from Spackman et al. 1997, used with permission.

Table 2. Documented occurrences of *Astragalus proximus*. Occurrences are arranged by location (state and county) and arbitrarily numbered. Questionable occurrences are shown with shading. Sources include Colorado Natural Heritage Program (CNHP) data and herbarium labels. ID information is from the source. CNHP ID's are Element Occurrence Records (of the format EO-00). Herbarium label ID's are collector name and collection number. Ownership/Management: BLM = Bureau of Land Management, NPS = National Park Service, NF = National Forest. Habitat type names are given as in the original source, using either scientific or common names. Population sizes are numbers of individual plants.

	County	Ownership/ Management	Date of Last Observation	Location	Elevation (ft.)	Habitat	Population Size	Source Identification
	COLORADO							
1	Archuleta	unknown	Jun-1899	Arboles	6,300	—	—	CNHP EO-09 (C.F. Baker 421)
2	Archuleta	USFS San Juan NF	1-Jul-1924	Chimney Rock Mesa W	6,800	Ponderosa pine / Gambel oak community. Dry soil	—	CNHP EO-04
3	Archuleta	unknown	11-Jun-1948	West of Pagosa Springs	6,800	Clay soil	—	CNHP EO-10
4	Archuleta	unknown	17-Jun-1951	Yellowjacket Pass	7,840	Oakbrush hillside	—	CNHP EO-11
5	Archuleta	Private	11-Jun-1990	Trujillo	7,180	Aspect variable. Slope 10-35%. Soil: brown, sandy, interbedded with dark gray shale and buff sandstone. Geology: Mancos or Lewis shale	300+	CNHP EO-05
6	Archuleta	USFS San Juan NF	7-Jul-1997	Montezuma Creek	7,350	Piñon pine/juniper community. Aspect: southeast to southwest. Slope: 8-15 degrees. Soil: Light brown sandy clay and shale, with rock fragments. Geology: Mancos shale, Lewis shale	182	CNHP EO-02
7	Archuleta	USFS San Juan NF	10-Jun-2001	Lower Piedra Campground Road	6,650	Ponderosa pine/Gambel oak community	100	CNHP EO-15
8	Archuleta	Southern Ute	18-Jun-2001	Highway 160	6,476	Barren clay soils of road cut, weedy	25	CNHP EO-14
9	Archuleta	USFS San Juan NF	18-Jun-2001	Chimney Rock Archeological Area	6,800	Ponderosa pine-Juniper/Gambel oak community. Aspect: variable. Slope: 0-10 degrees. Soil: dry, light brown clay light brown, sandy, with loose shale covering surface. Geology: Upper Cretaceous, Lewis or Mancos shale	350	CNHP EO-03
10	Conejos	unknown	21-Jun-1987	Canon	8,700	Ponderosa pine community. Aspect north-northwest. Soil: moist loam	—	CNHP EO-08
11	La Plata	unknown	09-Jun-1939	South of Durango	6,600	—	—	CNHP EO-12
12	La Plata	unknown	20-May-1943	South of Ignacio	—	In sagebrush	—	Ripley & Barneby 5337
13	La Plata	USFS San Juan NF	01-Jun-1994	Spring Creek at Ignacio	6,800	Piñon pine-Juniper/Sagebrush community. Aspect: northeast to southwest. Slope: 15+ degrees. Soil: grayish sandy clay. Geology: Upper cretaceous Animas Fm	150	CNHP EO-07
14	La Plata	Private	15-Jun-1995	NW of Allison	6,200	Sagebrush and transition to piñon-juniper	—	Komarek 474

Table 2 (cont.).

	County	Ownership/ Management	Date of Last Observation	Location	Elevation (ft.)	Habitat	Population Size	Source Identification
	NEW MEXICO							
15	Rio Arriba	unknown	28-May-1947	SW of Haynes	7,300	Benches among juniper in alkaline soil	—	Ripley & Barneby 8367
16	Rio Arriba	USFS Carson NF	27-May-1987	Carson National Forest, in middle Turkey Creek	—	On sandy soil in pinyon-juniper woodland	—	P.J. Knight 3534
17	Rio Arriba	USFS Carson NF	28-May-1987	Mouth of Cottonwood Canyon, Lower Bancos Canyon	6,400	On clay to sandy soil among *Juniperus osteosperma* and *Pinus edulis*	—	D. Wilken, E. Painter 14751
18	Rio Arriba	USFS Carson NF	28-May-1987	Two miles S of Hwy 64 in La Jara Creek	6,600	Sagebrush flat along north side of creek	—	R. Spellenberg and D. Jewell 9122
19	Rio Arriba	Jicarilla Apache	19-Jun-1992	N. of US 64 and W of Bancos Lake. Along fence line. Montane community. T39N, R3W	7,500	Montane community	—	Ken Heil 7168
20	Rio Arriba	BLM Farmington Field Office	18-May-1993	Near Gobernador, along gas line north of El Cedro Compression Station (Williams Field Service). Northwest of Gobernador Camp About 1 mile	—	—	—	K.D. Heil and B. Melton 7487
21	Rio Arriba	unknown	16-Jun-1994	About 10 miles northwest of Cuba on Highway 44	7,220	Common on sandy, seleniferous shale in pinyon-juniper woodland	—	R.C. Sivinski 2743
22	Rio Arriba	unknown	23-May-1995	Delgadito Canyon	6,197	Pinyon-Juniper community	—	Holmes 267
23	San Juan	unknown	May-1899	Aztec	5,500	—	—	Baker 427
24	San Juan	unknown	19-May-1943	Mesa north of Cedar Hill	6,100	Clay soil among juniper	—	Ripley & Barneby 5319
25	San Juan	unknown	28-May-1947	S of Bloomfield, along San Juan River	5,400	Gullied white clay and cobblestone bluffs along San Juan River	—	Ripley & Barneby 8384
26	San Juan	unknown	01-Jun-1952	East of Aztec	—	Sandy slopes	—	O.M. Clark 16251
27	San Juan	unknown	09-Jun-1953	North of Cedar Hill on state line, on Route 550, north of Aztec	—	Sandy arroyo bed	—	E.F. Castetter 10157
28	San Juan	NPS Chaco Canyon	17-Sep-1977	Chaco Canyon National Monument. Cly's Canyon, east side	6,240	Rocky slope of side rincon. Northeast exposure	—	A.C. Cully 171
29	San Juan	unknown	19-May-1981	Along Los Pinos River, 2 miles south of the New Mexico-Colorado border	—	Pinyon-juniper woodland	—	P.J. Knight 1427
30	San Juan	BLM Farmington Field Office	04-Jun-1982	Proposed La Plata coal mine site	—	Gully with sagebrush and greasewood, in otherwise pinyon-juniper woodland	—	R. Spellenberg, R. Soreng, L. Collyer 6559

Table 2 (concluded).

	County	Ownership/ Management	Date of Last Observation	Location	Elevation (ft.)	Habitat	Population Size	Source Identification
31	San Juan	BLM Farmington Field Office	05-Jun-1984	Proposed La Plata coal mine site	—	Chained area with juniper, pinyon	—	R. Spellenberg, W. Ruzzo 7794
32	San Juan	unknown	24-Apr-1985	5 miles south of Navajo Lake Dam, along the San Juan River	—	On sandy soil in pinyon-juniper woodland	—	P.J. Knight 3332
33	San Juan	unknown	03-Jun-1985	About 4 miles NE of La Plata on the La Plata Mine	6,600	Open disturbed soil among pinyon and juniper	—	Spellenberg and Corral 8215
34	San Juan	unknown	11-May-1992	BLM; along the Williams Field Service Pipeline northeast of Bloomfield; T29N R10W S3, SE/4	5,650	Desert Scrub Community	—	Heil & Hyder 87080
35	San Juan	BLM Farmington Field Office	14-May-1992	BLM; about 5 miles S of Bloomfield; T28N R11W S29 NW/4	5,773	Desert Scrub Community	—	Fleming 1169
36	San Juan	unknown	02-Jun-1992	6 miles north of Aztec in Kiffen Canyon	—	On silty sand in Pinyon-Juniper woodland	—	R.C. Sivinski and K. Lightfoot 1875
37	San Juan	unknown	17-May-1993	About 1 mile south of La Boca, CO and 1/4 mile South of NM/CO border	—	On seleniferous shale in pinyon-juniper woodland. Locally abundant	—	R.C. Sivinski 2143
38	San Juan	unknown	08-May-1995	1.5 to 2 miles west of Nageezi Trading Post	6,900	Sandy soils over minor sandstone outcrop; Pinyon-Juniper, Antelope bitterbrush, Western serviceberry, Indian ricegrass plant community	—	A. Clifford 95-141
39	San Juan	unknown	09-Jun-1998	Angel Peak Badlands, about 3 miles southwest of Angel Peak	7,050	Sodic sansdstone of the Nacimiento Formation	—	R.C. Sivinski 4458
40	San Juan	unknown	19-May-1999	Questa Pipeline	—	Base of slope in Juniper woodland. Cracked grey clay soil	—	T.K. Lowrey 1839
41	San Juan	BLM Farmington Field Office	16-May-2000	BLM Land, Pump Mesa. Gas well Phillips #240. T31N, R8W	—	Piñon-juniper woodland	—	Tim Reeves, 10085
42	Sandoval	unknown	21-May-1947	9 miles W of Cuba	7,300	Stiff sandy soil among juniper	—	Ripley & Barneby 8354
43	Sandoval	Jicarilla Apache	09-Jun-1953	20 miles northwest of Cuba, on Route 44	—	Roadside	—	E.F. Castetter 5966
44	Sandoval	unknown	11-Jun-1998	About 1.5 miles east of Monero	7,545	Seleniferous shale of valley bottom	—	R.C. Sivinski 4467

labels of unverified specimens; therefore, it is possible that some locations are not good records of *A. proximus*. There are probably additional specimens of *A. proximus* not obtained for this document that could add to the list of known locations for New Mexico. Due to the patchwork nature of land ownership in the San Juan Basin, and the lack of precise location information on many herbarium specimens, land ownership/management could not be determined for many locations. Within the boundaries of Region 2, the species is known from just twelve locations. Although ownership for most locations is unknown, five of the Colorado locations are on NFS lands of the San Juan National Forest within Region 2, and three of the New Mexico locations are on NFS lands of the Carson National Forest within Region 2. Other landowners and managers in the area are the Bureau of Land Management, the Bureau of Reclamation (Navajo Reservoir), the National Park Service, the Southern Ute and Jicarilla Apache tribes, the states of Colorado and New Mexico, and private owners. Tribal and BLM lands together account for over two thirds of the area within the range of *A. proximus*, with over 1 million acres (>404,000 ha) each. National Forest System lands make up about 7 percent, or some 230,000 acres (93,000 ha). Slightly over one quarter of this acreage is within Region 2. Private owners control about half a million acres (202,000 ha) in the area, and the remainder is split between other federal and state agencies.

The global distribution of *Astragalus proximus* is shown in the inset of **Figure 1** and lies in the upper basin of the San Juan River, west of the continental divide as it meanders through the San Juan Mountains of Colorado and New Mexico. As far as is known, this also represents the historical distribution of the species. One specimen from a collection made at Yellowjacket Pass (*Weber and Livingston 1951* at COLO) was later annotated as *A. flexuosus* (Lederer personal communication 2003). At least two other specimens from this collection are still listed as *A. proximus*, but a survey of the site in 2001 did not relocate the population, so this is a likely misidentification and is not shown on the maps. Another specimen at Colorado State University (*Douglas 1574,* 1987, shown as a black-centered white dot in **Figure 1**) is currently identified as *A. proximus*, but was collected in Conejos County, nearly 50 air miles (80.5 km) beyond the previously known range, and at a significantly higher elevation on the other side of the continental divide. Although the specimen superficially appears to have the identifying characters for *A. proximus* (glabrous pods, fewer leaflets), the extreme variability of *A. flexuosus*, which is previously known from this area, raises the possibility that this specimen is not *A. proximus*.

Within Region 2, *Astragalus proximus* is restricted to the extreme southern portion of Colorado, in La Plata and Archuleta counties. It is also found within Region 3, where it occurs only in northwestern New Mexico, in Rio Arriba, San Juan, and Sandoval counties. The greater part of the species' range lies in New Mexico, where it is reported to be much more common than in Colorado. Botanists familiar with the plant report that it occurs sporadically throughout its range in New Mexico, and is usually present in scattered patches on seleniferous shaley soils (Heil personal communication 2004, Sivinski personal communication 2004).

The species is usually regarded as a local endemic. In the schema of rarity outlined by Rabinowitz (1981), *Astragalus proximus* appears to fit the category of narrow geographic range/various habitats/small populations. *Astragalus proximus* does not appear to have highly specific edaphic restrictions like the sympatric *A. oocalycis*, but detailed habitat information is not currently available.

Population trend

Population trends for *Astragalus proximus* are largely un-quantified. Population sizes reported from Colorado range from 25 to 350 individuals, and occurrences on the San Juan NF range from 100 to 350 individuals (**Table 2**). In New Mexico, populations appear to be similarly sized, normally consisting of a dozen to several hundred individuals (Sivinski personal communication 2004); however, most records do not include population counts. There has been no rigorous multi-year population census effort that would allow more detailed description of population trends. For three Colorado (Region 2) occurrences with multi-year observations, population numbers are essentially stable across periods of several years although numbers fluctuate somewhat between observations (**Table 3**). However, anecdotal evidence suggests that populations can be extremely changeable, appearing and disappearing from year to year (Colorado Natural Heritage Program 2004). A few observers have postulated that abundance of *A. proximus* in a particular year may be due to precipitation patterns, with wet winters followed by dry springs favoring higher population numbers (Edwards 1994, Lyon personal communication 2004). Because most documented occurrences are not accompanied by population counts, information is insufficient to allow an assessment of current range-wide population trends.

Table 3. Population sizes of *Astragalus proximus* for three locations with repeat observations.

Source	Year / Count		
EO-02 (NFS)	**1990**	**1991**	**1997**
	200	200-	182
EO-03 (NFS)	**1994**	**1997**	**2001**
	300	243	350
EO-05	**1989**	**1990**	
	300+	300+	

Habitat

The global range of *Astragalus proximus* is perhaps best described as lying in the northeast quadrant of the geological structure known as the San Juan Basin (**Figure 4**). The basin is roughly circular, covering an area of approximately 16,000 square miles 41,500 km^2) in northwestern New Mexico into southwestern Colorado. Within this area, the known range of *A. proximus* encompasses about 5,000 square miles (13,000 km^2). The San Juan Basin is bordered on the west by the Defiance Uplift and the Chuska Mountains, and on the north by the San Juan Dome. The Zuni and Nacimiento uplifts form the southern and eastern edges of the basin. Surficial geology in the San Juan Basin consists primarily of Quaternary to Cretaceous-aged alluvium (unconsolidated silts, sands, clays, and gravels), sandstones, siltstones, shales, limestones, conglomerates, and coal (USDI Bureau of Land Management 2003a). All of the shales of Cretaceous age consist at least in part of gray arid black shale and are potential sources of selenium and other trace elements. *Astragalus proximus* appears to favor substrates of late Cretaceous to early Tertiary origin, and it is primarily found on sites underlain by the San Jose Formation, Nacimiento Formation, Pictured Cliffs Sandstone-Lewis Shale, and Animas Formation (**Figure 5**).

Elevations of reported stations range from 5,400 to 7,500 ft. (1,645 to 2,285 m; **Figure 6**), not including the two questionable specimens at 7,840 ft. (2,390 m) and 8,700 ft. (2,650 m). Annual precipitation within the distribution of *Astragalus proximus* ranges from about 7 to 19 inches (18 to 48 cm). Precipitation is greatest in the northeastern part of the range in Region 2 where *A. proximus* stations are at higher elevations on the southern slopes of the San Juan Mountains of Colorado. Precipitation amounts are fairly evenly distributed throughout the seasons, with somewhat more moisture being received during the late summer (Western Regional Climate Center 2004).

The climate of the San Juan Basin is characterized by cool, dry winters and warm, dry summers. Winter storms originating in the Pacific tend to lose most of their moisture before reaching the basin. Peak precipitation is associated with moisture moving into the region from the Gulf of Mexico during the late summer and early fall. The continental climate produces abundant sunshine and large diurnal variations in temperature. Prevailing winds in the area are generally from the southwest and west for much of the year. However, the east-west trending San Juan River Valley also tends to produce frequent easterly and westerly winds as daytime heating drives air up the valley, and night time cooling reverses the flow as cool air drains down the valley (Western Regional Climate Center 2004).

The range of *Astragalus proximus* overlaps the boundary between two ecoregions, as defined by The Nature Conservancy (2001). The San Juan Basin belongs primarily to the Colorado Plateau ecoregion while the southern flanks of the San Juan Mountains fall into the Southern Rocky Mountains ecoregion. Region 2 includes populations in both ecoregions, with locations on NFS lands within Region 2 all within the Southern Rocky Mountain ecoregion or on the boundary. Within its range, including locations on NFS lands within Region 2, *A. proximus* is broadly associated with the Rocky Mountain Ponderosa Pine Woodland, Colorado Plateau Pinyon-juniper Woodland, Intermountain-basins Semi-desert Shrub-steppe, and Rocky Mountain Gambel Oak-Mixed Montane Shrubland ecological system types (Rondeau 2001, NatureServe 2003b). The first two ecological systems are described as "matrix forming" communities, which may cover extensive areas of hundreds to millions of acres in their various successional stages. Matrix communities occur across a fairly broad range of environmental conditions in an area, and are shaped by regional-scale processes (Anderson et al. 1999). The other two systems are defined as "large patch" communities, which may form extensive cover over some areas, but are usually influenced primarily by local processes (Anderson et al. 1999). Characteristics of these ecological systems are summarized in **Table 4**, and more details are presented in **Appendix A**.

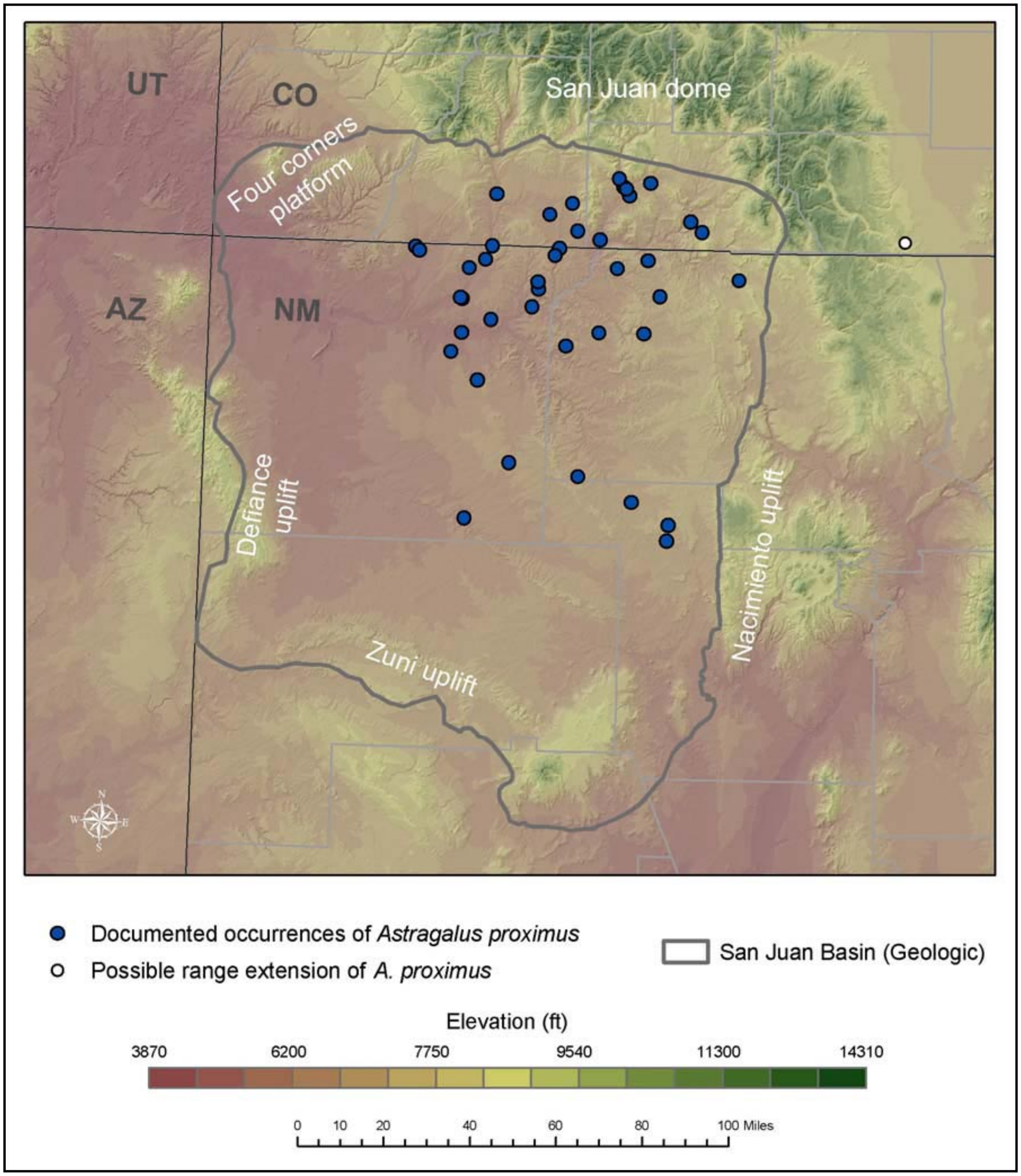


Figure 4. Range of *Astragalus proximus* in the San Juan Basin. Digital elevation model: USDI United States Geological Survey 2002. Basin boundary: USDI United States Geological Survey 2003.

Astragalus proximus is associated with a variety of vegetation associations that are characteristic of southwestern Colorado and northwestern New Mexico (see **Appendix A**). Occurrences of lower elevations in New Mexico are most often found in Great Basin grassland or pinyon-juniper communities. Occurrences in Colorado (within Region 2) are found in pinyon-juniper (with or without sagebrush) and ponderosa pine/Gambel oak communities. Occurrences have also been described from sagebrush, desert scrub, and open ground. Data from specimen labels and element occurrence records show *A. proximus* occurring with the associated species shown in **Table 5**.

Little information is available with which to characterize microhabitat preferences of *Astragalus proximus*. Soils, as reported from herbarium labels, are most often sandy, sandy clay, or clay with rock or shale fragments, or seleniferous shale. *Astragalus proximus* does not appear to be an extreme habitat specialist, but

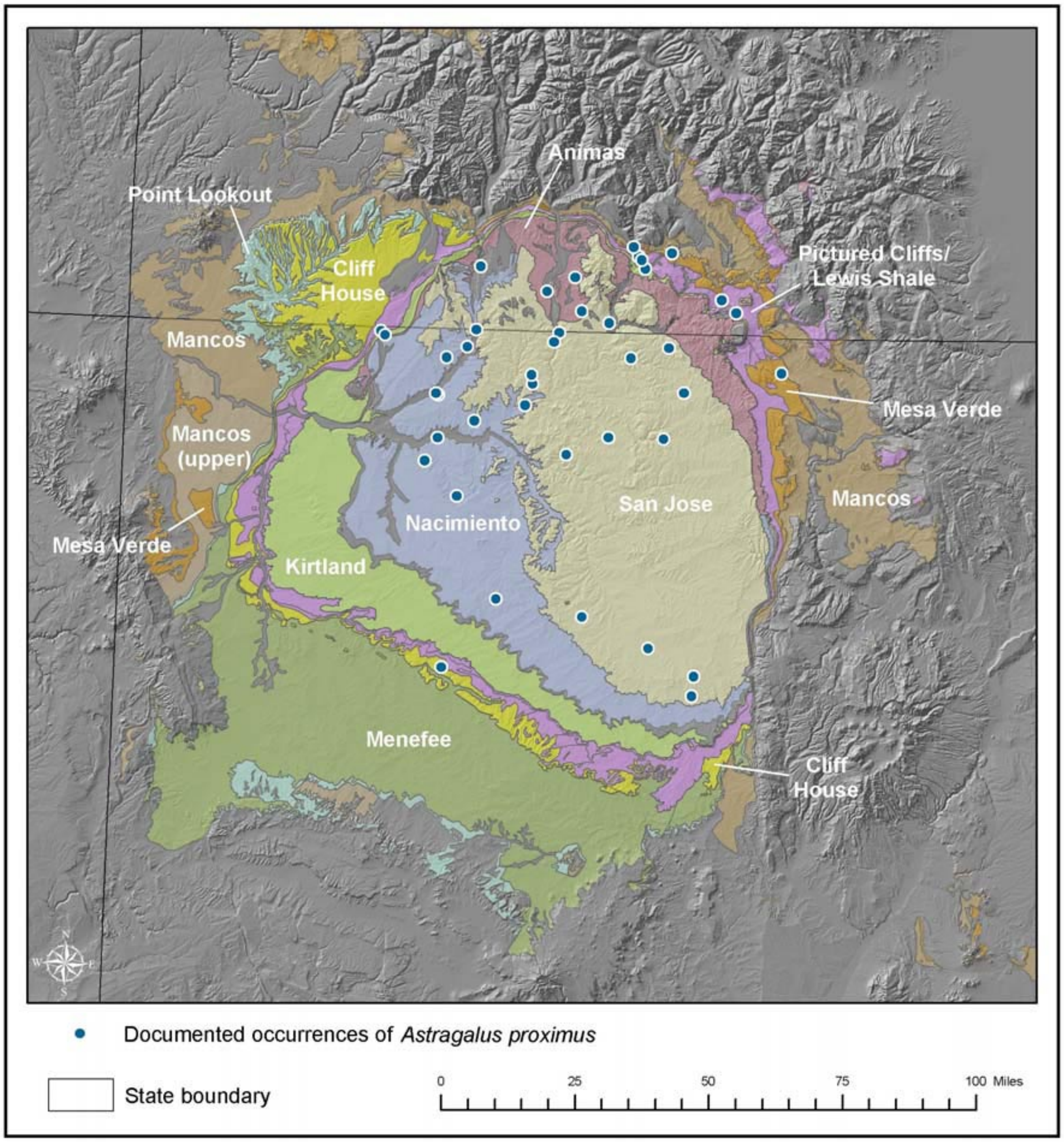


Figure 5. Surface geology of the San Juan Basin. Data from Colorado State Geologic Survey 1995, Green and Jones 1997.

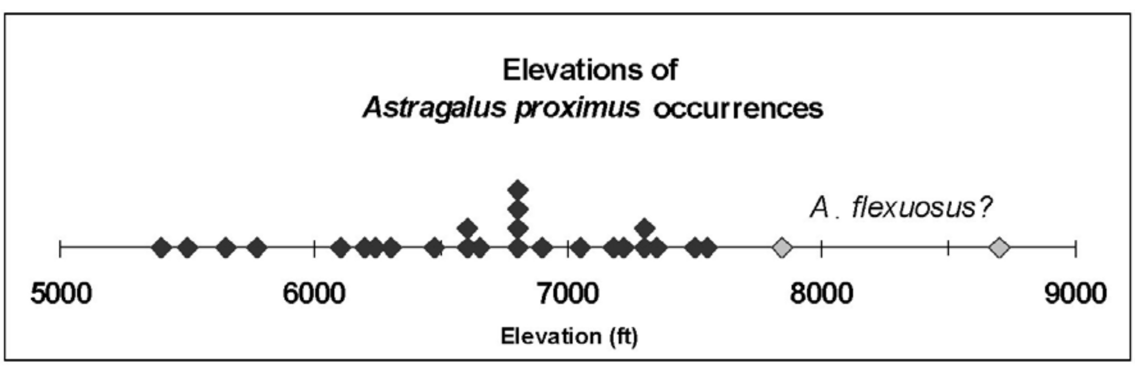


Figure 6. Elevation distribution of *Astragalus proximus*. Data from herbarium labels and Colorado Natural Heritage Program (2004).

Table 4. Ecological systems associated with *Astragalus proximus*.

Ecological System	Characteristics
Rocky Mountain Ponderosa Pine Woodland	Found at the lower treeline/ecotone between grassland or shrubland and more mesic coniferous forests typically in warm, dry, exposed sites. The communities are dominated by *Pinus ponderosa*, and normally have a shrubby understory. Occurrences are found on all slopes and aspects; however, moderately steep to very steep slopes or ridgetops are most common.
Rocky Mountain Gambel Oak-Mixed Montane Shrubland	Most commonly found along dry foothills and lower mountain slopes, and often situated above pinyon-juniper woodlands. In many occurrences, the canopy is dominated by *Quercus gambelii* although *Amelanchier* spp., *Cercocarpus montanus*, *Symphoricarpos* spp., and other shrubs may also be co-dominant.
Colorado Plateau Pinyon-juniper Woodland	Found on warm, dry sites on mountain slopes, mesas, plateaus, and ridges. 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 Semi-desert Shrub-steppe	Typically found at lower elevations on alluvial fans and flats with moderate to deep soils. This semi-arid shrub-steppe is typically dominated by graminoids such as *Achnatherum hymenoides*, *Bouteloua gracilis*, *Distichlis spicata*, *Hesperostipa comata*, *Pleuraphis jamesii*, *Poa secunda,* and *Sporobolus airoides*. The woody layer is often a mixture of shrubs and dwarf-shrubs.

it is possible that microhabitat characters controlling its distribution have not yet been identified.

Reproductive biology and autecology

Life history and strategy

Using the C-S-R (Competitive/Stress-Tolerant/Ruderal) model of Grime (2001), *Astragalus proximus* appears to fit best in the stress-tolerator category, along with many desert shrubland species. Stress in this habitat stems from nutrient limitation rather than competition. Grime (2001) notes that for perennials in low-rainfall habitats, restricted nutrient uptake is unavoidable. The reduced stature, apparent unpalatability, and potentially long lifespan of *A. proximus* tend to indicate it is a stress-tolerator. This trait is probably shared by many other *Astragalus* species of the Inter-Mountain West.

Although not otherwise a typical ruderal species, there is evidence that *Astragalus proximus* is tolerant of some disturbance under certain conditions. Field observers report plants growing in highway road cuts or in disturbed areas such as the visitor center clearing at Chimney Rock Archeological Area (Lyon personal communication 2004). On the other hand, populations in New Mexico appear to be intolerant of disturbance caused by oil and gas development, especially well pad construction (Sivinski personal communication 2004). A variety of factors, such as degree and timing of disturbance, soil type, and precipitation may contribute to variation in disturbance tolerance across the range.

As a perennial species that probably devotes one or more years to vegetative growth before reproducing, *Astragalus proximus* can be regarded more or less as a *k*-selected species using the classification scheme of MacArthur and Wilson (1967). Although individuals can flower profusely under some environmental conditions, the amount of total biomass devoted to reproduction under normal conditions is probably not large.

Reproduction

Although occasional new stems may arise from the underground caudex, *Astragalus proximus* is not rhizomatous and reproduces only by seed, not by vegetative reproduction or clonal growth. As with all *Astragalus* species, flowers of *A. proximus* contain both male and female reproductive organs. Mating system and degree of self-compatibility have not been investigated for *A. proximus*. 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 (*A. lonchocarpus*) *Astragalus* species were self-compatible and capable of setting as many fruits by selfing as by outcrossing. Flower manipulation was important in percent fruit set; un-manipulated flowers set fruit at much lower levels. One widespread species was not self-compatible. The restricted species experienced lower overall levels of embryo abortion in self-pollinated ovules compared to the widespread species.

Table 5. Species reported to be associated with *Astragalus proximus*. Most commonly reported species are shown in bold.

TREES:	**FORBS:**
Juniperus monosperma	*Allium cernuum*
Juniperus osteosperma	*Artemisia ludoviciana*
Juniperus scopulorum	*Aster glaucodes*
Pinus edulis	*Astragalus amphioxys*
Pinus ponderosa	*Astragalus bisulcatus*
Pseudotsuga menziesii	*Astragalus flavus*
Quercus gambelii	*Astragalus lonchocarpus*
	Astragalus oocalycis
SHRUBS / SUBSHRUBS:	*Calochortus nuttallii*
Amelanchier utahensis	*Castilleja chromosa*
Artemisia frigidia	*Chaenactis douglasii*
Artemisia nova	*Chaetopappa ericoides*
Artemisia tridentata	*Cirsium tracyi*
Artemisia tridentata ssp. *vaseyana*	*Cryptantha fulvocanescens*
Atriplex confertifolia	*Erigeron flagellaris*
Cercocarpus montanus	*Eriogonum racemosum*
Chrysothamnus spp.	*Heterotheca villosa*
Mahonia repens	*Hymenopappus filifolius*
Opuntia spp.	*Lathyrus eucosmus*
Prunus virginiana var. *melanocarpa*	*Leptodactylon pungens*
Purshia mexicana	*Linaria vulgaris*
Purshia stansburiana	*Lupinus kingii*
Purshia tridentata	*Lupinus polyphyllus*
	Maianthemum stellatum
GRAMINOIDS:	*Melilotus alba*
Achnatherum hymenoides	***Melilotus officinalis***
Bromus tectorum	*Penstemon barbatus*
Carex geyeri	*Penstemon strictus*
Festuca spp.	*Stanleya pinnata*
Hesperostipa comata	*Tetraneuris acaulis*
Hilaria jamesii	*Townsendia* spp.
Koeleria macrantha	*Wyethia x magna*
Pascopyrum smithii	
Poa spp.	
Poa fendleriana	

In both restricted and widespread species (one each), 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 proximus*, it may show the same pattern of self-compatibility and its effects as the two other restricted species. Future research could investigate the possibility of selfing in *A. proximus*, and whether this produces high levels of inbreeding depression.

Pollinators and pollination ecology

As do all members of the subfamily Papilionoideae, *Astragalus proximus* possesses papilionaceous flowers. The papilionaceous flower is the characteristic "pea" flower with a zygomorphic corolla consisting of large posterior and upright standard (banner), a lateral pair of long-clawed wings, and an innermost boat shaped keel (see figure 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 papilonaceous 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 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). Flowers of *Astragalus proximus* are smaller than those of many other *Astragalus* species, and thus they may be frequented by smaller pollinators.

Pollinators of *Astragalus proximus* have not been identified. Potential pollinators reported (Green and Bohart 1975, Sugden 1985, Karron 1987, Geer et al. 1995) 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*). Geer et al. (1995) reported over 27 species of bees visiting flowers of *A. montii*, *A. kentrophyta* and *A. miser*. *Osmia* spp. were the most frequent visitors to all three species. Green and Bohart (1975) concluded that pollen quantity and distribution on floral visitors belonging to Diptera and Coleoptera indicated that they were not likely to be successful pollinators of *Astragalus* species.

Phenology

Plants can begin flowering in April and continue into July. Specimens are often seen with both flowers and fruits, even in early June. Phenology may be earlier in New Mexico, as most specimens from that state were collected in the second half of May. Because identifications are most certain if specimens bear fruit, this implies that plants may already be fruiting as early as the second week of May in some locations. Within Region 2, plants are normally flowering in the first half of June. Most specimens are collected with both flowers and fruits. Fruits are probably mature by the end of July, but it is not clear when seeds are fully mature. Germination site requirements for *Astragalus proximus* are unknown.

Fertility and propagule viability

There are no data available with which to accurately assess the fertility and propagule viability of *Astragalus proximus*. Larger individuals of *A. proximus* may have several dozen stems, each with several dozen flowers. Fully fertilized flowers may produce 6 to 10 seeds (Barneby 1964). Under excellent conditions, without pollinator or resource limitations, an individual could potentially produce thousands of seeds in a single season. However, plants under natural conditions are undoubtedly producing far fewer viable seeds, perhaps several hundred for a larger individual in an average year.

Dispersal mechanisms

The probability of dispersal of seeds and other propagules decreases rapidly with increasing distance from the source (Barbour et al. 1987). The majority of seeds will remain close to the parent plant; very few long-distance dispersals occur. Pods typically remain on the plant after dehiscence, and the small size of the seeds probably insures that most are not dispersed further. Field observers report that occasionally pods will break off the plant before dehiscence (Heil personal communication 2004). In such cases, if seeds are mature, they may be dispersed some distance before escaping the pod. Rittenhouse and Rosentreter (1994) observed pods of *Astragalus amblytropis* rolling downslope under very light wind conditions, and under very windy conditions even upslope. Individual seeds are fairly small (2 to 2.4 mm long) and likely to quickly lodge in soil microsites once they leave the pod.

Seed predation has been reported for a variety of *Astragalus* species (Green and Palmbald 1975, 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. proximus* 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. proximus*.

Cryptic phases

Seed bank dynamics and seed longevity have not been investigated for *Astragalus proximus*. 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. proximus* seeds under natural conditions may remain viable for many years.

Numbers of *Astragalus proximus* seeds in the soil seed bank have not been investigated. Some other *Astragalus* species appear to maintain variable but potentially large seedbanks. Ralphs and Cronin (1987) reported a mean density of 394 seeds per m^2 (10.8 $ft.^2$) of soil for *A. lentiginosus* var. *salinus* in Utah. They found that seed density was not necessarily correlated with foliar cover of the species. Ralphs and Bagley (1988) reported widely variable seed density for *A. lentiginosus* var. *wahweepensis* in Utah, ranging from 20 to 4,346 seeds per m^2 (10.8 $ft.^2$), and they hypothesize that the seed bank is sufficient to allow "population outbreaks" (un-quantified) in years with favorable environmental conditions. Morris et al. (2002) reported densities from 24 to 753 seeds per m^2 (2 to 70 seeds per $ft.^2$) for *A. bibullatus* in the Central Basin of Tennessee. The anecdotal tendency for populations of *A. proximus* 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.

Another possible cryptic phase is a dormant stage in which an individual plant does not produce aboveground vegetation for one or more years and then "reappears" at a later time. Lesica (1995) reported this type of dormant phase in *Astragalus scaphoides*. Observations of one of the Chimney Rock populations suggest that plants can appear one year where none were seen in the previous year, so the possibility should be investigated for *A. proximus*, which has a subterranean caudex that might facilitate such dormancy. This type of sudden appearance could also indicate the presence of a soil seed bank that responds to the appropriate conditions with a large recruitment episode.

Phenotypic plasticity

Astragalus proximus appears to exhibit some phenotypic variation from north to south within its range. Individuals from populations in Colorado (Region 2) are reported to be generally more robust and to have more colorful flowers while plants in New Mexico tend to be very slender and have mostly white or greenish flowers (Sivinski personal communication 2004).

Mycorrhizal relationships

Endomycorrhizal fungi belonging to the taxonomic order Glomales are a key component of one of the most common underground symbioses. These endomycorrhizae are characterized by inter-and intracellular fungal growth in the root cortex where they form fungal 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 have been identified from a broad range of habitats occupied by *Astragalus proximus*, including semi-arid grasslands, sagebrush-steppe (Wicklow-Howard 1994), and pinyon-juniper (Klopatek and Klopatek 1987).

Roots of *Astragalus proximus* 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 has been reported in the genus *Astragalus*. In the endangered *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 (Fabaceae) 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 proximus* has not been investigated for nodulization. However, nodules have been reported for the closely related *A. flexuosus*, so it is possible that *A. proximus* also possesses this capacity.

Hybridization

Although other genera in the Fabaceae (e.g., *Oxytropis* and *Lathyrus*) have been reported to exhibit hybridization, the phenomenon is not prevalent in *Astragalus*. There is no evidence of hybridization in *A. proximus*, although individuals of the species may be morphologically intermediate with individuals of *A. flexuosus*. Karron (1987) and Geer et al. (1995) report that sympatric *Astragalus* species can share pollinators. In these instances, a mechanism to facilitate hybridization is available, but it is not known if hybridization is actually occurring. *Astragalus proximus* and the closely related *A. flexuosus* are sympatric, and because pollination dynamics and potential barriers to hybridization in *A. proximus* have not been investigated, the possibility remains open.

Demography

As an herbaceous perennial that is not monocarpic, *Astragalus proximus* exhibits overlapping generations. This characteristic is potentially important in the action of natural selection in that individuals of different ages will be exposed to slightly different selective processes (Harper 1977). Such selection can lead to temporal variation in population genetic structure, allowing soil 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 soil seed bank than in vegetative populations of the cedar glade endemic *A. bibullatus*. They suggest that the ability of the soil seed bank to preserve genetic diversity may depend on seed dormancy characters and on the relative size of the soil seed bank compared to the vegetative population. The investigation of these two factors could help clarify the genetic diversity issues for *A. proximus*.

Little is known about the population genetics of *Astragalus proximus*. 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. proximus* would be of interest due to the prediction of evolutionary theory that species with small ranges and few individuals will exhibit low levels of genetic polymorphism (Hartl and Clark 1989).

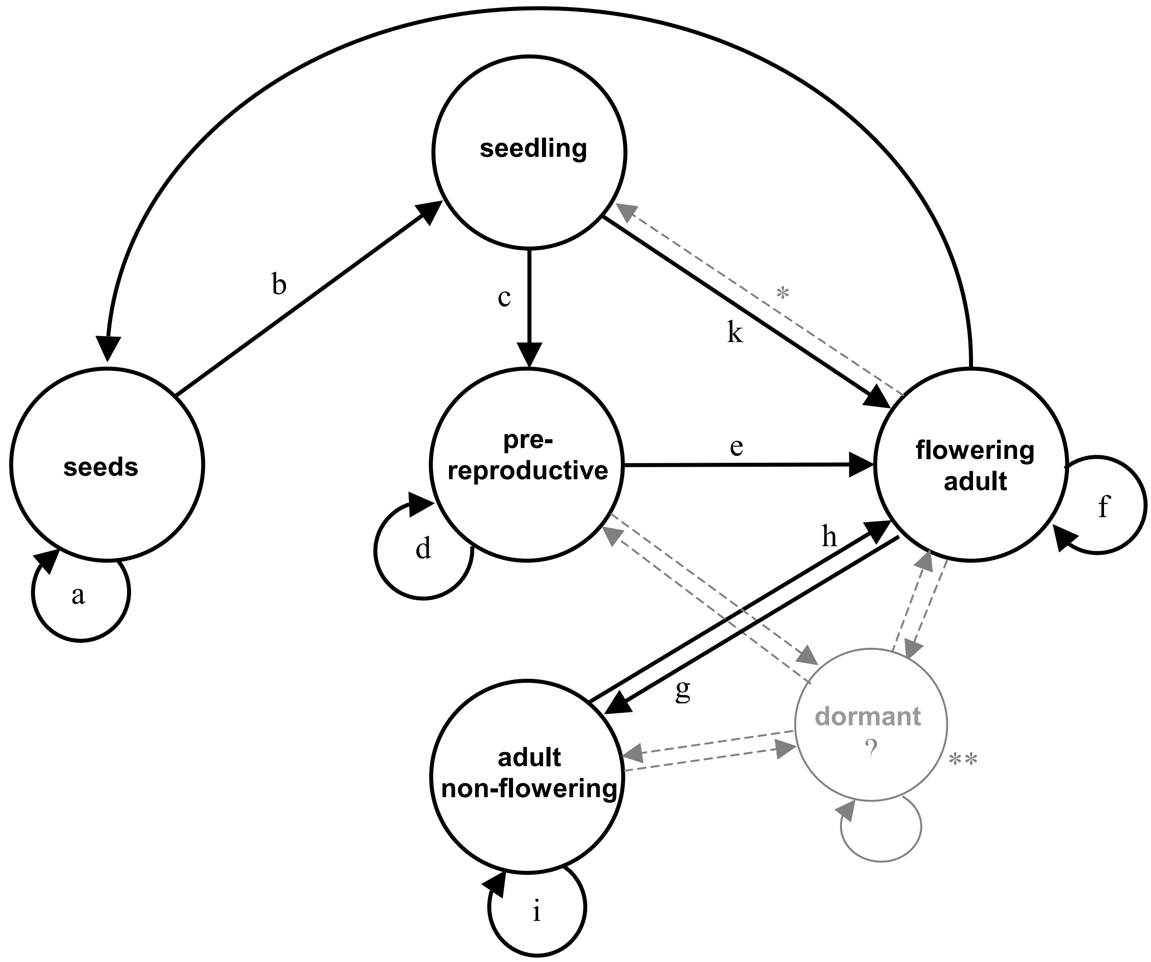
Lesica (1995) conducted an eight year demographic study of *Astragalus scaphoides*, a long-lived perennial endemic to east-central Idaho and adjacent Montana. It occurs in sagebrush steppe (a community dominated by *Artemisia tridentata* and *Pseudoroegnaria spicata*). In this species, some plants would become dormant for one to several years, producing little or no aboveground vegetation. Dormant plants constituted about 10 percent of the population and could remain dormant for up to five years before reappearing. The possibility of a similar dormancy stage in *A. proximus* needs to be investigated.

The lifespan of an *Astragalus proximus* individual is not known, but plants are thought to have a normal lifespan of more than just a couple of years (Sivinski personal communication 2004). In Lesica's (1995) study of *A. scaphoides*, 40 to 50 percent of individuals observed during the first year of the study were still alive eight years later.

Figure 7 shows a hypothetical life cycle diagram. Because there are no multi-year studies of *Astragalus proximus*, transition probabilities are left un-quantified. Under the basic scenario shown, flowering plants produce seeds in early- to mid-summer. These seeds overwinter and germinate in the spring or remain dormant. Seedlings may flower in their first year, or they may require one to several years to reach reproductive size/age. Reproductive adults flower every year as conditions permit. The model assumes a transition interval of t = one year, and plants do not move between stages in intervals less than t.

Until better demographic data are available for *Astragalus proximus*, it is impossible to conduct any kind of elasticity analysis to determine which demographic transitions are making the greatest contribution to population growth. An elasticity analysis of the extremely restricted Grand Canyon endemic *A. cremnophylax* var. *cremnophylax* (Maschinski et al. 1997) 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 population 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. Similar trends are possible for *A. proximus*.

Research on the concept of minimum viable populations was initiated largely in response to requirements of the National Forest Management Act of 1976 that the USFS maintain "viable populations" of species found in each national forest. The theory of minimum viable population (MVP) was developed under the animal model of the sexually reproducing, obligate outcrossing individual, and incorporated the effects of genetic stochasticity from elevated inbreeding coefficients in small population (Soulé 1980, Shaffer 1981). The MVP is the smallest population that is predicted to have a very high chance of survival for the foreseeable future (Primak 1995). Shaffer (1981) emphasized the probabilistic nature of the definition of



a. survival of dormant seeds in the seed bank
b. probability of seed becoming a seedling
c. survival of seedling to pre-reproductive stage
d. probability of individual remaining in pre-reproductive stage
e. probability of pre-reproductive becoming reproductive
f. probability of flowering adult flowering again next year
g. probability of flowering adult not flowering
h. probability of non-flowering adult flowering
i. probability of non-flowering adult remaining in non-flowering stage
j. seed production of flowering plants
k. probability of seedling flowering
* when do seeds germinate, i.e., are seedlings produced the same year?
** is there a dormant phase, and if so, probabilities of transition between this and other rosette stages?

Figure 7. Life cycle diagram for *Astragalus proximus* (after Caswell 2001).

an MVP, noting that survival probabilities and expected duration may be set at various levels (e.g., 95%, 99%, or 100%, 100, 1000, or 10,000 years). Different estimates for MVP size have been suggested in response to the various types of uncertainty affecting populations (e.g., demographic stochasticity, environmental stochasticity, large scale natural catastrophe, and genetic stochasticity; Shaffer 1981). Suggested MVP numbers have ranged from 50, to buffer demographic stochasticity, to 500, to buffer genetic stochasticity (Franklin 1980), to a range of 1,000 to 1,000,000, in the case of environmental stochasticity and natural catastrophes (Menges 1991). This variation in estimates highlights the necessity for Population Viability Analysis (PVA) models with robust parameters to be developed for each individual species. Such analyses, including numerical estimates of MVPs, require substantial empirical data and an understanding of the links among environmental variability, demography, and genetics in the species of interest (Menges 1991). There are currently no PVA models for *Astragalus proximus*, and available information on the species is currently insufficient to provide appropriate parameters for such an analysis.

Although the concept of standardized estimates for MVP size is appealing for conservation managers, current consensus is that most general PVA models lack adequate data to be realistic. Moreover, although PVA may occasionally be essential for the conservation of a species, most species will be adequately protected by habitat preservation and conservation strategies based on available autecological information (Menges 1991). Land managers are often required to make a determination about whether a management action is likely to cause a trend to federal listing or loss of viability, but this can be difficult to do under time and funding constraints. Furthermore, there is the potentially additive nature of repeated decisions that needs consideration. The combination of several smaller actions that do not individually cause a loss of viability may result in a significant impact on population trends that is not quickly apparent. Management decisions regarding sensitive species can be addressed as part of a cumulative effects analysis in project proposal analysis, and in regional analysis for sensitive species list development In general, the most effective strategy is to avoid negative impacts to sensitive species whenever possible, and to preserve the highest population numbers possible, rather than rely on a generic formula for MVP numbers.

Community ecology

Community ecology of *Astragalus proximus* is poorly understood. The species does not appear to exhibit a strong preference for any particular community type within its range, and associated species are variable.

Herbivores

Astragalus species are often poisonous to livestock. This character is due primarily 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 and found varying levels of nitro-toxin in about 52 percent of the species they examined. Presence and levels of nitro-toxins were fairly consistent among species belonging to the same taxonomic group. Although *A. proximus* was not among the species tested, all other members of the subsection Scytocarpi exhibited high concentrations of at least 20 mg nitro-toxin per gram of plant. These results indicate that *A. proximus* probably contains relatively high amounts of nitro-toxin.

Selenium absorbing species of *Astragalus* have been used in the detection and mapping of seleniferous and uranium-bearing areas and are also a source of livestock poisoning (Robinson and Alex 1987). Although it favors seleniferous soils, *A. proximus* does not appear to be a selenium-absorbing species. However, its unpalatability due to other toxins has not been investigated.

Some species of *Astragalus* appear to be resistant to herbivory (Rittenhouse and Rosentreter 1994). 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. Aphids also appeared to have an impact on reproductive output (Anderson 2001). Lesica (1995) reported increased predation on inflorescences of *A. scaphoides* when livestock were present. Field observers report little sign of use by vertebrate herbivores on *A. proximus*.

Competitors

Community relationships of *Astragalus proximus* have not been investigated. *Astragalus proximus* has been reported as sometimes occurring in fairly dense vegetation (Lyon personal communication 2004), even growing in lawn-like situations, which may indicate that it is a reasonably strong competitor. Intraspecific competition may be more important than interspecific competition since plants often grow in loose clumps. Plants are found in a variety of habitats, from open to moderately closed canopy situations, and they may be somewhat tolerant of shading. A number of invasive species have been reported as co-occurring with *A. proximus*; however, there is no data available that would help to determine if any of these species will become a serious competitor of *A. proximus* in the future.

Parasites and disease

There are no reports of disease in *Astragalus proximus*. Field observers have not reported any obvious damage to foliage or fruits. Stunted pods were reported for two plants at the Montezuma Creek population on the San Juan National Forest, but the cause of this phenomenon is not known.

Symbioses

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

CONSERVATION

Threats

A primary consideration in evaluating threats to the long-term persistence of *Astragalus proximus* is the fact that very little is known about the species. Although *A. proximus* is locally common in parts of its range and appears to have a stable population, its entire global range is contained within the northeastern San Juan Basin. Additive effects of threats to the population may be compounded by this restricted range. Based on the available information, there are several threats to *A. proximus*. In approximate order of decreasing priority, these are oil and gas development, road building and maintenance (including attendant sand and gravel mining), off-road vehicle use, grazing, fire, air pollution, and global climate change. Many of these threats are pertinent to at least some populations on the San Juan and Carson national forests. A lack of systematic tracking of population trends and conditions, and the lack of knowledge about its basic life cycle, habitat affinities, population extent, and demographics also contribute to the possibility that one or more of these factors will threaten the long-term persistence of the species. It is unlikely that the species could be suddenly decimated by anthropogenic activities, but without a range-wide monitoring of the species, individual populations could decline and disappear without much notice.

National Forest System lands on the San Juan National Forest support about 45 percent of known locations of *Astragalus proximus* in Region 2, but, as with other federal, state, and tribal lands, these have not been completely surveyed for occurrences. For any undocumented locations on NFS lands or other lands in Colorado or New Mexico, it is difficult to assess the extent of impacts from the above threats. In the absence of a coordinated effort to monitor and maintain populations, 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 in the San Juan Basin is likely to have a slow but steady negative effect on habitats, populations, and individuals of *A. proximus*. These factors constitute the most likely immediate threats to the species. Without systematic monitoring of the species throughout its limited range, population levels could be severely reduced before anyone realizes the extent of the losses.

Oil and gas development

The San Juan Basin is a significant hydrocarbon reservoir, containing natural gas, oil, coalbed methane, and coal. The area is responsible for over two thirds of New Mexico's natural gas production (some 1.1 trillion standard cubic feet in 1997) and about 5 percent of the state's oil production (USDI Bureau of Land Management 2003a). Within Region 2, the northern San Juan Gas Field can potentially produce 2.5 trillion cubic feet of methane over the next 30 years (USDA Forest Service San Juan National Forest 2002). There are currently over 18,000 active wells in the basin, and the life of a single well can extend as long as 50 years. Mining and other large-scale earthmoving (e.g., mine tailings removal, landfills and other ground disturbing actions) could destroy some populations and habitat, but such activity is unlikely to eliminate the entire species. **Figure 8** shows the extent of energy resource extraction activities in the range of *Astragalus proximus*. Well pad, pipeline, and service road construction are impacting a substantial portion of the habitat of *A. proximus*. The total area disturbed for each well is estimated to be on the order of 3.5 acres (1.4 ha) (USDI Bureau of Land Management 1998, 1999), resulting in a basinwide disturbance of some 63,000 acres (25,500 ha). Field observers report that populations do not easily re-establish in these disturbed areas (Sivinski personal communication 2004). In Region 2, wells and mines are primarily found on non-NFS lands, but there is some existing and proposed development in the HD

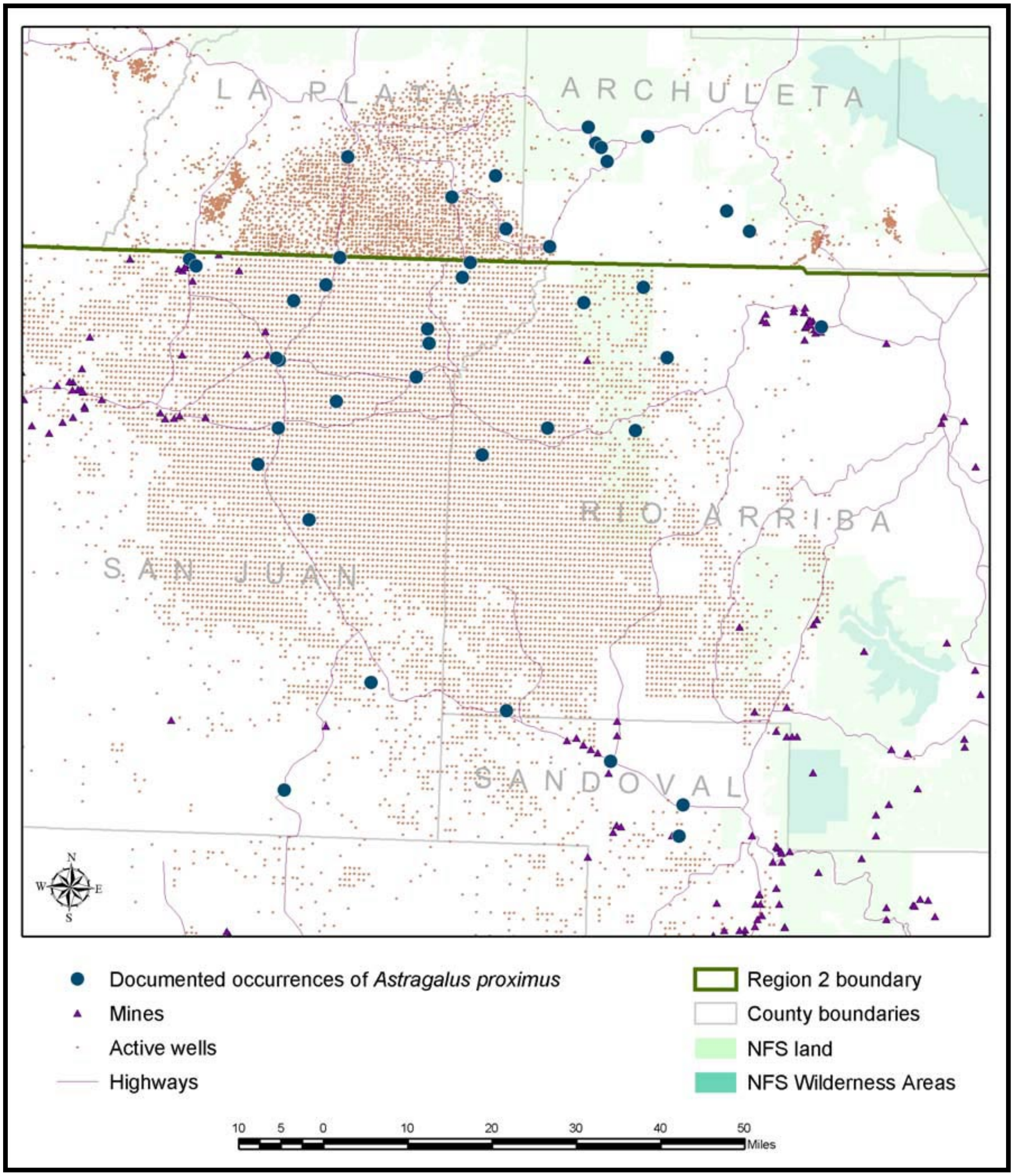


Figure 8. Energy resource development in the San Juan Basin. Mine locations: New Mexico Natural Heritage Program 2001, Active wells: New Mexico Energy, Minerals and Natural Resources Department 2004 and Colorado Oil and Gas Conservation Commission 2004.

Mountains area of the San Juan National Forest. Under the most ambitious development scenario, up to 296 additional wells would be constructed on NFS surface holdings. Together with additional wells on adjacent federal and private lands, the project could involve the construction of an estimated 207 miles of roads and pipelines as well as fifteen new compressor sites (USDA Forest Service San Juan National Forest 2002).

In addition to the direct surface disturbance due to oil and gas development, these activities can contribute extensively to habitat fragmentation (Weller et al. 2002). Although the impact of road, pipeline, and well pad construction on *Astragalus proximus* habitat quality is unknown, roads do increase the amount of edge habitat present in the landscape. Edges are the outer boundaries of an ecosystem that abruptly grade into another type of habitat (Forman and Godron 1986). Such boundaries are often created by naturally occurring processes such as floods, fires, and wind, but they can also be created by human activities such as roads, timber harvesting, agricultural practices, rangeland, and other management actions. Human-induced edges are often dominated by plant species that are adapted to disturbance. As the landscape is increasingly fragmented by large-scale, rapid anthropogenic conversion, these edges become increasingly abundant. Through its effects on plant-insect interactions, habitat fragmentation tends to decrease the effective population size (Holsinger and Gottlieb 1991), may affect 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).

Road building and maintenance

A few populations in Colorado, including at least one on the San Juan National Forest at Chimney Rock Archaeological Area, are in highway road cuts and other roadside environments, but throughout much of its range *Astragalus proximus* is not typically a roadside plant. Road construction and maintenance directly threaten some populations, and are likely to destroy habitat for others. For instance, Colorado Natural Heritage Program (2004) records indicate bulldozing and dumping activities have occurred near one of the NFS Chimney Rock Archaeological Area populations. In the balance, such disturbances are likely to weigh more heavily on the negative side for the species as a whole. About 44 percent of the species' habitat falls on public lands, which makes the possibility of direct impacts from residential development and attendant road construction on that portion of its range relatively small. However, human population numbers continue to increase in the area, especially in Archuleta County (United States Census Bureau 2004), and this is likely to lead to an increase in anthropogenic effects to the environment. When development does take place, it can increase habitat fragmentation and edge effects.

Off-road vehicle use

Motorized and non-motorized recreation, especially when it results in the creation of social trails, can also negatively affect populations of *Astragalus proximus*. Both mountain biking and off-road vehicle use on the San Juan National Forest have increased in the past few years (USDA Forest Service, San Juan National Forest 1999), and these activities have been observed in proximity to the populations at Chimney Rock Archaeological Area (Colorado Natural Heritage Program 2004). Road proliferation also greatly increases the ability of invasive species to move into new areas.

Grazing

Much of the public land in the San Juan Basin has active grazing allotments, and *Astragalus proximus* is exposed to grazing on both NFS and BLM public lands. *Astragalus proximus* has been documented on the Chimney Rock (records 4 and 9 in **Table 2**), Freeman Creek (record 7), HD (record 13), and Lower Valle Seco (record 6) allotments on the San Juan National Forest. Of these five occurrences, all are within active grazing allotments except the Chimney Rock populations (Brinton personal communication 2004). Livestock grazing is unlikely to directly threaten individuals or populations, as *A. proximus* is probably not generally palatable to cattle or horses. However, trampling by large concentrations of livestock could be detrimental to pollinators, as well as to some individual plants (Sugden 1985).

Fire

Astragalus proximus presumably evolved under natural cycles of fire and re-growth, at least where it occurs in woodland and forest settings. However, much of the area is dominated by sparsely vegetated landscapes that have little fuel, and fine fuels are often lacking in the understory throughout much of the area, regardless of the overstory fuel type (USDI Bureau of Land Management 2003a). The effect of fire suppression on habitat dynamics is unknown, but potentially important in the persistence of suitable habitat. This threat may also interact with the effects of global warming on dominant vegetation. For instance, if fire-prone vegetation types increase in expanse, the frequency and intensity of fire in the range of *A. proximus* may also increase.

Air pollution

An additional environmental factor in the range of *Astragalus proximus* is the presence of several large power plants in the San Juan Basin. The Four Corners Power Plant and nearby San Juan Generating Station are substantial emitters of sulfur dioxide (SO_2) and nitrogen oxides (NO_x), the primary causes of acid deposition. Nitrogen deposition may impact local and regional ecosystems in a variety of ways. Atmospheric deposition of nitrogen compounds and other pollutants can alter soil chemistry and concentrations of important soil nutrients. Woodland ecosystems may be damaged when acidic ions in the soil displace calcium and other nutrients from plant roots, inhibiting growth (United States Environmental Protection Agency 2002). Excess nitrogen inputs may alter species diversity by allowing native plants that have adapted to nitrogen-poor conditions to be outcompeted and replaced by more nitrogen-tolerant non-native species. Finally, very high levels of acid deposition can damage plant leaves and leach nutrients directly from foliage (Stolte 1991, United States Environmental Protection Agency 2002). The effect and intensity of these emissions within the San Juan Basin are generally unknown; however, both wet and dry nitrogen deposition are believed to be much higher in the surrounding higher elevation mountains than in the basin itself (Nanus et al. 2003). Because populations of *A. proximus* on NFS lands in Region 2 are at higher elevations that those in the rest of the species' range, this factor may be more important for these areas.

Global climate change

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 area around the San Juan Basin is an increase in both temperature and precipitation (National Assessment Synthesis Team 2000). Locally, this change is likely to drive an expansion of pinyon-juniper woodland and shrubland and a corresponding decrease in grassland area (National Assessment Synthesis Team 2000). Changes in dominant vegetation type may be beneficial or detrimental for *Astragalus proximus*, but with the current level of knowledge of its habitat requirements, it is impossible to predict the outcome. Although it is generally difficult or impossible to manage directly for this threat, land managers need to be aware of the possibility that interaction with the effects of global climate change may affect the severity of other threats.

It is unlikely that any single threat is sufficient to completely eliminate the species from its entire range. However, for species such as *Astragalus proximus*, with small global ranges, there is less margin for error in protection.

Influence of management activities or natural disturbances on habitat quality

The effects of management activities or natural disturbances on habitat quality for *Astragalus proximus* have not been studied. However, it is obvious that some land use activities in the San Juan Basin are contributing to habitat fragmentation for all native species, and that these activities can decrease habitat quality for *A. proximus*. The most pervasive activity is the development of coalbed methane production. Much of the area is produced at a spacing of 320 acres per well, and there are pilot projects underway to assess the feasibility of 160 acre spacing for some areas (USDI Bureau of Land Management 2003a, USDA Forest Service, San Juan National Forest 2002). Although the absolute percentage of land directly disturbed by well pads, pipelines, compressor stations, and connecting roads is small, the regular grid pattern of the development greatly increases the edge effects associated with the disturbance. This type of habitat-fragmenting disturbance is likely to isolate subpopulations and increase the potential for local extinction. Other management activities, such as timber harvest, livestock grazing, motorized recreation, and fire suppression, except as they are associated with soil disturbance, are not likely to have as great an impact on habitat quality and availability for *A. proximus*.

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 subpopulations. In particular, surface disturbance associated with energy resource development is likely to have a direct impact on individuals and populations of *Astragalus proximus*. Plants may be killed or damaged as a result of these activities, and population remnants may be unable to recolonize disturbed areas.

Maschinski et al. (1997) found that, although population levels of *Astragalus cremnophylax* var. *cremnophylax* at Grand Canyon National Park fluctuated after protection from trampling, modeling suggested that a protected population would stabilize, in contrast to the declining unprotected population. Although plants were able to tolerate some trampling, the trampling also 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 affected ground-nesting bees, which were responsible for pollinating *A. monoensis* in California. These results tend to suggest that populations of *Astragalus* species are more stable under conditions where disturbance is limited and is of a type under which the species has evolved.

Public lands of the San Juan Basin, including NFS lands, are widely used for variety of recreational activities, including off-highway vehicle (OHV) use. The Farmington Field Office of the BLM has designated thirteen OHV management units in the San Juan Basin, but has not yet developed management plans for most units. The vast majority of BLM holdings in the area have no current restrictions on OHV use (USDI Bureau of Land Management 2003a). In contrast, NFS lands of the area are generally under travel guidelines restricting OHV and motorcycle use to designated routes. In areas where travel is restricted and these restrictions are adequately enforced, impacts to individuals of *Astragalus proximus* are likely to be minimal.

Interaction of the species with exotic species

The potential interaction of *Astragalus proximus* with exotic species has not been investigated. In the San Juan Basin, invasive species are most prevalent in areas disturbed by surface activities (USDI Bureau of Land Management 2003a). Over 200 invasive and poisonous weeds have been identified from BLM holdings in New Mexico (USDI Bureau of Land Management 2003a). In Region 2, the San Juan National Forest tracks 85 invasive species (USDA Forest Service San Juan National Forest 2003). Of these, Canada thistle (*Cirsium arvense*) and musk thistle (*Carduus nutans*) are most frequently reported near documented locations of *A. proximus* on NFS lands. These species are commonly treated by spraying with the herbicide Tordon (picloram) (Colorado Natural Areas Program 2000). Such treatments are likely to also kill *A. proximus* individuals if they are growing in the treated area and the herbicide application is not focused on individual invasive plants. Yellow sweetclover (*Melilotus officinalis*) is another non-native species reported occurring with *A. proximus* in most of the occurrences on NFS lands within Region 2 (Colorado Natural Heritage Program 2004). This species is not tracked by the San Juan National Forest.

Threats from over-utilization

There are no known commercial uses for *Astragalus proximus*. In fact, although *Astragalus* is a very large genus, comparatively few species are of agricultural significance (Allen and Allen 1981). The prevalence of toxicity in the genus *Astragalus* greatly reduces their utility as forage. A variety of *Astragalus* species have served as a source of gum tragacanth, an insoluble carbohydrate gum that has been used for a variety of manufacturing and pharmaceutical purposes for hundreds of years (Allen and Allen 1981). At least one species of *Astragalus* (*A. membranaceous*, or 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 recommended for a variety of uses. There is no indication that *A. proximus* is likely to become a target of either of these types of commercial use.

Astragalus proximus is regularly collected in botanical surveys in the San Juan Basin, but it has never been the subject of formal scientific investigation. Available evidence indicates that population levels are sufficient to support collecting and research at similar or higher levels in the future, at least for New Mexico populations.

Conservation Status of the Species in Region 2

There is no evidence that the distribution or abundance of *Astragalus proximus* is declining in Region 2. However, numbers of plants in individual populations, including those on NFS lands, have been observed to fluctuate dramatically between years (Edwards 1991, Lyon personal communication 2004), and there are very few multi-year observations of *A. proximus* populations (none in areas outside Region 2) with which to analyze population trends. Furthermore, much of the probable range has not been surveyed for *A. proximus*, especially tribal lands. This lack of quantitative information also applies to the portion of the population that lies outside of Region 2, and makes it difficult to assign a conservation status with any degree of confidence.

Evidence presented in the previous sections indicates that the potential for a variety of surface disturbing activities that are likely to have a detrimental effect on *Astragalus proximus* populations is high throughout its range, both in Region 2 and in Region 3. Risks to populations from management activities are somewhat ameliorated in Region 2 because the species is perceived as being rare in this region, and because the exact locations of some populations are known to USFS and BLM personnel. In particular, the management practices at Chimney Rock Archeological Area are probably adequate to ensure the persistence of those populations. However, there are no conservation plans in place for the species anywhere in its range, so many populations can not be considered secure for any reason other than historical lack of activity in their vicinity.

Because the bulk of the suitable habitat and known populations are in New Mexico, occurrences of *Astragalus proximus* in Region 2 represent a peripheral sample of the entire population. As such, it is important to preserve these populations as reservoirs of local variation and adaptation.

The patchwork of ownership patterns within the range of *Astragalus proximus* means that cooperation among federal land managers and with a variety of state, tribal, and local entities is needed to ensure the persistence of the species. In order to minimize the effects of the many different land uses in the area, land managers must continue to be aware that the San Juan Basin is the only place where this species occurs, and that if it is not maintained here, it will be lost.

Management of the Species in Region 2

Implications and potential conservation elements

Astragalus proximus is found in a variety of habitats and land management situations in the San Juan Basin, and these differences are likely to have differential effects on the persistence of the species. Current evidence suggests that *A. proximus* populations are small and scattered, but that the species occurs more or less continuously in suitable habitat throughout its range. The dispersed nature of these populations may render them especially susceptible to environmental changes or management policies that introduce fragmentation into once continuous habitat. Surface disturbing activities, such as road building and energy resource development, are the primary source of habitat change in the area.

Desired environmental conditions for *Astragalus proximus* include undisturbed and unfragmented tracts of habitat that are large enough to sustain natural ecosystem processes for both the plant and its pollinators. Landscape connectivity should be sufficient to allow metapopulation dynamics to function. From a functional standpoint, ecosystem processes on which *A. proximus* depends appear to remain largely intact, at least in the southern portion of its range. Whether this will remain true under the energy resource development level projected for the area is uncertain. Further research on the ecology and distribution of *A. proximus* will help to develop effective approaches to management and conservation.

It is likely that a thoughtful assessment of current management activities on lands occupied by *Astragalus proximus* would identify some opportunities for change that would be inexpensive and have minimal impacts on the livelihood and routines of local residents, ranchers, managers, stewards, and recreationists while conferring substantial benefits to *A. proximus*. Potential beneficial management actions on behalf of *A. proximus* are evaluated in the following discussion.

Tools and practices

Species inventory

Colorado Natural Heritage Program data and herbarium collections provide the majority of information on *Astragalus proximus* occurrences (**Table 2**). Because *A. proximus* is not tracked by the New Mexico Natural Heritage Program, New Mexico records are exclusively from herbarium specimens. While these sources present a generalized picture of the species' total range, the true extent and population numbers remain essentially unquantified. Thus, a priority for species inventory work is to focus on obtaining more complete data on the number and size of populations both in Colorado and New Mexico. This effort is particularly necessary to resolve the disparity between the perception of *A. proximus* as rare in Colorado and relatively common in New Mexico. A clearer picture of the relative abundance of *A. proximus* throughout its range would enable prioritization of any additional inventory and monitoring activities. In addition, inventory and monitoring of populations on NFS lands could focus on locations that are likely to be affected by implementation of management decisions.

The objective of most vascular plant inventories is to produce a species list rather than to document the distribution of a single species. Methods of species inventory for plants are poorly standardized in some aspects although many are based upon fundamental methodology. Inventory methods based upon standard protocols suitable for the scale and purpose of the inventory are more likely to result in data that documents the distribution of single species such as *Astragalus proximus*. The following list of steps is based on an outline adapted from the National Park Service Guidelines for Biological Inventories (USDI National Park Service 1999; **Appendix B**) and summarizes its application to *A. proximus*.

Step 1: Compile and Verify Historical and Predicted Species Data

This assessment document compiles much of the existing information for *Astragalus proximus*. However, adequate information on soil types, micro-habitat requirements, disturbance tolerance, and other factors is lacking. Information from herbarium records is often vague and may be of questionable provenance if specimens have not been validated by experts. A primary focus of the initial phase of species inventory is the collection of more detailed information on the preferred habitats of *A. proximus*. This is likely to involve a preliminary field investigation to characterize habitats of some of the known occurrences in both New Mexico and Colorado in more detail. This information can then be used to determine the habitat specificity of *A. proximus* and to direct further inventory efforts.

The second phase of inventory is likely to involve compiling detailed soil, vegetation, and topography maps and aerial photos for the area of interest. Some information may have to be converted to digital format. Detailed soil maps for the entire area may not be readily available. In some cases, the information can be inferred from vegetation types visible on orthophotos.

Step 2: Identify Specific Objectives

The first phase of inventory is likely to focus on determining presence/absence habitat characteristics for *Astragalus proximus*. Since the factors influencing the distribution of *A. proximus* on the landscape are not known, the collection of a broad array of habitat data will enable the identification of the environmental factors (e.g., soil characteristics, community condition, elevation, level of disturbance, microsite characteristics) controlling the distribution of the species. Once the appropriate habitat parameters have been established, the second phase of inventory can focus on obtaining a reasonable estimate of population sizes and numbers 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, if any, and will greatly increase our knowledge of true population numbers. Until a baseline of *A. proximus* distribution patterns and overall abundance has been established, it is not appropriate to conduct specialized plot sampling studies. Additional priorities may be developed with reference to management objectives. USFS managers may wish to prioritize inventories on lands being considered for oil and gas leasing, or other potential disturbances.

Step 3: Habitat Delineation

Data currently available for habitat delineation are extremely general and may not be sufficient for the preliminary investigation. This step will be an iterative process, proceeding from the generalized habitat information to more specific delineation. For the initial phase, habitat characteristics summarized in this assessment document can be augmented by advice and input of botanists who have observed or collected *Astragalus proximus* in the field. This expert knowledge should be used to identify a representative sample of known populations that can be visited to collect the data needed for more detailed habitat delineation.

Step 4: Sampling Strategy, Sampling Frame and Sample Selection

For the initial survey, it is important to select sample populations that represent all known habitats, and, where possible, are easy to access. Inventory efforts will be most effective if they are completed during the flowering and fruiting season, preferably in the first half of June, to facilitate correct identification of the target species. Initial efforts may involve intensive soil sampling and careful estimation of population numbers. During these preliminary surveys, it is more appropriate to concentrate on collecting a wide variety of data (e.g., slope, aspect, soil characteristics, population and community structure) than to focus on visiting every known population.

The second phase of inventory will select areas to be searched based on the habitat delineation developed from the initial phase. The exact sampling strategy chosen will depend on the level of habitat detail available and the distribution patterns that appear. One of the most important goals of a range-wide inventory is to obtain rough population estimates, using size categories such as 1 to 10, 10 to 100, 100 to 1,000, and so forth.

Step 5: Field Survey

Trained professionals who are familiar with the taxa in question, able to distinguish between *Astragalus proximus* and *A. flexuosus*, and familiar with detailed methods of soil and habitat characterization are required. Collection of voucher specimens may be appropriate. The use of a Global Positioning System (GPS) will provide quick and accurate data collection of location and population extent. Although much of the habitat to be searched is federal land, access through private or tribal land may be required. Preparatory work may require obtaining permission for access.

Step 6: Data Analysis and Evaluation / Database Development and Reporting

In the initial phase, the habitat information collected at known population locations can be used to develop a predictive model of species occurrence that can be extrapolated to the appropriate habitats. Model information can then be used to compile a probable distribution map or similar field inventory tool for the second phase of inventory. Ideally, all inventory results will be made widely available to state and federal agencies, natural heritage programs, local and regional experts, and interested members of the public by the publication of a report summarizing the entire inventory process, and including conclusions about the need for further inventory, the extent of the population, and critical habitat characteristics.

Habitat inventory

Many of the techniques used in habitat inventory are similar to those described for species inventory. In fact, the habitat delineation component of species inventory provides the starting point for subsequent habitat inventory. The use of aerial photography, topographic maps, soil maps, and geology maps to identify inventory search areas is a widely used and highly effective technique. This technique is most effective when basic knowledge of a species' substrate and habitat specificity is available.

In the case of *Astragalus proximus*, important factors to quantify during habitat inventory will include the proximity of habitat to well pads, compressor stations, roads and pipelines, the degree of disturbance in the area, variation in surface soil composition, and habitat structure. It would be potentially useful to investigate the possible association of *A. proximus* with biological soil crusts since these are very sensitive to disturbance (Johnston 1997). Also of interest is the extent to which *A. proximus* habitat overlaps that of the selenophilous *A. oocalycis*. The tendency for *A. proximus* populations to be scattered in diverse habitats and the pervasiveness of threats to these habitats may require wide-ranging inventory efforts to identify habitat requirements.

Population monitoring

Population monitoring is among the highest priorities for research on *Astragalus proximus*. A minimal level of effort could provide an ongoing qualitative awareness of population trends and potentially provide insight into factors influencing the viability of a population. Since population numbers appear to be stable, presence/absence monitoring could give early warning of declining population trends. This data could be collected yearly at established stations that are easily accessed. Ideally, 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. Such efforts may be especially important if drought is having a large impact on populations.

Quantitative data on the dynamics of subpopulations and the population as a whole are almost entirely lacking. One of the most useful methods would involve monitoring marked individuals over the course of several years. This would require the establishment of permanent plots or transects in areas with sufficient numbers of individuals to provide decent sample sizes. Lesica (1987) describes one possible method. Ideally, marked individuals in permanent quadrats or transects would form a core study area for a surrounding population in which the total number of individual plants was determined annually. Plots should be large enough to contain a reasonable sample size and to remain useful as plants die and are recruited. Sample sizes may need to be greater than one or two hundred plants. Rittenhouse and Rosentreter's (1994) study of *Astragalus amblytropis* used three nonrandomized transects to obtain an initial sample size of 105, 63, and 40 plants. Over the course of one year, these sample sizes declined to 19, 6, and 6 plants, respectively. Although this type of decline may be extreme, it highlights the need to ensure that original sample size is sufficient to maintain the study. Plots in large populations could cover a portion of the population while those in smaller populations might contain the entire local occurrence.

At first, 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 are difficult to interpret (e.g., plants that had no flowers at observation time 1 have abundant fruit at observation time 2). During the first year of monitoring, it is important to establish the timing of critical seasonal elements such as flowering and fruit set, and to identify the most useful and practical data collection protocols. Subsequent years could concentrate on collecting data at these established times.

The semi-rhizomatous growth form of *Astragalus proximus* means that it is difficult to determine individual size classes in the field. Growth patterns of the species might be more easily studied by growing seeds under controlled conditions and utilizing the data gained in this way to clarify the growth patterns observed in the field. Such studies would have the advantage of also identifying germination requirements. Within the broader demographic monitoring, it would be useful to establish concurrent, smaller focused studies to examine pollination dynamics and seed production/dispersal.

Quantitative studies are time consuming and expensive. Although *Astragalus proximus* does not appear to merit such levels of study from management personnel at this time, it is important to keep it in mind as a potential research subject for other investigators. Information on the possibility of such studies can be shared with San Juan Basin area residents such as San Juan College students and faculty, or federal agency researchers.

Habitat monitoring

Habitat monitoring may need to be conducted on a broader scale than that of population monitoring. This decision will be driven by the results of species inventory and monitoring and by the habitat characteristics identified during inventory. If habitat monitoring is not possible, or if it is deemed unnecessary, then documenting habitat characters, associated species, evidence of current land use and management, disturbance impacts, and so forth for monitored populations would contribute to our knowledge of the species. However, until more is known about the species' habitat requirements, it is possible that only monitoring the habitat of a few known populations will risk missing important trends.

The use of photo points for habitat monitoring is described in Elzinga et al. (1998). Practical details of photographic monitoring are covered exhaustively in Hall (2001). This is a powerful technique that can be done quickly in the field. Though it does not provide detailed cover or abundance data, it can help to elucidate patterns observed in quantitative data.

Beneficial management actions

The establishment of an interstate awareness of *Astragalus proximus* is perhaps the most useful conservation strategy. The fact that over 40 percent of the species' known range is on federal land places federal land managers in a good position to establish and perpetuate such a strategy. In general, management actions that minimize the impacts of surface disturbance and that promote natural levels of connectivity between subpopulations will tend to benefit populations of *A. proximus*. Wherever possible, road, well pad, and pipeline construction can be located to avoid *A. proximus* populations. It is important to combine the monitoring and control of construction activities and off-road vehicle travel with practices that prevent the spread of weeds into *A. proximus* populations. These practices might include public educational outreach about the invasive species problem, periodic monitoring of areas most at risk for 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, it is best to use control methods that will not negatively impact *A. proximus* individuals growing in the area.

Tools available to the USFS for conservation of *Astragalus proximus* in Region 2 include continued listing of *A. proximus* as a sensitive species, regulating the use of NFS lands where *A. proximus* occurs, and increasing the protective level of management area designations for *A. proximus* occurrences. In some instances, it may be possible for the USFS to contribute to the conservation of *A. proximus* 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. proximus* material for storage or propagation of off-site populations. Implementation of these and other tools largely depends on the acquisition of better information on known or suspected occurrences.

Seed banking

No seeds or genetic material are currently in storage for *Astragalus proximus* at the National Center for Genetic Resource Preservation (Miller personal communication 2003). It is not among the National Collection of Endangered Plants maintained by the Center for Plant Conservation (Center for Plant Conservation 2002). Since the species is locally common, seeds can be collected and submitted for such storage.

Information Needs

Distribution

At this time, our knowledge regarding the extent of *Astragalus proximus* distribution is accurate only on a broad scale. Within the known distribution, accurate information on the real abundance of the species is needed. It will be difficult to formulate conservation strategies for Region 2 without clarifying this issue. More complete information on the environmental characters influencing the distribution patterns would also be invaluable in formulating management strategies. Finally, the possibility of a Region 2 range extension into Conejos County should be further investigated.

Life cycle, habitat, and population trend

The dynamics of the broad habitat types where *Astragalus proximus* is found are reasonably well documented. However, the specific position of *A. proximus* within these ecological systems is not well understood. Furthermore, although the species has been casually observed in the field for many years by a variety of workers, there are no 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 several populations would greatly clarify the population dynamics of *Astragalus proximus*. In particular, it would be useful to identify the time of germination, germination requirements, life expectancy, seed bank dynamics, and transition probabilities for different lifecycle stages. The development of an elasticity analysis could identify the critical stages of the life cycle and aid in the identification of threats to the persistence of *A. proximus*. Similarly, multi-year census or tracking efforts for some populations would greatly facilitate the quantification of population trends for the species as a whole. The species appears to be sufficiently abundant to allow this type of research without noticeable impact to the population as a whole.

Response to change

The effects of environmental variation on the reproductive rates, dispersal mechanisms, and establishment success of *Astragalus proximus* have not been investigated. The same is true for its relationship with herbivores, pollinators, and exotic species. As a consequence, the effects of both fine- and broad-scale habitat change in response to management or disturbance will be difficult to evaluate. Detailed information on the habitat requirements of *A. proximus* will enable better understanding of the potential effects of disturbance and management actions in these habitats. In particular, investigation of the response of the species to soil disturbances produced by well pad and road construction would be beneficial. 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. proximus* is also needed. The effects of grazing on the habitat and pollination ecology of *A. proximus* are also of interest.

Metapopulation dynamics

The apparent tendency of *Astragalus proximus* to occur in scattered, small populations and for some populations 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. proximus*. It would be most useful for baseline studies 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. proximus* persisting at either the local or regional scale.

Demography

As with metapopulation dynamics, current demographic information is also not sufficient to enable a good analysis of the persistence of *Astragalus proximus* at either the local or regional scale. The most useful demographic information would include: 1) the determination of whether individual and population numbers are increasing, decreasing, or stable; 2) the identification of which life cycle stages have the greatest influence on population trends; and 3) the determination of what biological factors influence 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. proximus*. Collection of useful demographic data will require the investment of two to three years at a minimum, ideally more. While providing useful data, short-term studies can miss important demographic events that reoccur 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 proximus*. Pilot studies may be required to adapt some methods to the particular growth and distribution patterns of *A. proximus*. Please see the Population monitoring section under Tools and practices above for details.

Restoration methods

Restoration methods have not been explicitly developed for this species. Existing reclamation and restoration guidelines for resource extraction activities such as mines and well drilling do not have specific provisions for the restoration of *Astragalus proximus* populations. The prevalence of such activities in the species' range and indications that *A. proximus* does not easily recolonize disturbed areas make this a priority topic for further research.

Research priorities for Region 2

Research priorities for *Astragalus proximus* are, in order of priority, population inventory, identification of critical habitat factors, population monitoring at a level sufficient to detect trends, restoration methods, pollination dynamics and possible impacts on pollinators, demographic studies sufficient to perform elasticity analyses, and quantification of the effects of land management practices on the survival and persistence of the species.

Additional research and data resources

Some additional information on population locations and habitats may be available from herbarium specimens not consulted for this document, especially at the Range Science Herbarium, Animal and Range Sciences Department of New Mexico State University. 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).

Alluvium – sediments deposited by erosional processes, usually by streams.

Botanical surveys – surveys that try to determine which species are present in an area – but do not rigorously determine absence.

Catabolize – the process of subjecting to catabolism, the metabolic breakdown of large molecules in living organisms, with accompanying release of energy.

Caudex – the persistent, often woody base of an herbaceous perennial (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).

Conglomerate – a coarse-grained sedimentary rock composed of rounded fragments of pebbles, cobbles, or boulders.

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

Glabrous – smooth, without hairs.

Local endemic – restricted to a small geographic region. Although the term local endemic is not strictly defined in botanical literature, it is generally taken to mean that the range is small in comparison with that of other plants.

Monocarpic – a plant that dies after flowering, although it may take several years to flower. Synonymous with semelparous (Silvertown and Lovett Doust 1993).

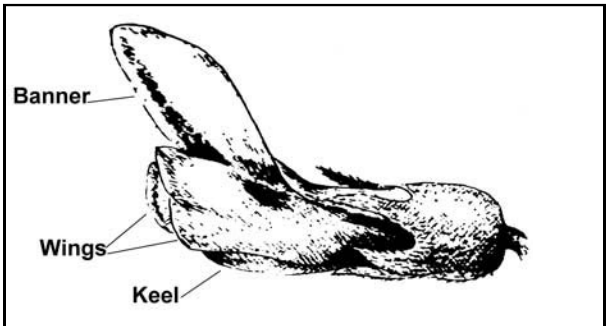
Monoecious – a plant that bears male and female reproductive structures in the same flower, or separate male and female flowers on the same plant (Allaby 1998).

Oblanceolate – reversely lanceolate, long and narrow, but broadest at the tip instead of the base (Weber and Wittmann 2001).

Occurrence – see Population.

Orthophoto – an aerial photograph that has been rectified into a uniform-scale image. An orthophoto may serve as a base map onto which other map information may be overlaid.

Papilionaceous – of flowers, butterflylike, with a banner petal, two wing petals, and two (fused) keel petals (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).

Photo point – refers to the direction of a photograph from a specified camera location. Multiple photo points may be taken from the same camera location (Hall 2001).

Population – as used in this assessment, discrete groups of *Astragalus proximus* individuals that are separated from the next nearest known group of *A. proximus* individuals by at least 1 km (0.62 miles) and is the same as occurrence as used in this assessment.

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.

Seleniferous – referring to soil or ore containing selenium.

Stipitate – borne on a stipe or stalk (Harris and Harris 1994).

Stipules – a pair of leaf-like appendages at the base of the leaf stalk in some leaves (Harris and Harris 1994).

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

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

Xerophytic – adapted to growing in very arid conditions.

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).

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Appendix A

Ecological Systems Descriptions

From NatureServe 2003b (literature citations are included at the end of this appendix).

Rocky Mountain Ponderosa Pine Woodland – matrix

This very widespread ecological system is most common throughout the cordillera of the Rocky Mountains. It is also found in the Colorado Plateau region, west into scattered locations in the Great Basin, and north into southern British Columbia. These woodlands occur at the lower treeline/ecotone between grassland or shrubland and more mesic coniferous forests typically in warm, dry, exposed sites. Elevations range from less than 500 m in British Columbia to 2800 m in the New Mexico mountains. Occurrences are found on all slopes and aspects, however, moderately steep to very steep slopes or ridgetops are most common. This ecological system generally occurs on igneous, metamorphic, and sedimentary material derived soils, with characteristic features of good aeration and drainage, coarse textures, circumneutral to slightly acid pH, an abundance of mineral material, rockiness, and periods of drought during the growing season. These woodlands in the eastern Cascades, Okanagan and northern Rockies regions receive winter and spring rains, and thus have a greater spring "green-up" than the drier woodlands in the central Rockies. *Pinus ponderosa* is the predominant conifer; *Pseudotsuga menziesii*, *Pinus edulis*, and *Juniperus* spp. may be present in the tree canopy. The understory is usually shrubby, with *Artemisia nova*, *A. tridentata*, *Arctostaphylos patula*, *A. uva-ursi*, *Cercocarpus montanus*, *C. ledifolius*, *Purshia stansburiana*, *P. tridentata*, *Quercus gambelii*, *Symphoricarpos oreophilus*, *Prunus virginiana*, *Amelanchier alnifolia*, and *Rosa* spp. common species. *Pseudoroegneria spicata* and species of *Hesperostipa*, *Achnatherum*, *Festuca*, *Muhlenbergia*, and *Bouteloua* are some of the common grasses. Mixed fire regimes and ground fires of variable return interval maintain these woodlands, depending on climate, degree of soil development, and understory density.

Environment: This ecological system within the region occurs at the lower treeline/ecotone between grassland or shrubland and more mesic coniferous forests typically in warm, dry, exposed sites at elevations ranging from 1,980 to 2,800 m (6,500 to 9,200 ft.). It can occur on all slopes and aspects; however, it commonly occurs on moderately steep to very steep slopes or ridgetops. This ecological system generally occurs on igneous, metamorphic, and sedimentary material derived soils, including basalt, basaltic, andesitic flows, intrusive granitoids and porphyrites, and tuffs (Youngblood and Mauk 1985). Characteristic soil features include good aeration and drainage, coarse textures, circumneutral to slightly acid pH, an abundance of mineral material, and periods of drought during the growing season. Some occurrences may occur as edaphic climax communities on very skeletal, infertile, and/or excessively drained soils, such as pumice, cinder or lava fields, and scree slopes.

Surface textures are highly variable in this ecological system ranging from sand to loam and silt loam. Exposed rock and bare soil consistently occur to some degree in all the associations. *Pinus ponderosa* / *Arctostaphylos patula* represents the extreme with typically a high percentage of rock and bare soil present.

Precipitation generally contributes 25 to 60 cm annually to this system, mostly through winter storms and some monsoonal summer rains. Typically a seasonal drought period occurs throughout this system as well. Fire plays an important role in maintaining the characteristics of these open canopy woodlands. However, soil infertility and drought may contribute significantly in some areas as well.

Dynamics: *Pinus ponderosa* is a drought-resistant, shade-intolerant conifer which usually occurs at lower treeline in the major ranges of the western United States. Historically, ground fires and drought were influential in maintaining open-canopy conditions in these woodlands. With settlement and subsequent fire suppression, occurrences have become denser. Presently, many occurrences contain understories of more shade-tolerant species, such as *Pseudotsuga menziesii* and/or *Abies* spp., as well as younger cohorts of *Pinus ponderosa*. These altered occurrence structures have affected fuel loads and alter fire regimes. Pre-settlement fire regimes were primarily frequent (5 to 15 year return intervals), low-intensity ground fires triggered by lightning strikes or deliberately set fires by Native Americans. With fire suppression and increased fuel loads, fire regimes are now less frequent and often become intense crown fires, which can kill mature *Pinus ponderosa* (Reid et al. 1999).

Establishment is erratic and believed to be linked to periods of adequate soil moisture and good seed crops as well as fire frequencies, which allow seedlings to reach sapling size. Longer fire-return intervals have resulted in many occurrences having dense subcanopies of overstocked and unhealthy young *Pinus ponderosa* (Reid et al. 1999).

Mehl (1992) states the following: "Where fire has been present, occurrences will be climax and contain groups of large, old trees with little understory vegetation or down woody material and few occurring dead trees. The age difference of the groups of trees would be large. Where fire is less frequent there will also be smaller size trees in the understory giving the occurrence some structure with various canopy layers. Dead, down material will be present in varying amounts along with some occurring dead trees. In both cases the large old trees will have irregular open, large branched crowns. The bark will be lighter in color, almost yellow, thick and some will like have basal fire scars."

Grace's warbler (*Dendroica graciae*), Pygmy nuthatch (*Sitta pygmaea*), and flammulated owl (*Otus flammeolus*) are indicators of a healthy ponderosa pine woodland. All of these birds prefer mature trees in an open woodland setting (Jones 1998, Levad 1998, Winn 1998 as cited in Rondeau 2001).

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Colorado Plateau Pinyon-Juniper Woodland - matrix

This ecological system occurs on dry mountains and foothills of the Colorado Plateau region from the Western Slope of Colorado to the Wasatch Range, south to the Mogollon Rim. It is typically found at lower elevations ranging from 1,500 to 2,440 m. These woodlands occur 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 osteosperma* dominate the tree canopy. *Juniperus scopulorum* may co-dominate or replace *J. monosperma* at higher elevations. Understory layers are variable and may be dominated by shrubs, graminoids, or be absent. Associated species include *Arctostaphylos patula*, *Artemisia tridentata*, *Cercocarpus intricatus*, *C. montanus*, *Coleogyne ramosissima*, *Purshia stansburiana*, *P. tridentata*, *Quercus gambelii*, *Bouteloua gracilis*, *Pleuraphis jamesii*, or *Poa fendleriana*. This system occurs at higher elevations than Great Basin Pinyon-Juniper Woodland and Colorado Plateau shrubland systems where sympatric.

Inter-Mountain Basins Semi-Desert Shrub-Steppe – large patch

This ecological system occurs throughout the Intermountain West, typically at lower elevations on alluvial fans and flats with moderate to deep soils. This semi-arid shrub-steppe is typically dominated by graminoids (greater than 25 percent cover) with an open shrub layer. Characteristic grasses include *Achnatherum hymenoides*, *Bouteloua gracilis*, *Distichlis spicata*, *Hesperostipa comata*, *Pleuraphis jamesii*, *Poa secunda*, and *Sporobolus airoides*. The woody layer is often a mixture of shrubs and dwarf-shrubs. Characteristic species include *Atriplex canescens*, *Artemisia tridentata*, *Chrysothamnus greenei*, *C. viscidiflorus*, *Ephedra* spp., *Ericameria nauseosa*, *Gutierrezia sarothrae*, and *Krascheninnikovia lanata*. The general aspect of occurrences may be either open shrubland with patchy grasses or patchy open herbaceous layer. Disturbance may be important in maintaining the woody component. Microphytic crust is very important in some occurrences.

Environment: This ecological system occurs throughout the Intermountain West from the western Great Basin to the northern Rocky Mountains and Colorado Plateau at elevations ranging from 300 m up to 2500 m. The climate where this system occurs is generally hot in summers and cold in winters with low annual precipitation, ranging from 18 to 40 cm and high inter-annual variation. Much of the precipitation falls as snow, and growing-season drought is characteristic. Temperatures are continental with large annual and diurnal variation. Sites are generally alluvial fans and flats with moderate to deep soils. Some sites can be flat, poorly drained and intermittently flooded with a shallow or perched water table often within 1 m depth (West 1983). Substrates are generally shallow, calcareous, fine-textured soils (clays to silt-loams), derived from alluvium; or deep, fine to medium-textured alluvial soils with some source of sub-irrigation during the summer season. Soils may be alkaline and typically moderately saline (West 1983). Some occurrences occur on deep, sandy soils, or soils that are highly calcareous (Hironaka et al. 1983).

Vegetation: The plant associations in this system are characterized by a somewhat sparse to moderately dense (10 to 70 percent cover) shrub layer of *Artemisia tridentata* ssp. *tridentata*, *Ericameria nauseosa*, *Chrysothamnus viscidiflorus*, *Gutierrezia sarothrae*, *Sarcobatus vermiculatus*, or *Atriplex canescens*. Other shrubs occasionally present include *Purshia tridentata*, *Ephedra viridis*, and *Tetradymia canescens*. Trees are very rarely present in this system, but some individuals of *Pinus ponderosa*, *Juniperus scopulorum*, *Juniperus occidentalis*, or *Cercocarpus ledifolius* may occur. The herbaceous layer is dominated by bunch grasses which occupy patches in the shrub matrix. The most widespread species is *Pseudoroegneria spicata*, which occurs from the Columbia Basin to the northern Rockies. Other locally dominant or important species include *Sporobolus airoides*, *Leymus cinereus*, *Festuca idahoensis*, *Pascopyrum smithii*, *Bouteloua gracilis*, *Distichlis spicata*, *Hesperostipa comata*, *Pleuraphis jamesii*, *Elymus lanceolatus*, *E. elymoides*, *Pleuraphis jamesii*, *Koeleria macrantha*, *Muhlenbergia richardsonis*, *Hesperostipa comata*, and *Poa secunda*. Annual grasses, especially the exotics *Bromus japonicus* and *Bromus tectorum*, may be present to abundant. Forbs are generally of low importance and are highly variable across the range, but they may be diverse in some occurrences. Species that often occur are *Symphyotrichum ascendens* (= *Aster adscendens*), *Collinsia parviflora*, *Penstemon caespitosus*, *Achillea millefolium*, *Erigeron compositus*, *Senecio* spp., and *Taraxacum officinale*. Other important genera include *Astragalus*, *Oenothera*, *Eriogonum*, and *Balsamorhiza*. Mosses and lichens may be important ground cover. Forbs are common on disturbed weedy sites. Weedy annual forbs may include the exotics *Descurainia* spp., *Helianthus annuus*, *Halogeton glomeratus*, *Lactuca serriola*, and *Lepidium perfoliatum*.

Hironaka, M., M.A. Fosberg, and A.H. Winward. 1983. Sagebrush-grass habitat types of southern Idaho. Forestry, Wildlife, and Range Experiment Station Bulletin No. 15, University of Idaho, Moscow, ID. 44 pp.

West, N.E. 1983. Western Intermountain sagebrush steppe. Pages 351-374 in: N.E. West, editor. Temperate deserts and semi-deserts. Ecosystems of the world, Volume 5. Elsevier Publishing Company, Amsterdam.

Rocky Mountain Gambel Oak-Mixed Montane Shrubland – large patch

This ecological system occurs in the mountains, plateaus, and foothills in the southern Rocky Mountains and Colorado Plateau including the Uinta and Wasatch ranges and the Mogollon Rim. These shrublands are most commonly found along dry foothills, lower mountain slopes, and at the edge of the western Great Plains from approximately 2,000 to 2,900 m in elevation. They are often situated above pinyon-juniper woodlands. Substrates are variable and include soil types ranging from calcareous, heavy, fine-grained loams to sandy loams, gravelly loams, clay loams, deep alluvial sand, or coarse gravel. The vegetation is typically dominated by *Quercus gambelii* alone or co-dominant with *Amelanchier alnifolia*, *A. utahensis*, *Artemisia tridentata*, *Cercocarpus montanus*, *Prunus virginiana*, *Purshia stansburiana*, *P. tridentata*, *Robinia neomexicana*, *Symphoricarpos oreophilus*, or *S. rotundifolius*. There may be inclusions of other mesic montane shrublands with *Q. gambelii* absent or as a relatively minor component. This ecological system intergrades with the lower montane-foothills shrubland system and shares many of the same site characteristics. Density and cover of *Q. gambelii* and *Amelanchier* spp. often increase after fire.

Environment: This ecological system typically occupies the lower slope positions of the foothill and lower montane zones. They may occur on level to steep slopes, cliffs, escarpments, rimrock slopes, rocky outcrops, and scree slopes. Climate is semi-arid and characterized by mostly hot-dry summers with mild to cold winters and annual precipitation of 25 to 70 cm. Precipitation mostly occurs as winter snows but may also consist of some late summer rains. Soils are typically poorly developed, rocky to very rocky, and well-drained. Parent materials include alluvium, colluvium, and residuum derived from igneous, metamorphic, or sedimentary rocks such as granite, gneiss, limestone, quartz, monzonite, rhyolite, sandstone, schist, and shale. Although this is a shrub-dominated system, some trees may be present. In older occurrences, or occurrences on mesic sites, some of the shrubs may acquire tree-like sizes. Adjacent communities often include woodlands or forests of *Abies concolor*, *Pinus ponderosa*, *Pseudotsuga menziesii*, or *Populus tremuloides* at higher elevations, and *Pinus edulis* and *Juniperus osteosperma* on the lower and adjacent elevations. Shrublands of *Artemisia tridentata* or grasslands of *Festuca* sp., *Stipa* sp., or *Pseudoroegneria* sp. may also be present at the lower elevations.

Vegetation: Vegetation types in this system may occur as sparse to dense shrublands composed of moderate to tall shrubs. Occurrences may be multi-layered, with some short shrubby species occurring in the understory of the dominant overstory species. In many occurrences of this system, the canopy is dominated by the broad-leaved deciduous shrub *Quercus gambelii*, which occasionally reaches small tree size. Occurrences can range from dense thickets with little understory to relatively mesic mixed-shrublands with a rich understory of shrubs, grasses and forbs. These shrubs often have a patchy distribution with grass growing in between. Scattered trees are occasionally present in stands and typically include species of *Pinus* or *Juniperus*. Characteristic shrubs that may co-occur, or be singularly dominant, include *Amelanchier alnifolia*, *A. utahensis*, *Arctostaphylos patula*, *Artemisia tridentata*, *Cercocarpus montanus*, *Ptelea trifoliata*, *Prunus virginiana*, *Purshia stansburiana*, *Robinia neomexicana*, *Rosa* spp., *Symphoricarpos oreophilus*, and *S. rotundifolius*. The herbaceous layer is sparse to moderately dense, ranging from 1 to 40 percent cover. Perennial graminoids are the most abundant species, particularly *Aristida* spp., *Bouteloua curtipendula*, *B. eriopoda*, *B. gracilis*, *Carex inops*, *C. geyeri*, *Elymus arizonicus*, *Eragrostis* spp., *Festuca* spp., *Koeleria macrantha*, *Muhlenbergia* spp., and *Stipa* spp. Many forb and fern species can occur, but none have much cover. Commonly present forbs include *Achillea millefolium*, *Artemisia* spp., *Geranium* spp., *Maianthemum stellatum*, *Thalictrum fendleri*, and *Vicia americana*. Ferns include species of *Cheilanthes* and *Woodsia*. Annual grasses and forbs are seasonally present, and weedy annuals are often present, at least seasonally.

Dynamics: Fire typically plays an important role in this system, causing die-back of the dominant shrub species in some areas, promoting stump sprouting of the dominant shrubs in other areas, and controlling the invasion of trees into the shrubland system. Natural fires typically result in a system with a mosaic of dense shrub clusters and openings dominated by herbaceous species. In some instances, these associations may be seral to the adjacent *Pinus ponderosa*, *Abies concolor*, and *Pseudotsuga menziesii* woodlands and forests. Ream (1964) noted that on many sites in Utah, Gambel oak may be successional and replaced by bigtooth maple (*Acer grandidentatum*).

Ream, R.R. 1964. The vegetation of the Wasatch Mountains, Utah and Idaho. Unpublished Ph.D. dissertation, University of Wisconsin, Madison, WI. 190 pp.

Appendix B

Guidelines for Biological Inventories

Adapted from National Park Service 1999.

<u>Step 1:</u> Compile and Verify Historical and Predicted Species Data

There is often already some information available on a particular species, but it is usually stored in numerous locations and formats such that it is not readily accessible to land managers, interpreters, scientists, and the public. Also, much of the existing information needs to be evaluated for its accuracy and consistency before it can be relied upon for making management decisions. Field investigations to obtain comprehensive distribution and abundance information for a particular species of vascular plant often would be prohibitively expensive, and for many species the level of information that is already available from past field studies, museum and herbarium collections, regional field guides, and other observation records are adequate for most uses if the information can be compiled, verified, and made available in a useable format. The first step in conducting biological inventories is to compile and organize existing information of what is known from the area of interest, and to use this information to identify gaps that can be filled by targeted field investigations.

<u>Step 2:</u> Identify Specific Objectives

This step should determine the level of information needed for a species given funding and personnel constraints, and identify the species of special concern for which more intensive field investigations are needed to determine their distribution and relative abundance. Different degrees of inventory intensity will result in four basic levels of information: (1) presence/absence; (2) abundance categories; (3) relative abundance; and (4) absolute abundance.

Presence/absence information is often associated with habitat information, and can be used to determine species richness for each habitat as well as to develop distribution maps. For many species, it is possible with little additional field investigation to assign an abundance category to each species for each habitat, such as abundant, common, or rare, rather than just documenting species occurrence. Whenever possible, it is better to attempt some quantitative approach to estimating abundance and to summarize these numerical estimates into abundance categories such as common or rare, than to initially collect the data in loosely-defined abundance categories. For species of special concern, a well-designed field inventory using methods such as multi-scale plots may be needed to provide the level of information needed.

These objectives, in combination with the habitats delineated in Step 3 will determine the level of inventory intensity required. Whenever possible, inventories for more than one species should be combined for cost effectiveness.

<u>Step 3:</u> Habitat Delineation

Geographic Information System (GIS) technology has proven to be a powerful and useful tool for organizing, displaying, analyzing, and integrating natural resource information, and is routinely used by many land management agencies. Habitat delineation will usually involve bringing together all of the relevant GIS themes (e.g., soil, geology, topography), aerial photographs, and other existing information needed to develop a basic habitat cover map that shows the appropriate habitat types for the taxa to be inventoried. Management issues (e.g., fire management zones) and administrative boundaries should also be considered in this step.

<u>Step 4:</u> Sampling Strategy, Sampling Frame and Sample Selection

Based on information from Steps 1-3, determine the appropriate habitats, season, and protocols to be used in conducting the inventory for the species requiring field investigations. The inventory design must take into consideration both spatial (habitat) and temporal (season and time of day) factors. The design must also indicate which habitat variables will be collected in association with the inventories, keeping in mind that variables for which GIS themes exist or can be created will be most useful for future modeling and analysis.

Using the habitat cover map developed in Step 3, develop a sampling frame by identifying all potential search plots or paths and those selected to be sampled. In accessible areas with relative homogenous habitat, a systematic grid with a random start should be considered. If there are distinctly different habitat types, habitat stratification should be considered, with separate samples taken in each major habitat type. For species with very specialized habitat requirements and a spotty distribution, potential plots may be limited to patches of appropriate habitat. In each case, include a random component in selecting which sample units are to be sampled and collect independent samples so that statistical inferences can be made to the entire habitat or area. Keep in mind that systematic grids and random sampling in proportion to the area of each stratum tend to capture common species, and that multi-scale plots for vegetation and specialized searches of rare habitats and species may be required depending on the objectives. In mountainous terrain, there may be only a few paths where it is possible to climb. In such situations, identify a relatively large number of feasible sample plots or paths and then randomly select those to be inventoried.

<u>Step 5:</u> Field Survey

Sample the randomly selected plots or transects for the species of interest, recording habitat information at each sampling location. Use methods that are compatible with other well-established local, regional, or national inventory or monitoring efforts wherever possible to increase the comparability and interpretability of the data. Surveys should be conducted by trained professionals who are familiar with the taxa in question.

<u>Step 6:</u> Data Analysis and Evaluation / Database Development and Reporting

Conduct preliminary analyses of the data to determine if and where additional sampling is needed. For species for which only presence/absence or abundance category information is needed, develop GIS themes based on the habitats delineated in Step 3. For species targeted for field sampling, use the habitat information collected at locations where a species was found in analyses such as discriminant function or logistic regression analysis to develop predictive models of species occurrence that can be extrapolated to the appropriate habitats. For each species of special concern, use these models with appropriate GIS themes to produce a “probable distribution map”, indicating areas of the park where the species is likely to occur. For species requiring relative abundance information, analyze the results and develop GIS themes describing relative abundance in different habitat types and seasons, including links to tables that summarize mean values and their standard errors. A report should be prepared that summarizes the results of the inventory and documents key decisions in the process, such as objectives, habitat delineation, and the sampling frame and layout of sampling plots or transects. Results should be easily available to land managers, researchers, and the public, and should describe the work in enough detail that another person could conduct the inventory based on the written report and associated GIS products.