Mentzelia chrysantha Engelmann ex Brandegee (golden blazing star): A Technical Conservation Assessment

Prepared for the USDA Forest Service, Rocky Mountain Region, Species Conservation Project

July 3, 2006

David G. Anderson
Colorado Natural Heritage Program
Colorado State University
Fort Collins, CO

Peer Review Administered by
Society for Conservation Biology

Anderson, D.G. (2006, July 3). *Mentzelia chrysantha* Engelmann ex Brandegee (golden blazing star): a technical conservation assessment. [Online]. USDA Forest Service, Rocky Mountain Region. Available: http://www.fs.fed.us/r2/projects/scp/assessments/mentzeliachrysantha.pdf [date of access].

ACKNOWLEDGMENTS

This research was facilitated by the helpfulness and generosity of many experts, particularly Janet Coles, Tass Kelso, Erik Brekke, Susan Spackman Panjabi, Patricia Holmgren, and Jerry Powell. Their insights into the distribution, habitat, taxonomy, and ecology of *Mentzelia chrysantha* were crucial to completing this assessment. Thanks to Beth Burkhart, Greg Hayward, Andy Kratz, Jim Maxwell, Nancy Warren, Gary Patton, and Joy Bartlett for assisting with questions and project management. Thanks to Kimberly Nguyen for the work on the layout and for bringing this assessment to Web publication. Janet Coles, Tass Kelso, and Susan Spackman Panjabi were very generous with their time and provided information and expertise. Susan Spackman Panjabi also helped to acquire and locate specimen label data. Annette Miller provided information for the report on seed storage status. Jerry Powell offered insights into the management of *M. chrysantha* in highway right-of-ways. Karin Decker offered advice and technical expertise on map production. Nan Lederer and Tim Hogan provided valuable assistance at the University of Colorado Herbarium. Tara Santi and Sabrina Chartier assisted with literature acquisition. The help of Colorado Natural Heritage Program staff (Georgia Doyle, Michael Menefee, Ron Abbott, and Jill Handwerk) who reviewed parts of the first draft of this assessment and offered input is gratefully acknowledged. Thanks to my family (Jen, Cleome, Melia) for their support.

AUTHOR'S BIOGRAPHY

David G. Anderson is a botanist with the Colorado Natural Heritage Program (CNHP). Mr. Anderson's work at CNHP includes inventory, mapping, and monitoring of rare plants and noxious weeds throughout Colorado, maintaining and updating CNHP's database, and writing reports on the rare plants of Colorado. He has worked with CNHP since 1999. Much of Mr. Anderson's prior experience comes from five years of fieldwork studying the flora and ecosystem processes of the Alaskan and Canadian Arctic. Mr. Anderson also served in the Peace Corps as a science teacher in the Solomon Islands from 1996 to 1998. Mr. Anderson received his B.A. in Environmental, Populational, and Organismic Biology from the University of Colorado, Boulder (1991) and his M.S. in Botany from the University of Washington, Seattle (1996).

COVER PHOTO CREDIT

*Mentzelia chrysantha (*golden blazing star). Photograph by Janet Coles, used with permission.

In every state in the Union, plants of great esthetic and scientific value are becoming rare by reason of the same accidental changes in environment as are responsible for the depletion of animal wildlife.

…No species can persist whose environment is no longer habitable. The next move is to examine each threatened species, to analyze its requirements for reproduction and survival, to build out of this knowledge a technique of conservation, and to bring this technique to the attention of landowners who can apply it. Wildflower conservation can…be spread so that it covers more than a few microscopic public reservations. It can be made to become a normal accompaniment of civilized agriculture.

Aldo Leopold (1936)

SUMMARY OF KEY COMPONENTS FOR CONSERVATION OF *MENTZELIA CHRYSANTHA*

Status

Mentzelia chrysantha Engelmann ex Brandegee (golden blazing star) is a narrow endemic whose global distribution is limited to the Arkansas River Valley in Fremont and Pueblo counties, Colorado. It is known from 28 occurrences along 40 miles of the Arkansas River in the vicinity of Cañon City and Pueblo. The total population of *M. chrysantha* is approximately 5,400 plants. It is ranked imperiled (G2S2) by NatureServe and the Colorado Natural Heritage Program. *Mentzelia chrysantha* is included on the Bureau of Land Management (BLM) Colorado State Sensitive Species List for the Royal Gorge Field Office, but the USDA Forest Service does not list it as a sensitive species. It is not listed as threatened or endangered under the Federal Endangered Species Act although it was at one time a Category 2 candidate for listing.

Primary Threats

Observations and quantitative data suggest several threats to the persistence of *Mentzelia chrysantha*. In order of decreasing priority, these threats are residential and commercial development, mining, recreation, right-of-way management, exotic species invasion, grazing, effects of small population size, climate change, and pollution. Fremont County is among the fastest growing counties in the United States, and low-density development is proceeding rapidly throughout the Arkansas Valley. Many of the known occurrences are located in highway right-of-ways where they are at risk from weed invasion and management.

Primary Conservation Elements, Management Implications and Considerations

Mentzelia chrysantha has not been documented on National Forest System land. Although one occurrence is documented within 1 mile of the San Isabel National Forest boundary, it is unlikely that *M. chrysantha* occurs within the forest because the geologic substrate is unsuitable. Nonetheless, searches of this area are needed to make a determination. Two areas on the San Isabel National Forest (one at the northern extent of the Wet Mountains, the other southeast of the town of Gardiner) are the highest priority areas for surveys on National Forest System land.

Five (possibly six) occurrences are located all or in part on land managed by the BLM, where they benefit from some protection due to its status as a BLM sensitive species. Two occurrences are within the Garden Park Area of Critical Environmental Concern (ACEC) where they benefit from management intended to protect cultural and paleontological resources within the ACEC. However, all occurrences are threatened to varying degrees by off-highway vehicle use, mountain biking, and the indirect effects of grazing. Occurrences at Pueblo Reservoir in Pueblo State Park are protected from residential development and mining, but the park does not manage specifically to protect this plant. Measures to protect occurrences in right-of-ways along state and federal highways were implemented in 2004. Much of the known population is found on private land where it is threatened by residential development, mining, and grazing.

Pursuing conservation easements on private land is a highly effective approach to conserving *Mentzelia chrysantha*. Species inventories are needed to understand the distribution and abundance of *M. chrysantha*. Research is needed to investigate the taxonomic relationships, population biology, and autecology of *M. chrysantha*, to ensure that conservation efforts on its behalf are effective.

TABLE OF CONTENTS

EDITORS: Janet Coles and Beth Burkhart, USDA Forest Service, Rocky Mountain Region

LIST OF TABLES AND FIGURES

Tables:

Figures:

INTRODUCTION

This assessment is one of many being produced to support the Species Conservation Project for the Rocky Mountain Region (Region 2) of the USDA Forest Service (USFS). *Mentzelia chrysantha* (golden blazing star) is the focus of an assessment because of its high degree of rarity and endemism, and because of concern for its viability. While it is not considered a sensitive species by the USFS, it is a management concern for the USFS because of the proximity of occurrences to National Forest System land. It is considered a sensitive species by the Bureau of Land Management's (BLM) Royal Gorge Field Office.

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

Goal of Assessment

Species conservation assessments produced as part of the Species Conservation Project are designed to provide forest managers, research biologists, and the public 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. Rather, it provides the ecological backgrounds upon which management must be based and focuses on the consequences of changes in the environment that result from management (i.e., management implications). Furthermore, it cites management recommendations proposed elsewhere and examines the success of those recommendations that have been implemented.

Scope of Assessment

This assessment examines the biology, ecology, conservation status, and management of *Mentzelia chrysantha* with specific reference to the geographic and ecological characteristics of Region 2. Because basic research has not been conducted on many facets of the biology of this species, literature on several of its congeners was used to make inferences. Although much of the literature on this species originates from field investigations of congeners outside the region, this document places that literature in the ecological and social context of the central Rocky Mountains. Similarly, this assessment is concerned with reproductive behavior, population dynamics, and other characteristics of *M. chrysantha* 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. All known publications, reports, and element occurrence records on *Mentzelia chrysantha* are referenced in this assessment, and most of the experts on this species were consulted during its synthesis. All known specimens of *M. chrysantha* were viewed to verify occurrences and to incorporate specimen label data. Specimens were searched for at University of Colorado Herbarium (COLO), Colorado State University Herbarium (CS), Rocky Mountain Herbarium (RM), San Juan College Herbarium (SJMC), University of Northern Colorado Herbarium (GREE), Kalmbach Herbarium, Denver Botanic Gardens (KHD), New Mexico State University Range Science Herbarium (NMCR), and University of New Mexico Herbarium (UNM). This assessment emphasizes refereed literature, but non-refereed publications, personal communications, and reports were used when additional information was unavailable elsewhere. Unpublished data (e.g., Natural Heritage Program records) were important in estimating the geographic distribution of this species. While these data contain the vast majority of the useful information known on *M. chrysantha*, they required special attention because of the diversity of persons and methods used in collection.

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

Our knowledge of *Mentzelia chrysantha* is sparse and incomplete; there apparently have been no studies of its autecology. Existing information is mostly from herbarium labels, field surveys, and anecdotal observations. The paucity of information for *M. chrysantha* forced the author to rely heavily on personal communications with botanists that have had experience with the species, and to draw inferences from other members of the genus *Mentzelia* where possible.

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

Peer Review of This Document

Assessments developed for the Species Conservation Process have been peer reviewed before their release on the Web. This assessment was reviewed by Colorado Natural Heritage Program (CNHP) staff before submission for peer review. Peer review for this species assessment was administered by the Society for Conservation Biology. At least two anonymous reviewers provided comments that were synthesized by USFS project partners. 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

Mentzelia chrysantha is not a sensitive species in Region 2 (USDA Forest Service 2003a). Its merits as a possible sensitive species were evaluated in 2002 (McKee 2002), but it was determined that it did not warrant sensitive species status because it does not occur, nor is it likely to occur, on National Forest System land (Proctor no date). *Mentzelia chrysantha* is included on the BLM Colorado State Sensitive Species List for the Royal Gorge Field Office (Bureau of Land Management 2000), and it is cited as a "species of concern in the Great Plains of North America" (USDA Forest Service 2003b). *Mentzelia chrysantha* has no status under the Endangered Species Act of 1973 (U.S.C. 1531-1536, 1538-1540). In 1992 it was recommended for Category 2 (C2) status (Jordan 1992) but was never formally listed nor proposed for listing. *Mentzelia chrysantha* does not have any status with the International Union for Conservation of Nature and Natural Resources (Ayensu and DeFilipps 1978).

NatureServe (2006) considers *Mentzelia chrysantha* to be globally imperiled (G2). Because it is only found in Colorado, it is also considered imperiled (S2) by the CNHP (Colorado Natural Heritage Program 2006). It is considered imperiled because it is known from only 28 occurrences worldwide, and many of these consist of small numbers of individuals. Four occurrences have not been seen in more than 20 years.

Existing Regulatory Mechanisms, Management Plans, and Conservation Strategies

No conservation plans have been drafted that specifically address the conservation needs of *Mentzelia chrysantha* (Grunau et al. 2003). Species designated as sensitive by the BLM are provided, at a minimum, the level of protection given federal candidates for listing under the Endangered Species Act (Bureau of Land Management 2001). This species occurs in the BLM's Garden Park Area of Critical Environmental Concern (ACEC), where it benefits from special management intended to prevent damage to the area's cultural and natural resources. Concern for the invasion of ACECs by noxious weeds resulted in preliminary research on the impacts of non-native species on *M. chrysantha* at the Garden Park ACEC (Anderson et al. 2001).

The Colorado Natural Heritage Program has developed Potential Conservation Areas (PCAs) to facilitate awareness of this species and its habitat during management planning. PCAs are an estimate of the primary area supporting the long-term survival of targeted species and plant communities, based on an assessment of the biotic and abiotic factors affecting the persistence and population viability of the targets with the area. The CNHP supplied these estimates to Pueblo

County (Spackman Panjabi et al. 2003), the BLM (Anderson et al. 2001), and the U.S. Fish and Wildlife Service and the Colorado Department of Transportation (Grunau et al. 2003) The Nature Conservancy lists *Mentzelia chrysantha* as a conservation target in the Central Shortgrass Prairie Ecoregion (The Nature Conservancy 1998, The Nature Conservancy 2005).

Grunau et al. (2003) developed best management practices to be implemented in occurrences of *Mentzelia chrysantha* that are located within right-of-way boundaries (**Table 1**). These practices include provisions for erosion mitigation, adjusting the mowing regime to phenologically appropriate times, re-seeding disturbed areas with native site-appropriate species, and avoiding habitat destruction to the extent practicable.

Adequacy of current laws and regulations

Mentzelia chrysantha has no legal protection that would prevent the destruction of its habitat or individuals. Because it is included on the Sensitive Species List for the Royal Gorge Field Office, BLM planners must give consideration to this species in order to maintain the species within its habitat. However, only three occurrences of *M. chrysantha* are known from BLM land.

Occurrences in highway right-of-ways and on private land make up the majority of the known occurrences of *Mentzelia chrysantha*. Regulatory measures for the management of this species in highway right-of-ways have been drafted by Grunau et al. (2003) and were implemented in 2004 (Smith personal communication 2006). Because there are no laws in place that protect this species on private lands, current laws and regulations protecting this species are inadequate to conserve the species within its native range. Given current human population growth trends and land use plans within the entire global range of this species, future impacts to occurrences of *M. chrysantha* are likely. Although this species tolerates some types of periodic anthropogenic disturbance that allow it to persist in waste places and road cuts, these locations have little conservation value and would not guarantee its long-term viability.

Adequacy of current enforcement of laws and regulations

Current legal protections that apply to *Mentzelia chrysantha* pertain only to occurrences on land owned by the BLM. Thus, there are currently no enforceable laws or regulations that confer any protection to occurrences of this species on private, state, or other federal lands.

Biology and Ecology

Classification and description

Mentzelia chrysantha Engelmann ex Brandegee is a member of the Loasaceae (blazing star family). Although the Loasaceae is a diverse and striking family,

Table 1. Best management practices specific to targeted rare plant species developed by Grunau et al. (2003). These practices were implemented by the Colorado Department of Transportation in 2004.

1.If target plant(s) are present, mowing will be avoided until late in the season (mid- September) if possible. The timing of these efforts is important because flowering does not occur until mid-summer, and therefore, seeds are not fully developed until fall. If mowing cannot wait until autumn (e.g., for safety reasons), spring mowing (prior to June 15) will still allow plants to complete their reproductive life cycle.
2. Re-seeding of disturbed areas will be with a mix of native graminoids and forbs wherever possible. Native mixes shall be specified and/or approved by the Colorado Department of Transportation landscape architect.
3. Herbicide applications will be used only if the herbicide targets monocots but not dicots. If monocot-targeted herbicides are used, timing of application is not an issue.
4. Where road widening results in alteration of the hydrologic regime, efforts will be made to ensure that water flow is not interrupted.
5. While the majority of known occurrences for golden blazing star (*Mentzelia chrysantha*) are in the right-of-way of existing roads, road widening is not expected to occur within 165 ft. of existing populations of this plant. This species does not transplant well. Re-seeding disturbed areas may be a viable alternative, but it is very important not to decimate the original seed source population. This species is not abundant, and seed availability is limited. Seed harvest is restrained so as not to deplete the soil seed bank in remaining populations. Therefore, habitat destruction for this species will be avoided to the maximum extent practicable.

in many respects it is little studied (Weigend 2003). Its members are characterized by an intricate floral morphology, an inferior ovary, and elaborate, sometimes stinging hairs (Heywood 1993). The Loasaceae is one of only four families whose members have stinging hairs, but *Mentzelia* species do not have them (Fahn 1979 in Mauseth 1988). It is a small family, consisting of approximately 292 species in approximately 15 genera. Almost all of its members are found in North and South America, but one genus is found in the Marquesas Islands of Polynesia and another (*Kissenia*), represented by only two species, is found in Africa and Arabia (Heywood 1993, Weigend 2003). The Loasaceae have been noted for their biochemistry, as they produce a class of phytochemicals called iridoids. Many iridoid compounds, particularly glucosides, are of potential medical and taxonomic value. These have been studied extensively from a pharmacological (El-Naggar et al. 1980, El-Naggar et al. 1982, Nicoletti et al. 1995, Villegas et al. 1997, Bucar et al. 1998), phytochemical (Bliss et al. 1968, Danielson et al. 1973, Danielson et al. 1975, Jensen et al. 1981, Catalano et al. 1995), and chemotaxonomic (Muller et al. 1998, Frederiksen et al. 1999) perspective.

There has been much taxonomic confusion over the proper placement of the Loasaceae in the angiosperm family tree since it lacks obvious close relatives based on morphology (Brown 1971). Various authors have aligned it with the Cactaceae, Turneraceae, and Passifloraceae. It was placed in the subclass Dilleniidae, order Violales, and is considered to be most closely related to the Begoniaceae by Cronquist (1981). This classification is used by Heywood (1993) and the PLANTS National Database (USDA Natural Resources Conservation Service 2006. Takhtajan (1997) included the Loasaceae in the Lamiidae. However, recent taxonomic research suggests that it probably does not belong in the Dilleniidae and shows many affinities with the Asteridae (Mabberley 1997, Weigend et al. 2000). This was first suggested by Thorne (1983) based on the presence of iridoids in the Loasaceae and on other characters (Weigend et al. 2000). More recently, molecular phylogenetic research using *rbcL* sequence data (Xiang et al. 1993, Xiang and Soltis 1998) and sequence data for the chloroplast gene *matK* (Xiang et al. 2002) has provided further convincing evidence that the Loasaceae belongs in the subclass Asteridae, order Cornales. The recent assessment of the phylogenetic relationships within the Cornales by Xiang et al. (2002) places the Loasaceae nearest the Hydrangeaceae. Additional research is needed to resolve the phylogenetic position of the Loasaceae. Given the conflicting cladograms inferred from the available molecular datasets for the Loasaceae, Weigend (2003) recommends using a classification based on morphological characteristics until better molecular data are available. **Table 2** summarizes the classification of *Mentzelia chrysantha*.

As circumscribed by Weigend (2003), the Loasaceae consists of two subfamilies, the Loasoideae and the Mentzelioideae. Urban and Gilg (1900) included a third subfamily (Gronovioideae), and this

Table 2. Classification of *Mentzelia chrysantha* after USDA Natural Resources Conservation Service 2002, with sources (not necessarily the original source) of particular subdivisions cited below.

Kingdom	Plantae (Plants)
Subkingdom	Tracheobionta (Vascular Plants)
Superdivision	Spermatophyta (Seed Plants)
Division	Magnoliophyta (Flowering Plants)
Class	Magnoliopsida (Dicotyledons)
Subclass	Asteridae[1] (Dilleniidae[2])
Order	Cornales[1] (Violales[2])
Family	Loasaceae (Loasa Family)
Subfamily	Mentzelioideae
Tribe	Mentzelieae[3]
Genus	*Mentzelia* (Blazing Star)
Section	*Bartonia*[4]

[1]Stevens 2002, Xiang et al. 2002
[2]USDA Natural Resources Conservation Service 2006
[3]Weigend et al. 2002
[4]Darlington 1934

broader circumscription is perhaps the most familiar and is followed by numerous authors (e.g., Heywood 1993). However, recent systematic studies based on phytochemical and genetic data suggest that its members belong in their own family (Gronoviaceae) (Weigend 1997, Weigend et al. 2000). *Mentzelia chrysantha* is in the subfamily Mentzelioideae (Gilg 1894), which includes three genera: *Eucnide*, *Mentzelia*, and *Schismocarpus* (Weigend et al. 2000). This subfamily consists almost entirely of annual or perennial herbs although one species, *M. arborea*, is a small tree. *Mentzelia* is included in the tribe Mentzelieae (Gilg 1894).

The genus *Mentzelia* has been treated under numerous other names (Darlington 1934), which can lead to confusion when referencing older literature. The floras and field guides for Colorado from the last 100 years include *M. chrysantha* under a variety of names that reflect the lack of agreement among taxonomists regarding the proper treatment of this genus. Weigend (2003) includes a detailed list of the synonyms for *Mentzelia* (**Table 3**). The history of the synonymy for *Mentzelia* is described well in Darlington (1934), Brown (1971), and Christy (1995). Most of the synonyms are no longer in use since they have been determined to be illegitimate (violating the International Code of Botanical Nomenclature), already in use, or the members have been subsumed under the genus *Mentzelia*. Some authors, most notably Weber and Wittmann (2001), use the genus *Nuttallia*, a segregate genus that was originally applied by Rafinesque in 1817. However, this name is also now used for a genus of clam native to Asia (for example, see Mills 1999-2000). Most authors, including the current monographer of the family (Dr. Maximilian Weigend), do not support the subdivision of the genus and include these taxa within *Mentzelia*. In this assessment, this species is treated as *M. chrysantha* to adhere to the nomenclature of Kartesz (1999) and USDA Natural Resources Conservation Service (2006), which is used as a taxonomic standard by NatureServe and the Colorado Natural Heritage Program (NatureServe 2006).

Mentzelia is the most poorly understood genus of the Loasaceae, with many vaguely defined species (Weigend 2003). It also has a reputation for being a difficult group taxonomically (Holmgren and Holmgren 2002). As currently circumscribed, it includes approximately 80 species (Weigend et al. 2000). Nine-carbon iridoids (deutzioside) are restricted to the genus *Mentzelia* (Weigend et al. 2000). *Mentzelia* is a genus composed of annual or perennial herbs, sub-shrubs, shrubs or small trees that range from southern Canada to Chile, Argentina, the Caribbean, and the Galapagos Islands. There are apparently two centers of distribution for members of *Mentzelia*, in Mexico and in the southwestern United States (Darlington 1934, Reveal 2003, Weigend 2003). Almost all members of the genus *Mentzelia* in North America occur in the Intermountain West and in the western Great Plains (Kartesz 1999). Only one member of section *Bartonia* occurs outside North America, but even it is also found in Texas, Oklahoma, and Mexico (Darlington 1934).

Mentzelia is divided into four sections (*Bicuspidaria*, *Bartonia*, *Eumentzelia*, and *Trachyphytum*). *Mentzelia chrysantha* is a member of section *Bartonia*, which includes approximately 40 species (Darlington 1934, Thompson 1963, Christy 1995, Holmgren and Holmgren 2002).

Table 3. Synonyms for Mentzelia (from Weigend 2003 and Mills 1999-2000).

Synonym	Region 2 Usage	Status[1]
Bartonia		nomen illegitimum
Nuttallia	Weber and Wittmann 2001, Rydberg 1922	still in use but is also a genus of bivalves
Torreya		nomen illegitimum
Acrolasia	Rydberg 1922	reduced to synonymy
Creolobus		reduced to synonymy
Crysostoma		reduced to synonymy
Touterea	Rydberg 1906	nomen nudum
Trachyphytum		nomen nudum
Hesperaster		nomen illegitimum
Bicuspidaria		reduced to synonymy

[1]**Nomen illegitimum –** the necessary criteria for valid names in the ICBN is not fulfilled or is violated.

Nomen nudum – unavailable name, with lacking description or indication of a description.

The genus *Mentzelia* has diversified greatly in western North America. It is among several other noteworthy genera (including *Astragalus*, *Ipomopsis*, and *Eriogonum*) that show a strong propensity for speciation and specialization in the arid parts of western North America. There is therefore much endemism among these taxa with many naturally rare species limited to a particular geological formation or other limited habitat. The genus *Mentzelia* has been noted for its high degree of endemism (Hill 1977). Section *Bartonia* has shown a particularly strong tendency towards adaptive radiation. Of the species in the section *Bartonia*, Prigge (1986) wrote:

> "This section of *Mentzelia* demonstrates considerable morphological diversity and adaptability and has radiated into many of the diverse and often isolated habitats resulting from the wide range of substrate, elevation, and precipitation of the Colorado Plateau province of eastern Utah, western Colorado, northern Arizona and western New Mexico. Many species of this section occur on unusual substrates that are commonly unsuitable for most species because of textural properties or high concentrations of evaporites or minerals. *Mentzelia* is apparently able to exploit these habitats by escaping intense competition from species that occur on more suitable substrates. Edaphic factors and isolation are very important in their speciation and probably account for the many edaphically restricted and often locally endemic populations of *Mentzelia*."

Analysis of the floral morphology of section *Bartonia* suggests that its members are the most basal of the Loasaceae, and may actually have given rise to the rest of the family (Brown 1971). Nonetheless, even section *Bartonia* has a somewhat specialized, derived floral morphology (Christy 1995).

There has been no detailed taxonomic study of *Mentzelia chrysantha* to date using molecular data or a modern cladistic approach. Christy (1995) used several morphological characteristics to generate cladograms of most members of section *Bartonia* (35 species), but unfortunately *M. chrysantha* was not included in her study. Dr. Barry Prigge has also studied the taxonomy of section *Bartonia* but did not complete work on *M. chrysantha* (Coles personal communication 2003).

History of knowledge

Mentzelia chrysantha was first collected by Charles Christopher Parry in 1874 (*#78*). Using Parry's specimen, *M. chrysantha* was described by George Engelmann (1876) and included in T.S. Brandegee's Flora of Southwestern Colorado. The Loasaceae were treated in a lengthy Latin monograph that included *M. chrysantha* (Urban and Gilg 1900), but there has been no monograph of the family since, although Wiegend is working on an updated monograph that is not yet complete.

Mentzelia chrysantha was included in the early floras of the Rocky Mountain region including Coulter and Nelson (1909) and Rydberg (1906, 1922). It was collected infrequently through the late 1800s and early 1900s, but many specimens originally collected as *M. chrysantha* have turned out to be another species. This has led most authors to include Wyoming, Utah, and other parts of Colorado in the range of *M. chrysantha* (e.g., Coulter and Nelson 1909, Rydberg 1906, Rydberg 1922, Darlington 1934, Harrington 1954, Rickett 1973). Some of Parry's collections included a label with the heading "Flora of Southern Utah," which caused some of the confusion. See the Distribution and abundance section for further discussion of this issue.

Josephine Darlington wrote the current monograph of the genus *Mentzelia* (1934). Her circumscription of species in the genus is generally the only one available. Recent work has helped to resolve the taxonomy of section *Bartonia*, but the relationships and species delimitations in this group remain unclear (Christy 1995). *Mentzelia chrysantha* and its sympatric congeners are no exception, and a thorough investigation of these taxa is needed (Kelso personal communication 2003). Problems with available keys to the *Mentzelia* species of this area have contributed to confusion on their identity in the Arkansas Valley (Kelso et al. 1995). Annotation of specimens from Wyoming and other parts of Colorado by experts (e.g. Prigge, Thompson, and Zavortink) has led to a clearer picture of the range of *M. chrysantha* and has shown that it is a narrow endemic. Collections of *M. chrysantha* have been made recently by Sylvia Kelso (Kelso et al. 1995), Janet Coles, Kathy Carsey, and Tim Chumley, further enhancing our knowledge of its range and habitat. These specimens are housed at the University of Colorado Herbarium, Carter Herbarium at Colorado College, Colorado State University Herbarium, and Rocky Mountain Herbarium in Laramie.

Surveys by Janet Coles and Jim Von Loh with the Colorado Natural Areas Program in 1991 and by Susan Spackman Panjabi and Sandra Floyd with the Colorado Natural Heritage Program (Spackman and Floyd 1996) identified new occurrences of *Mentzelia chrysantha* and confirmed many other reports of this species. Susan Spackman Panjabi studied the reproductive biology of *M. chrysantha* in 2001, in which pollinator visitation during timed observations was documented and pollinator exclusion experiments were conducted (Spackman Panjabi 2004).

Non-technical description

Members of section *Bartonia* are short-lived, rosette-forming, more or less suffrutescent biennials or monocarpic perennials (Christy 1995). Species in *Bartonia* bear flowers that open in the evening (or in the morning in one species), with petals that grade into stamens through petaloid staminodia (Mabberley 1997, Holmgren and Holmgren 2002). While descriptions of the members of section *Bartonia* (including *Mentzelia chrysantha*) write that their flowers have ten petals, only five of these are true petals, while the other five are probably "petaloid staminodia," since their vascular supply comes from the stamen trunk (Brown 1971).

Like other members of section *Bartonia*, *Mentzelia chrysantha* is a biennial or monocarpic perennial. In favorable years, it can complete its lifecycle in two years, but it can persist for several years as a rosette awaiting a favorable year. After it bolts and flowers, the plant dies (Colorado Natural Heritage Program 2006). The plant has thick, erect, mostly unbranched stems, 2 to 6 dm tall (**Figure 1**). The leaves are 2 to 15 cm long, elongated (ovate-lanceolate to ovate), and sinuous-dentate (Harrington 1954, Spackman et al. 1997). The leaves, stems, and fruits are covered in a dense vesture of trichomes (hairs), which are characteristic of members of section *Bartonia* (**Figure 2**). The hairs of *Mentzelia* are elaborately hooked or barbed, and they may serve as a physical defense against insects (Eisner et al. 1998), as a dispersal mechanism, and in reflecting light to reduce heat load and water usage (Christy 1995). *Mentzelia chrysantha* produces numerous bright lemon yellow or golden yellow perfect flowers with 10 petals (Spackman et al. 1997, NatureServe 2006, Colorado Natural Heritage Program 2006; **Figure 3**). There are 50 to 80 seeds per capsule (Harrington 1954). The seeds are very narrowly winged, with a papillose testa (seed coat) (Weber and Wittmann 2001). The characteristics of the seed coat are generally regarded as being of great taxonomic value in *Mentzelia* (Hill 1976).

Like many taxa in the Loasaceae, *Mentzelia chrysantha* is difficult to identify due to fuzzy species boundaries and due to its sympatry with congeners (*M. decapetala*, *M. nuda*, and *M. reverchonii*). Confident identification of *M. chrysantha* is complicated by the limited differences between it and *M. reverchonii* (Coles personal communication 2003, Kelso personal communication 2003). These species probably represent a group that has recently speciated, and they may even represent a group of differentiated but not fully speciated taxa (Kelso personal communication 2003).

Mentzelia reverchonii is often found with *M. chrysantha*. Weber and Wittmann (2001) distinguish *M. reverchonii* from *M. chrysantha* using seed characteristics that were originally recognized by Dr. Barry Prigge (Colorado Natural Heritage Program 2006). *Mentzelia reverchonii* has broadly winged seeds that have few papillae on the seed coat while the seeds of *M. chrysantha* have narrow wings and are distinctly papillose (Darlington 1934, Great Plains Flora Association 1986). However, these characters are subtle and variable, and make it difficult to identify plants in vegetative or flowering stages. In the rosette stage, *M. chrysantha*, *M. reverchonii*, *M. decapetala*, and *M. nuda* cannot be reliably distinguished (Coles personal communication 2003, Colorado Natural Heritage Program 2006).

Mentzelia nuda is also found with *M. chrysantha* at some locations, but it is more easily distinguished from *M. chrysantha* than *M. reverchonii*. *Mentzelia nuda* has cream-colored flowers and blooms in June while *M. chrysantha* has golden yellow flowers and blooms from July to early September (Spackman et al. 1997).

Mentzelia chrysantha is found in different habitats than *M. densa*, which facilitates the distinction of these species (**Table 4**). Weber and Wittmann (2001) lumped *M. densa* within *M. speciosa*, but they separate *M. speciosa* from *M. chrysantha* on the basis of the stem (stout and mostly unbranched in *M. chrysantha*, slender and branched in *M. speciosa*) and flowers (closely massed in *M. chrysantha*, well separated in *M. speciosa*). The leaf pubescence of *M. chrysantha* is reportedly retrorse while that of *M. speciosa* is erect (Colorado Natural Heritage Program 2006). The growth form of *M. densa* is distinctively hemispheric while that of *M. chrysantha* is taller and more erect. Hill (1976) includes SEM photographs of the seed coat of *M. densa* but did not include *M. chrysantha* in this study.

Figure 1. *Mentzelia chrysantha.* Photograph by Janet Coles (from Spackman et al. 1997, Colorado Native Plant Society 1997).

Photographs of the flowers and habitat of *Mentzelia chrysantha* are available in Spackman et al. (1997). An illustration by Janet Wingate is also available in Spackman et al. (1997), and it includes details of the flower, fruit, and hairs. Photographs of the plant and its habitat, and a range map appear in Spackman Panjabi (2004) and Spackman Panjabi et al. (2003). Colorado Native Plant Society (1997) includes a photograph (**Figure 1**) and a small range map.

For identification, the most up-to-date key available is that of Weber and Wittmann (2001), which includes a couplet that can distinguish *Mentzelia chrysantha* from *M. reverchonii* (**Table 4**). This key and the descriptive information in Spackman et al. (1997) are the two best tools for diagnosing *M. chrysantha* in the field. Darlington (1934) and Harrington (1954) offer descriptions of *M. chrysantha*, but these sources state that the seeds are not winged. Great Plains Flora Association (1986) has keys and descriptions of other *Mentzelia* species that occur with *M. chrysantha*, but *M. chrysantha* is not included. **Table 4** is a summary of diagnostic information on *M. chrysantha* and its sympatric congeners.

Distribution and abundance

Mentzelia chrysantha is a narrow endemic, found only along a 40-mile stretch of the Arkansas River Valley on particular geologic substrates in an area

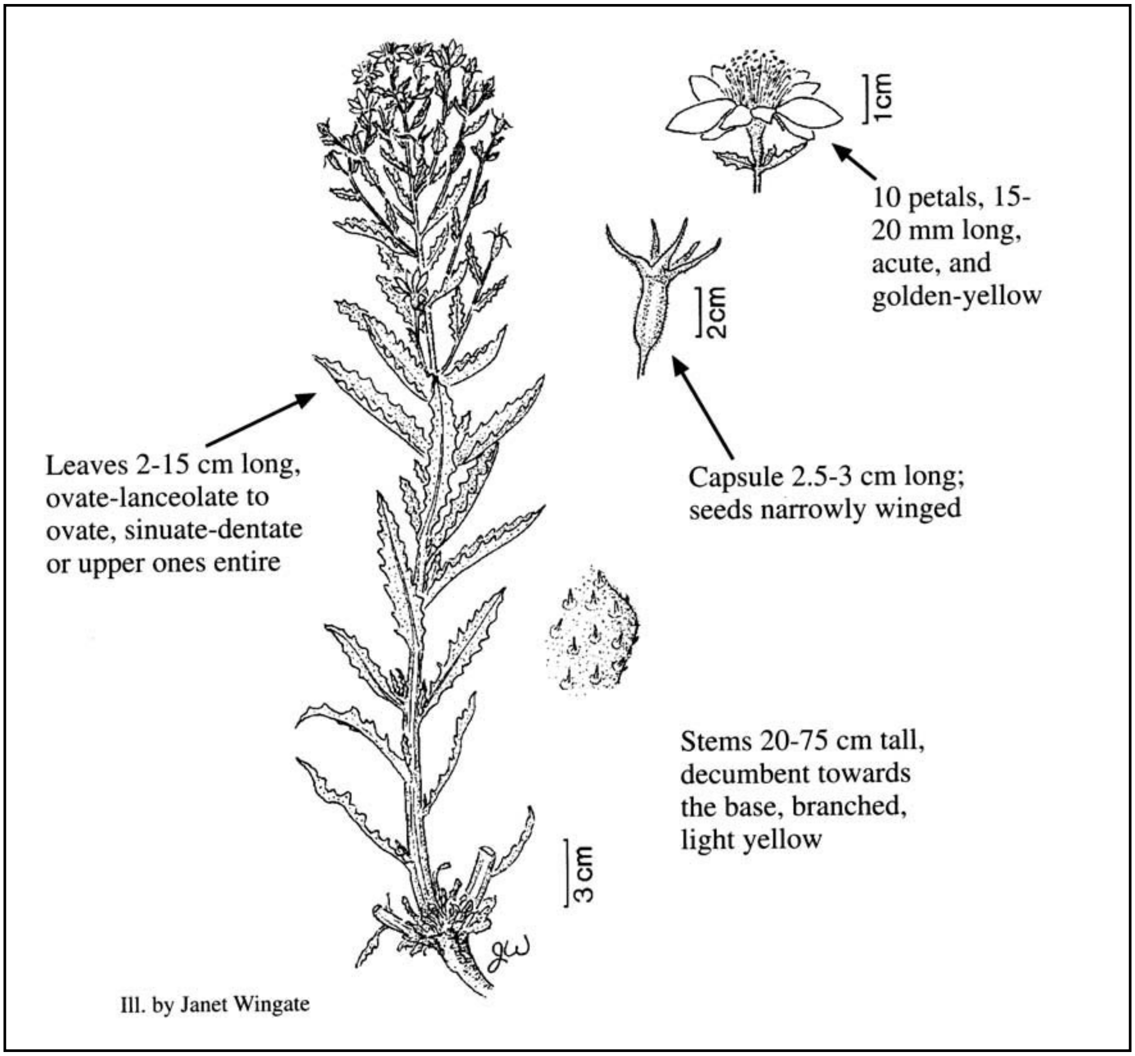

Figure 2. Illustration of *Mentzelia chrysantha* showing diagnostic features (from Spackman et al. 1997).

that includes Cañon City and Pueblo, in Fremont and Pueblo counties and at Fort Carson (**Figure 4**). It is known from a total of 28 occurrences, and all but four of these have been seen in the last 20 years. All the known occurrences of *M. chrysantha* are within about 20 miles of the town of Portland.

There is one record of *Mentzelia chrysantha* in El Paso County, from a collection in 1946 (*W. Penland #3400* at Carter Herbarium), but the precise location of this record is uncertain (Kelso personal communication 2003). Attempts by the author to find this occurrence in 2000 were unsuccessful (Doyle et al. 2001). Although Penland noted that he collected it in El Paso County, it is quite possible that he was actually in Fremont County or Pueblo County. His description on the specimen label, "15.0 mi S of Colo. Springs; near beginning of Pueblo cut-off" is vague. The actual location of the route to which Penland referred is not known, but it could be within the current boundary of Fort Carson Military Reserve, or along the approximate route now followed by State Route 115. Fifteen miles south of Colorado Springs along this road would have put him very close to the Fremont County border. Because this record is so questionable and because the plant has not been seen in El Paso County since, the range of *M. chrysantha* is generally cited as including only Pueblo and Fremont counties. However, *M. chrysantha* was collected by Tim Chumley within 0.3 miles south of the El Paso County border, 1.5 miles east of the town of Henkel (Chumley 1998; CO EO#18). This is the most disjunct occurrence and is approximately 18 miles from the nearest occurrences at Pueblo State Reservoir. Attempts were made in 2002 to revisit this occurrence and to verify it, and although *M. nuda* was observed, no *M. chrysantha* plants were found (Spackman Panjabi et al. 2003, Colorado Natural Heritage Program 2006).

Figure 3. The flowers of *Mentzelia chrysantha*. Photograph by Susan Spackman Panjabi, used with permission.

The elevation of *Mentzelia chrysantha* occurrences as documented in element occurrence records ranges from 4,700 to 6,520 ft. (Colorado Natural Heritage Program 2006). This is somewhat lower than the 5,075 to 7,000 ft. cited by Chumley (1998) or the 5,120 to 5,700 ft. described by Spackman et al. (1997).

The total number of individuals estimated in element occurrence records for *Mentzelia chrysantha* is 5,400 (Colorado Natural Heritage Program 2006). However, the total population is probably larger than this since half of the 28 records do not include a population count or estimate. The historical abundance of *M. chrysantha* may have been greater before human alterations of its habitat such as reservoir construction, mining, grazing, residential development, and road construction. The largest occurrence known is at Brush Hollow (BLM), where approximately 2,000 plants were reported. One thousand plants each were reported at Pueblo Reservoir (Colorado Division of Wildlife and privately owned) and Pierce Gulch (Fort Carson Military Reserve). **Table 5** is a summary of all known occurrences of *M. chrysantha*.

The range of *Mentzelia chrysantha* was previously thought to include Wyoming, Utah, and other parts of Colorado (Rydberg 1906, Coulter and Nelson 1909, Rydberg 1922, Darlington 1934, Harrington 1954, Rickett 1973), but improved understanding of *Mentzelia* species throughout the West has resulted in a clearer picture of its true range. Several specimens noted in Darlington (1934) have since been annotated as other species. These include four specimens from southern Wyoming, and a specimen from Manitou Springs, Colorado. Another specimen at COLO (Walker s.n.) from Idaho Springs, Colorado was annotated from *M. chrysantha* to *M. speciosa*.

Two type collections (isosyntypes) of *Mentzelia chrysantha* are housed at the New York Botanical Garden (NY) (New York Botanical Garden 2003). These specimens, collected by C.C. Parry (*#78*) include no geographic information besides a printed label titled "Flora of Southern Utah," leading to confusion about whether this species occurs in Utah. On this topic, Holmgren et al. (2005) wrote: "Darlington (1934, page 171) noted that *M. chrysantha* "probably [occurs] in Utah. This report may have been based on a misidentified syntype of *M. chrysantha* (*C.C. Parry #78*, vicinity of St. George, Washington Co., Utah, at GH!, NY!). The Parry specimen is *M. pterosperma*." Patricia Holmgren states that no specimens of *M.*

Table 4. Summarized diagnostic characters for *Mentzelia chrysantha* and four of its sympatric or nearly sympatric congeners. Sources include Darlington (1934), Great Plains Flora Association (1986), Spackman et al. (1997), Weber and Wittmann (2001), Coles (personal communication 2003), and Kelso (personal communication 2006).

	M. chrysantha	***M. reverchonii***	***M. densa***	***M. decapetala***	***M. nuda***
Habitat	Barren slopes in clayey calcareous soils, derived mostly from Niobrara Shale.	Gravelly and limestone soils.	Washes, naturally disturbed sites, and steep rocky slopes on Precambrian granodiorite, gneiss, gravel, and scree.	On and near sandstone outcrops of the front range.	Sandy soil on the plains, roadsides.
Habit	Stems thick and erect, mostly unbranched, 2-6 dm tall.	Up to one m tall; stems branched above.	Up to 3 dm tall, very branched with marcescent stems forming a hemispherical tuft.	Coarse and erect from a taproot, one to several stems, branched above, up to one m tall.	Less coarse than M. decapetala, erect, stems one to few, branched above, up to one m tall.
Leaves	Leaves retrorsely pubescent, 2-15 cm long, ovate-lanceolate to ovate, sinuous-dentate, upper leaves sessile, often entire.	Basal and cauline leaves 3-8 cm long, linear to lanceolate, leaves above gradually reduced and somewhat clasping basally; leaves shallowly lobed to mostly regularly fin-or coarse-toothed.	Leaves narrowly linear-lanceolate to oblanceolate, sinuate-pinnatifid into linear-lanceolate lobes about 1.5-2 mm wide.	Lower leaves short-petiolate and more or less lanceolate, upper leaves sessile; leaves 5-15 cm long, 1.5-4 cm wide, not reduced above, the margins regularly or irregularly sinuate to serrate, serrations acute to acuminate (not dentate), scabrous.	Lower leaves short-petiolate and oblanceolate, upper leaves sessile; leaves 4-10 cm long, 1.5-2 cm wide, usually somewhat reduced above, coarsely serrate or dentate, acute to obtuse, scabrous.
Flowers	Petals 1.5-2 cm long, acute, golden yellow.	Petals spatulate, 1-3 cm long, yellow.	Petals 1-1.5 cm long, acute, golden yellow.	Petals 5-7 cm long, 1-2 cm wide, cream colored; bracts partly fused to ovary wall.	Petals 1.5-4 cm long, 0.3-1 cm wide, not overlapping in anthesis, white; bracts not fused to ovary wall.
Capsules	Capsule 2.5-3 cm long.	Cylindrical, 1.5-3 cm long.	Cylindrical, 1.3-1.5 cm long.	Cylindrical, (1.5)3-5 cm long, (1)1.5-2 cm wide.	More or less cylindric, (1)2-3 cm long, 8-10mm wide.
Seeds	Narrowly winged, face is distinctly papillose.	Broadly winged, face is hardly papillose.	Round ovoid, thin, flat, strongly winged.	Flattened with rudimentary wings.	Broadly winged, flattened.
Phenology	Flowers July - early September.	Similar to *M. chrysantha* - no specific information.	July and early August-September.	No information.	Flowers in June.
Blooming	18:00 to 21:00	Evening.	Open at night.	Late afternoon to about midnight.	Late afternoon to sunset.
Range	Pueblo and Fremont counties, Colorado.	Frequent in southeastern Colorado, southwestern Oklahoma, eastern New Mexico, Texas panhandle.	Middle Arkansas Valley in Fremont and Chaffee counties, Colorado.	Western Great Plains.	Widespread on the Great Plains.

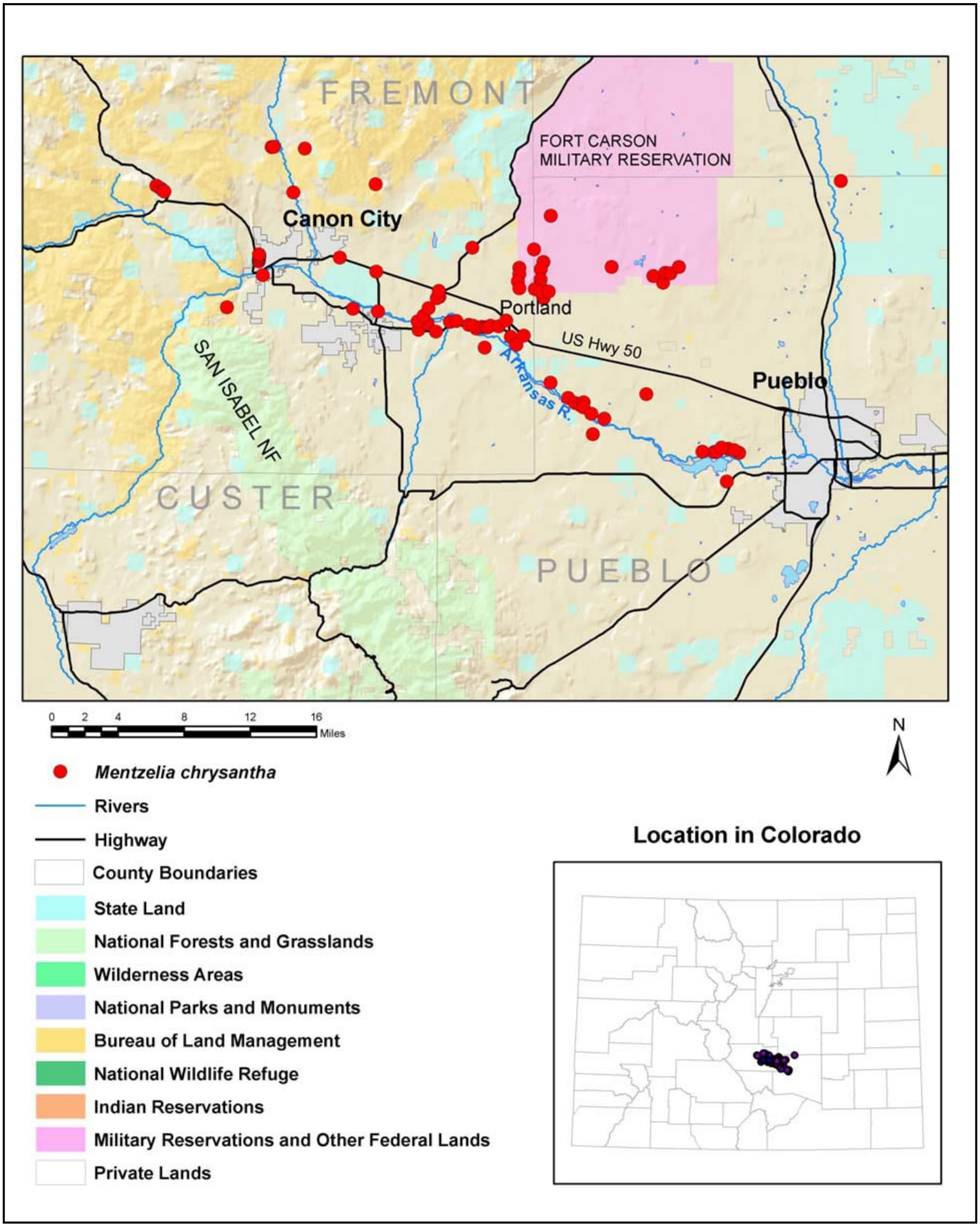

Figure 4. Land status map for the global range of *Mentzelia chrysantha*.

Table 5. Summary information for the 28 occurrences of *Mentzelia chrysantha*. EO# is the Colorado Natural Heritage Program element occurrence number.

EO#	County	Location	Owner	Date last observed	Abundance	Elevation (ft.)	Habitat and Notes
1	Fremont	Brush Hollow	Bureau of Land Management (BLM) Royal Gorge Field Office; Private; Colorado Department of Transportation (CDOT) roadside right-of-way	8/23/2001	thousands	5,120 to 5,160	Growing on barren south-facing slopes, on road and railroad cuts, and on river cut banks, also in grassland. Growing in river cobbles, Quaternary gravels, and eroding Niobrara and Pierre shale outcrops in gray clay. Slopes mostly at about 20%. Associated taxa: *Frankenia jamesii*, *Atriplex confertifolia*, *Oryzopsis hymenoides*, and *Oreocarya* sp.
3	Fremont	Portland	CDOT roadside right-of-way; Private	7/9/1993	not reported	5,100 to 5,200	Along road and on barren slopes on various members of the Niobrara shale formation. Was observed on otherwise barren cut slopes, on limestone hills.
4	Pueblo	Pueblo Reservoir	State of Colorado (Department of Reclamation)	1995	not reported	4,840 to 5,100	Shortgrass prairie vegetation dominated by Bouteloua gracilis and Juniperus monosperma. Rather steeply sloped terrain (15-45%) below steep bluffs. Soil fine-textured with rock chips, derived from limestone bluffs above. Slope: ~ 5%. Soils: silty.
5	Fremont	Portland	CDOT roadside right-of-way; Private	5/29/1998	200	5,080 to 5,160	On shale barrens, sometimes covered with river cobbles. Open pinyon-juniper and short-mid-grass prairie in adjacent areas. Also on steep road cuts and natural slopes 20-40% of all aspects. Associated taxa: *Frankenia jamesii*, *Oryzopsis hymenoides*, *Oreocarya* sp., *Atriplex canescens*.
6	Fremont	Florence	Unknown	9/1/1921	not reported	5,676	Dry hills.
7	Fremont	Florence	Private	1991	not reported	5,200 to 5,260	At several locations, individuals or populations occur within the right-of-way of a major road, and also outside of right-of-way.
8	Fremont	Highway 120	Private	5/29/1998	200	5,020 to 5,100	Shale barren, sometimes covered with river cobbles. On steep road cuts and natural slopes. 20-40% of all aspects. Open pinyon-juniper and short-mid-grass prairie in adjacent areas. Associated taxa: *Frankenia jamesii*, *Oryzopsis hymenoides*, *Oreocarya*, and *Atriplex canescens*.

Table 5 (cont.).

EO#	County	Location	Owner	Date last observed	Abundance	Elevation (ft.)	Habitat and Notes
9	Fremont	Cañon City	State of Colorado; Private	7/8/1995	"hundreds"	5,300 to 5,520	Narrow outcrop of Niobrara shale. Plants occur on east-facing slopes. Area serves as powerline corridor and is heavily used as off road vehicle recreation area. Plants occur mostly in fine silty soil derived from shale. Estimated amount of potential habitat: five acres. Potential habitat occupied: 75%. Associated species: *Stipa neomexicana*, *Oryzopsis hymenoides*, *Atriplex canescens*, *Salsola* sp., *Frankenia jamesii*, *Sporobolus* sp., *Bromus tectorum.*
10	Fremont	Garden Park	BLM Royal Gorge Field Office; Private	7/22/2001	50	6,200 to 6,520	Occurs only on most open barren clay slopes, except for one group of plants on an old road cut along a ridge. 20-40% slope, all aspects. 80% bare ground. Highly erosive slope. Soil: clay and silty clay, alkaline, with gypsum crystals on the surface of the clay soil. Associated species include *Frankenia jamesii*, *Atriplex canescens*, *Atriplex* sp., and *Salsola* sp.
11	Fremont	Cope's Quarry	BLM Royal Gorge Field Office; Private	7/9/1995	200	6,320 to 6,340	Many of the plants observed were on an excavation site, also on natural outcrop. On fine silty clay with colluvial gravel and cobbles, soils chocolate brown to light gray in color. 90% bare ground. Associated with *Oryzopsis hymenoides*, *Eriogonum* sp., and *Stipa neomexicana*. Open pinyon juniper woodland with *Cercocarpus montanus* occurs in adjacent areas.
12	Fremont	Beaver Creek	CDOT roadside right-of-way; Private	5/29/1998	50	5,100 to 5,120	On road cut at junction of Ft. Hayes limestone and Smokey Hill chalk, and on a steep slope of Niobrara shale outcrop. Slope: 40%. Bare ground: 70%. Southwest facing slope. Full sun. Associated taxa: *Mirabilis rotundifolia*, *Frankenia jamesii*, *Oryzopsis hymenoides*, *Artemisia bigelovii*, and *Atriplex canescens*.

Table 5 (cont.).

EO#	County	Location	Owner	Date last observed	Abundance	Elevation (ft.)	Habitat and Notes
13	Fremont	Florence	CDOT roadside right-of-way; Private	1991	not reported	5,360	Along roads and on barren slopes.
14	Fremont	Florence	Private	1991	not reported	5,200 to 5,300	Along roads and on barren slopes.
15	Fremont	Cañon City	Unknown	1874	not reported	5,332	No information.
16	Fremont	Fourmile Creek	Private	6/29/1998	40	5,760 to 5,800	Plants widely scattered on east-facing slope of a 60 foot cliff face of white shale with layers of clay. 95% bare rock/soil. Natural exposure adjacent to county road.
18	Pueblo	Overton Road	Private	7/15/1996	not reported	5,240	In cholla grassland.
19	Fremont	Temple Canyon Road	BLM Royal Gorge Field Office; Private	7/15/1996	not reported	5,860 to 6,000	Eroded, steep slopes above a dry wash. This occurrence is approximately one mile from the San Isabel National Forest Boundary.
20	Pueblo	Pueblo Reservoir	State of Colorado (Department of Reclamation)	7/19/2001	1,000	4,700 to 4,910	Most plants are in areas disturbed by road, bike trail, and campground construction. A few are on naturally eroding, steep shale slopes. Vegetation is sparse in areas with the most plants. Slope: 15-90%. Aspect: All. Topographical position: mid- lower slope. Geology: Niobrara shale. Soil: Stony silt loam. Associated species: *Atriplex confertifolia*, *Hesperostipa comata*, *Hilaria jamesii*, *Achnatherum hymenoides*, *Juniperus monosperma*, and *Salsola* sp.
21	Pueblo	Upper Pueblo Reservoir	Colorado Division of Wildlife; Private	8/19/2002	200	4,960 to 5,020	On eroding dark shale on steep eroding walls, debris fans, and landslide scars. Most of the slope is in natural condition, but plants also occur along a small dirt road and along railroad embankments. Plants prefer sites with occasional severe disturbances (plants are early seral). Slope: 25-100%. Aspect: all. Topographic position: lower-mid slope. Geology: Niobrara shale. Soil: stony, silty clay and silty clay. Habitat comments: vegetation is sparse in areas with the most plants. Common associated species: *Frankenia jamesii*, *Juniperus monosperma*, *Chrysothamnus nauseosus*, *Achnatherum hymenoides*, *Oligosporus pacificus*, *Yucca glauca*, *Psoralidium* spp., *Atriplex* sp., and *Zinnia grandiflora*.

Table 5 (concluded).

EO#	County	Location	Owner	Date last observed	Abundance	Elevation (ft.)	Habitat and Notes
22	Fremont	Phantom Canyon	Unknown, probably BLM Royal Gorge Field Office and/or Private	6/7/1947	not reported	6,200	No information.
23	Pueblo	Pueblo West	Private	7/17/2001	50	5,030	Roadside outcrop of shale within a residential development. *Oenothera harringtonii* and *Oonopsis puebloensis* are also present at this location.
24	Fremont	Cactus Mountain	BLM Royal Gorge Field Office; Private	8/25/2000	100	6,220	On a highway road cut. Topographic position: midslope. Light exposure: open. Moisture: dry. Associated species: *Mentzelia nuda*, *Juniperus* sp., Pinyon, and mountain shrubs.
25	Fremont	Clevinger Ranch	Private	11/11/2000	100	5,140	Habitat type: open shrubland. Slope: 0-10%. Light exposure: open. Moisture: very dry. Parent Material: dark shale. Soil texture: dark thin shale. Total bare ground cover: 75%. Associated plant community: *Frankenia jamesii*, *Atriplex confertifolia*, *Oryzopsis hymenoides* but very sparse. Additional associated plant species: *Oonopsis puebloensis*.
27	Pueblo	Fort Carson	U.S. Department of Defense Fort Carson Military Reservation	7/27/1995	not reported	5,580 to 5,740	Dry roadside on road cut on east side of road under sandstone bluffs.
28	Fremont	Beat Creek	Colorado State Land Board; Private	9/11/1978	not reported	5,520	Disturbed roadside.
30	Fremont, Pueblo	Pierce Gulch	U.S. Department of Defense Fort Carson Military Reservation; Private	6/23/2004	1,000+	5,260 to 5,700	On slopes of a gulch, on calcareous shales; throughout bottom of valley on roadsides.
31	Pueblo	Stone City	U.S. Department of Defense Fort Carson Military Reservation	1995	not reported	5,520	No information.
32	Pueblo	Red Creek	U.S. Department of Defense Fort Carson Military Reservation	1995	not reported	5,800	No information.

chrysantha are known from Utah (Holmgren personal communication 2003).

Population trend

There are no quantitative data that could be used to infer the population trend of *Mentzelia chrysantha*. There has been no population monitoring that could provide insight into population trend, and population size is not known for many of the known locations. Impacts to individual plants and their habitat from human activities, such as commercial and residential development, mining, grazing, and transportation infrastructure, suggest that there has been a downward trend. Loss of habitat and anthropogenic disturbance of remaining habitat has probably caused a downward trend. However, *M. chrysantha* is locally abundant in some anthropogenically-created and maintained habitats such as road cuts (Kelso et al. 1999a).

Because *Mentzelia chrysantha* is a short-lived species, population sizes are likely to fluctuate naturally due to annual climatic variation. As a stress-tolerant species, it is likely that while drought probably reduces or eliminates recruitment of seedlings, juvenile plants (rosettes) are probably capable of surviving one or more dry years. This makes it difficult to assess the population size accurately in any given year.

The impoundment of the Arkansas River to form Pueblo Reservoir probably affected occurrences of *Mentzelia chrysantha*. Portions of the occurrences currently known from the north side of Pueblo Reservoir were probably inundated, but no information is available from which the number of individuals lost could be estimated. Strip mining for cement production is ongoing throughout much of the area occupied by *M. chrysantha*, impacting occurrences and habitat.

Habitat

Mentzelia chrysantha occurs in the Temperate Steppe Division of the Dry Domain in the Ecoregion classification of Bailey (1995). Within the Temperate Steppe Division, it is found on the margins of the Great Plains-Palouse Dry Steppe Province and the Southern Rocky Mountain Steppe-Open Woodland-Coniferous Forest-Alpine Meadow Province.

The climate of the Arkansas River Valley below Cañon City is arid, with low humidity, low annual precipitation, and hot summer temperatures. Prevailing weather patterns place this area in the rain shadow of the Sangre de Cristo and Mosquito ranges. Temperature and precipitation data are available from the Arkansas River Valley at Cañon City (1948 to 2002) and Pueblo Reservoir (1975 to 2002) within the range of *Mentzelia chrysantha* (Western Regional Climate Center 2003). In typical years, July and August are the wettest months of the year in this part of Colorado. This pattern corresponds to the timing of high reproductive effort for *M. chrysantha*. These months average approximately 2 inches of rain from monsoonal afternoon thundershowers. These months are also the hottest of the year, with maximum daily temperatures often exceeding 100 ºF. Total average annual precipitation at Cañon City and Pueblo Reservoir are almost identical (12.75 in. and 12.79 in., respectively), but quite a bit more falls as snow in Cañon City (36.1 in.) than at Pueblo Reservoir (20.7 in.).

Mentzelia chrysantha is typically found on barren slopes and road cuts of limestone, shale, or alkaline clay (**Figure 5**; Spackman et al. 1997, Kelso et al. 1999a, Colorado Natural Heritage Program 2006, NatureServe 2006). Because it is always found on alkaline, calcium-rich substrates, it is probably a calciphile (Kelso et al. 1999b, Coles personal communication 2003, Kelso personal communication 2003, Colorado Natural Heritage Program 2006). As a calciphile, it is possible that *M. chrysantha* will take up toxic levels of phosphorus in slightly acidic soils as described by Musick (1976) for *Larrea divaricata*.

The habitat of *Mentzelia chrysantha* consists of moderately disturbed, wasting slopes such as those above the Arkansas River (Coles personal communication 2003). Slopes are usually moderately steep in the shale barrens of the Arkansas River, averaging 20 to 25 percent; no particular aspect is favored (Kelso et al. 1999a). *Mentzelia chrysantha* occupies slopes and road cuts, where it grows prolifically and is often the only plant species growing in large numbers (Kelso et al. 1999a, Coles personal communication 2003, Spackman Panjabi personal communication 2003). It is particularly abundant on road cuts along U.S. Highway 50. The largest road cut occurrences have been seen on sites where the road cut is terraced; plants are often abundant on the terraces (**Figure 6**).

Geology

Mentzelia chrysantha is found on a variety of geologic formations, mainly marine deposits from the upper (late) Cretaceous period (Kelso et al. 1999b, Colorado Natural Heritage Program 2006). These include (in order of priority as habitat for *M. chrysantha*) the Niobrara Shale (Smoky Hill Member

Figure 5. Habitat for *Mentzelia chrysantha*. Photograph by Bill Jennings (from Spackman et al. 1997).

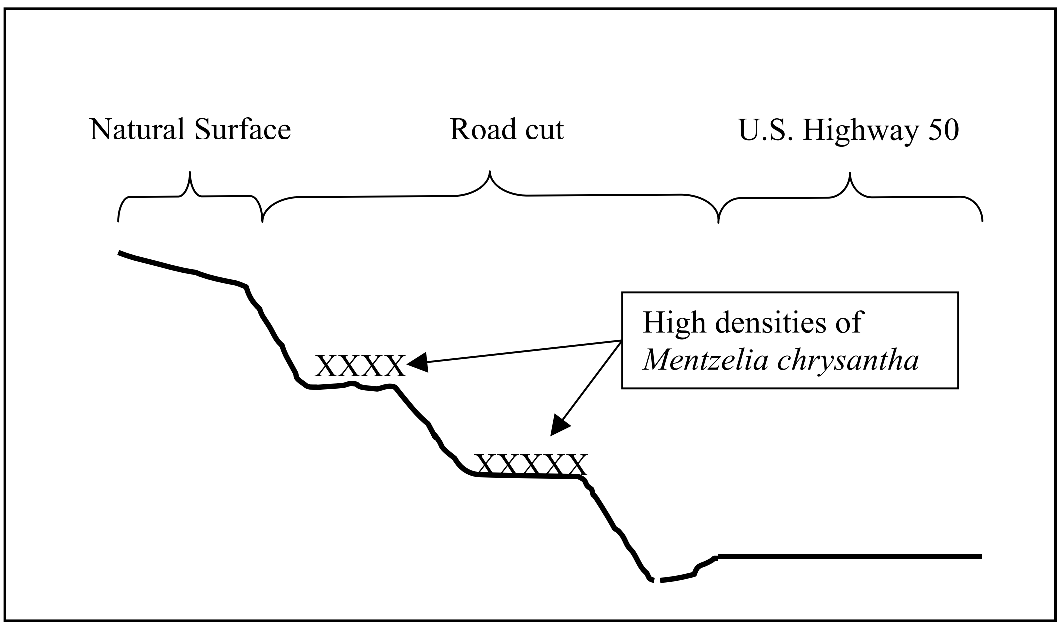

Figure 6. Diagrammatic representation of a typical road cut population of *Mentzelia chrysantha* (as described by Coles personal communication 2003).

and Fort Hays Member), Carlile Shale, Greenhorn Limestone, Graneros Shale, Quaternary Alluvium, and Pierre Shale (**Figure 7**; Scott and Cobban 1964, Tweto 1979, Kelso et al. 1995). *Mentzelia chrysantha* is found primarily on the Smoky Hill member of the Niobrara shale, which is widespread throughout the middle Arkansas Valley, especially in the vicinity of Florence. The Smoky Hill member includes seven subunits that vary greatly in texture and color (may be olive black, yellow-brown, olive gray, pale yellow, or yellow gray). Quaternary alluvium in the vicinity of the Arkansas River is also derived from the marine deposits on which *M. chrysantha* is found. Kelso et al. (1995) and Kelso et al. (2003) offer excellent overviews of the geobotany of the Arkansas Valley and include figures showing the local stratigraphy.

Outcrops of shale are common throughout the mountain west. There are many locations along the Colorado Front Range where the formations on which

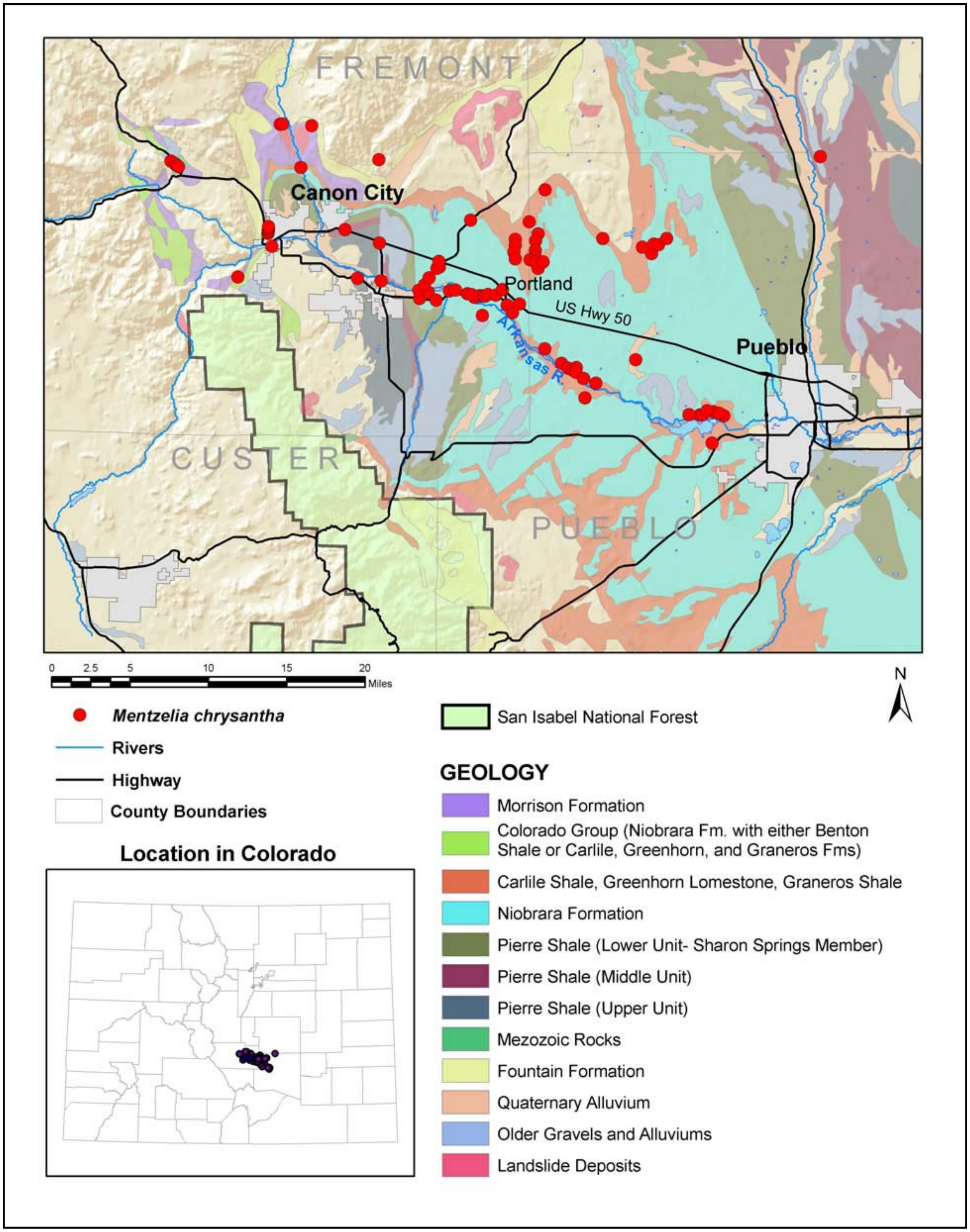

Figure 7. Geology underlying the global range of Mentzelia chrysantha, after Tweto (1979).

Mentzelia chrysantha is found, including Niobrara Shale, are exposed. It is likely that the narrow endemism of *M. chrysantha* is to some extent controlled by edaphic factors, but it is not known what has constrained its distribution to the limestones, shales, and alluviums of the Arkansas River Valley. Prigge (1986) hypothesized that many members of section *Bartonia* in the mountain west are recently evolved habitat specialists.

Mentzelia chrysantha is not known to occur on National Forest System land. It is found within one mile of the San Isabel National Forest boundary south of Cañon City (CO EO#19). This occurrence is at the edge of the Cañon City- Florence Basin, which consists of Cretaceous sedimentary deposits and Quaternary outwash and alluvium (Scott 1977). The north and east boundaries of the San Isabel National Forest in the Wet Mountains roughly follows the Wet Mountain Fault, which marks a sharp geologic boundary. The Wet Mountains within the San Isabel National Forest consist primarily of Precambrian volcanics including Migmatitic Biotite Gneiss and Granodiorite (Scott and Taylor 1974). To the southeast of the town of Greenwood, there are Permian sedimentary deposits of the Fountain Formation on the San Isabel National Forest, but this is outside the area known to be occupied by *M. chrysantha* (**Figure 7**; Tweto 1979).

Soils

Mentzelia chrysantha is typically found in poorly developed soils that are high in clay and/or silt content (Larsen et al. 1979, Wheeler et al. 1995). These soils are generally not suited to agriculture, and this has prevented the conversion of much of the Arkansas Valley to haymeadows or farmland. Soil map units in which *M. chrysantha* is found (in order of importance) fall into the Manzanola, Limon, Nunn, Swissvale, and Stoneham series (**Table 6**; Larsen et al. 1979, Wheeler et al. 1995).

In a study of the phenomenon of the edaphic endemism in the Arkansas Valley, Kelso et al. (2003) characterized the geobotany of chalk barrens at 29 sites where *Mirabilis rotundifolia* occurs in Fremont, Pueblo, Otero, and Las Animas counties. The ranges of *M. rotundifolia* and *Mentzelia chrysantha* overlap, and these species occur together at least one location (CO EO#12). Soils were characterized as moderately to strongly alkaline, with a high percentage of fine particles. There was no indication that the soils have unusual geochemical signatures or hidden toxicity. These observations, coupled with the observation that *Mirabilis rotundifolia* germinates and grows well in commercial potting soil in a greenhouse, led the researchers to the conclusion that the edaphic endemism of *M. rotundifolia* is due to its tolerance of limited water and nutrient availability that excludes other plant species that would normally compete with it for these resources. Whether this is also the case for *Mentzelia chrysantha* has not been investigated.

Landscape context

Mentzelia chrysantha is typically found on wasting slopes, but it also frequently occurs on flat surfaces. It is known from slopes of all aspects, but there is some indication that it favors south-facing slopes (Colorado Natural Heritage Program 2006).

Reproductive biology and autecology

In the Competitive/Stress-Tolerant/Ruderal (CSR) model of Grime (2001), characteristics of *Mentzelia chrysantha* most closely approximate those of a stress-tolerant ruderal species. As with many

Table 6. Soil characteristics in *Mentzelia chrysantha* occurrences (from Larsen et al. 1979, U.S. Department of Agriculture 1994, and Wheeler et al. 1995).

Soil Series	Characteristics
Manzanola	Fine grained (with high silt and/or clay content), formed in alluvium, moderately alkaline, on 1 to 5 percent slopes, deep and well drained, with a layer of calcium carbonate 10 to 20 inches below the surface.
Limon	Deep, well drained soils on foot slopes, fans and stream terraces, formed in clayey alluvium, 0 to 12 percent slopes, moderately alkaline.
Nunn	Deep, well drained soils on foot slopes, fans and stream terraces, formed in clayey alluvium or loess, 0 to 8 percent slopes, neutral pH to moderately alkaline.
Swissvale	Shallow, well drained soils on mountainsides, formed from sandstone or siltstone, 20 to 55 percent slopes, skeletal and loamy, often gravelly or rocky, neutral pH to mildly alkaline.
Stoneham	Deep, well drained soils, loamy, brown to brownish gray, formed on terraces, slope is 0 to 3 percent, moderately permeable

species of *Mentzelia*, *M. chrysantha* is found on sites that are moderately disturbed. The most consistent feature of ruderal species in the CSR model is an annual or short-lived perennial life history (Grime 2001). *Mentzelia chrysantha* is probably a biennial under ideal conditions but can persist for several years as a rosette while it awaits favorable conditions for flowering. Like other members of *Mentzelia* section *Bartonia*, *M. chrysantha* devotes all of its reserves to producing numerous flowers on a tall inflorescence and dies after setting seed (Darlington 1934, Christy 1995).

A number of observations suggest that disturbance plays an important role in the autecology of *Mentzelia chrysantha*. This species evolved under a natural disturbance regime on wasting shale slopes in unstable clayey soils. *Mentzelia chrysantha* does not appear to tolerate prolonged or constant disturbance, such as strip mining. It favors sites that are periodically disturbed but not constantly used, such as highway right-of-ways, and it colonizes newly disturbed or exposed shale surfaces if they are not continuously disturbed, such as road cuts (Coles personal communication 2003). Other species in section *Bartonia*, including *M. multicaulis*, have a similar tendency. Biennials are often found in sites that are disturbed periodically but not every year (Barbour et al. 1987). It is likely that *M. chrysantha* favors disturbed sites because there are fewer competitors. *Mentzelia chrysantha* is almost never seen in sites where competitive species are found. In its typical shale barren habitat, vegetation cover is naturally sparse, probably due to a combination of stress and disturbance imposed by the harsh edaphic conditions characteristic of shale barrens. The erosive nature of the shale and limestone soils where *M. chrysantha* occurs probably results in natural chronic disturbance even in late seres.

Due to human alteration of its habitat, *Mentzelia chrysantha* appears to have exploited habitats that are maintained by anthropogenic disturbance such as road cuts and highway right-of-ways. While this might permit *M. chrysantha* to persist and may even allow it to colonize areas that were previously unsuitable, reliance on human-imposed disturbance regimes puts it directly in the path of human impacts.

While its life history, tolerance of (or perhaps affinity for) disturbance, and ability to colonize disturbed sites typifies *Mentzelia chrysantha* as a ruderal species, it also has attributes of a stress-tolerator as defined by Grime (2001). Its ability to thrive in soils that are heavy, droughty, and deficient in nutrients suggests that the species is tolerant of the stresses imposed by the aberrant edaphic conditions of its habitat. Soils derived from shale are inherently stressful to plants due to their low oxygen levels in the rhizosphere, expansion and contraction, poor water infiltration, and high osmotic potential (reviewed in Potter et al. 1985). If *M. chrysantha* is a calciphile, it has adaptations that permit it to grow best in soils rich in calcium carbonate (Art 1993).

As a biennial or monocarpic perennial with relatively large amounts of biomass allocated to the production of seeds, the life history of *Mentzelia chrysantha* is best classified as *r*-selected (using the classification scheme of MacArthur and Wilson 1967). The role of disturbance in the autecology of *M. chrysantha* also typifies it as an *r*-selected species, as does its semelparous life history and lack of strong competitive interactions (Pianka 1970). Because biennials have a short life span and lack the ability to reproduce vegetatively, there is strong selective pressure for successful sexual reproduction in a given year (Spira and Pollak 1986).

Reproduction

Members of section *Bartonia* are predominantly outcrossing and self-incompatible (Thompson and Prigge 1984). Lack of seed set under greenhouse conditions has shown that *Mentzelia nuda* (in section *Bartonia*) is an obligate outcrosser (Brown and Kaul 1981). However, other studies have reported some degree of self-compatibility or facultative autogamy in *Mentzelia* (e.g., Brown 1971, Thompson and Prigge 1984, Little 1985). Most species of *Mentzelia* exhibit adaptations that encourage outcrossing (Brown 1971). During anthesis, the stigma is exerted above the anthers, presumably to reduce the potential for self-pollination.

Results of a preliminary study of the floral biology of *Mentzelia chrysantha* showed that it is an obligate outcrosser (Spackman Panjabi personal communication 2003, Spackman Panjabi 2004). In 2001, bagged flowers did not set seed while unbagged flowers on the same plant produced a great deal of seed.

Polyploidy has not been observed in section *Bartonia*. The haploid chromosome number (n) is 10 for *Mentzelia chrysantha* (Thompson 1963).

Pollinators and pollination ecology

The pollination ecology of the Loasaceae has been little studied. Potential pollinators of members of section *Bartonia* include bees, bumble bees, wasps, butterflies, syrphids, flies, and ants (Thompson 1963, Brown and Kaul 1981, Keeler 1981, Little 1985, Christy 1995). Brown (1971) noted honeybees and sphinx moths as being among the visitors of *Mentzelia* decapetala flowers. A preliminary investigation of the pollination biology of *M. chrysantha* was completed in 2001 (Spackman Panjabi 2004). Several other species endemic to the Arkansas River Valley were also studied in this project (*M. densa*, *Oenothera harringtonii*, *Mirabilis rotundifolia*, *Penstemon degeneri*, and *Oönopsis puebloensis*).

The flowers of *Mentzelia chrysantha* open at 18:00 and remain open until 21:00 (Spackman Panjabi 2004). Those who have observed the opening of the flowers have noted anecdotally that "you could set your watch by it" (Coles personal communication 2003, Spackman Panjabi personal communication 2003). Pollinator visitation was greater on cloudy evenings. The flowers open repeatedly for an unknown number of evenings. Pollen viability has not been measured in *M. chrysantha*, but studies of other members of section *Bartonia* suggest that it is probably high, exceeding 90 percent in most cases (Christy 1995).

Members of section *Bartonia* show no structural adaptations to specific pollinators although the petaloid staminodia and flower color variation may serve to attract certain pollinators (Christy 1995). *Mentzelia chrysantha* appears to rely on a broad suite of insects for pollination. Plants with very little floral specialization are considered 'promiscuous plants' because they utilize unspecialized, generalist pollinators as pollen vectors (Grant 1949, Bell 1971). Reliance on a broad suite of pollinators for pollinator services probably buffers promiscuous plants from population swings of any one pollinator (Parenti et al. 1993). Insect visitors collected on or near *M. chrysantha* (**Table 7**) and observed during timed observations of its flowers

Table 7. Insects collected during visitation to *Mentzelia chrysantha* at two sites in the middle Arkansas Valley, Fremont and Pueblo counties, Colorado, July 17-18, 2001. Identification determined by Drs. B. Kondratieff and H.E. Evans. Table from Spackman Panjabi (2004).

Order	Family	Genus	Species	# collected	% of total collected
Coleoptera (beetles)	Aponidae (a weevil)	*Apion*	sp.	2	2%
Diptera (flies)	Bombyliidae			1	1%
	Bombyliidae (bee flies)	*Poecilognathus*	*scolopax*	2	2%
	Syrphidae (syrphid flies)	*Eristalis*	*stipator*	1	1%
	Syrphidae	*Eupeodes*	*volucris*	1	1%
	Tachinidae (tachinid flies)			2	2%
Total Diptera				**7**	**7%**
Hemiptera (true bugs)	Miridae (plant bugs or leaf bugs)			1	1%
Hymenoptera (bees, wasps, and ants)	Andrenidae. (solitary bees)	*Andrena*	sp.	2	2%
	Andrenidae	*Perdita*	sp.	16	17%
	Apidae	*Apis*	*mellifera* (honey bee)	16	17%
	Apidae	*Bombus* (bumble bees)	*nevadensis*	4	4%
	Apidae	*Bombus*	*griseocollis*	1	1%
	Formicidae (ants)	*Formica*	sp.	11	12%
	Halictidae (halictid bees)	*Halictus*	*confusus*	1	1%
	Halictidae	*Lasioglossum*	sp.	18	19%
Total Hymenoptera				**69**	**73%**
Thysanoptera (thrips)				9	9%
Unidentified				7	7%
Total collected				**95**	**100%**

(**Figure 8**) included bees, flies, and ants. Average visitation rate for all insects visiting *M. chrysantha* was 6.0 visits per flower per 30 minutes, mostly by bees, wasps, and flies (Spackman Panjabi 2004). Many of the taxa observed (*Perdita*, *Lasioglossum*, *Bombus*, and *Andrena*) are solitary, ground-nesting bees (Borror et al. 1989, Finnamore and Michener 1993). None of the insects visiting *M. chrysantha* in 2001 are specialists (Spackman Panjabi 2004).

Ants may play a role in the reproductive biology of *Mentzelia chrysantha*. They were frequent floral visitors to *M. chrysantha* in 2001, visiting an average of 0.89 corollas per 30 minutes (Spackman Panjabi 2004). Although ants can act as pollinators, it is unlikely that ants are pollinating *M. chrysantha*; ant pollination is rare and difficult to verify (Hickman 1974, Beattie et al. 1984). However, Keeler (1981) made some interesting observations on the role of ants in the reproductive biology of *M. nuda*. In this species, nectar is produced while the flower is open, and it continues to be produced through approximately half of the development of the fruit after the petals and stamens have fallen away. When the plant is in flower, ants are excluded from reaching the nectaries by the numerous stamens, but during fruiting the ants can reach the nectaries and they visit them frequently. Keeler (1981) excluded ants from visiting the postfloral nectaries of some plants while permitting normal ant visitation on other plants. Plants where ants were excluded showed significantly lower seed set and greater damage to capsules from seed predators than did the controls. It appears that ants defend the developing seed capsules from potential predators. The prolonged production of nectar, though energetically costly, is an effective payoff for the protection provided by ants. Given the close relationship between *M. nuda* and *M. chrysantha*, it is plausible to speculate that *M. chrysantha* is involved in a similar ant-plant symbiosis. *Mentzelia chrysantha* may offer a nectar reward to pollinators, but it is not known whether it has post-floral nectaries such as those of *M. nuda*.

Phenology

The seeds of *Mentzelia chrysantha* germinate in the early spring or in late summer during a wet monsoon year (Kelso personal communication 2006). *Mentzelia chrysantha* is in flower through most of the late summer months, during which it bears numerous flowers in a tall inflorescence. Plants are in bloom from July to early September, and they are in fruit from late August into September (Spackman et al. 1997). Because *M. chrysantha* occurs in xeric sites, the periodicity of successful recruitment may coincide with wet or otherwise favorable years during which seedlings can become established. Seeds are dispersed in the fall and winter. Dead stalks with dehisced fruits remain erect through the fall and into winter, during

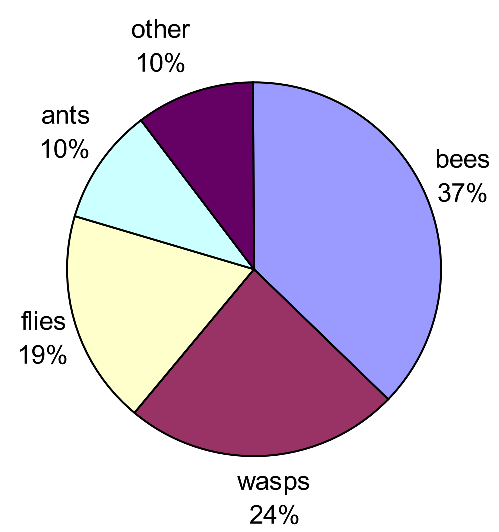

Figure 8. Proportion of observed insect visits by flies, ants, wasps, bees, and other unidentified insects during 13 30-minute observations of Mentzelia chrysantha at two study sites in Colorado's middle Arkansas Valley. Figure from Spackman Panjabi 2004.

which the seeds are blown and shaken from the fruits and may be dispersed by animal vectors. There has been no investigation of the germination requirements and safe site conditions for *M. chrysantha*.

Fertility and propagule viability

There has been no investigation of the fertility and seed longevity of *Mentzelia chrysantha*, but seed viability in the Loasaceae tends to be short (Brown 1971). Although ruderal species tend to have greater seed longevity than other species (Rees 1994), studies of other taxa suggest that the seeds of *Mentzelia* are only viable for approximately two years (Brown 1971). However, in viability tests of the seeds of the closely related *M. densa*, 48 percent were still viable after two years (Coles 1990). The seeds tested were not fully mature, so viability may be even higher using mature, oven-dried seed. A single fruit (capsule) of *M. chrysantha* typically produces 50 to 80 seeds (Harrington 1954).

Dispersal mechanisms

As a biennial or short-lived monocarpic perennial, seed bank dynamics are particularly important in the life cycle of *Mentzelia chrysantha*. Because the long-term viability of *M. chrysantha* seeds is probably limited, it is imperative that it successfully produces a robust seed crop almost every year. Seeds of section *Bartonia* are winged, which may aid dispersal (Brown 1971). When ripe, the capsule dehisces to allow the seeds to disperse. Strong winds can rock the stiff stems back and forth, flinging seeds out of the capsules (Kelso personal communication 2003). The distinctive velcro-like hairs of *M. chrysantha* are present on the stems, leaves, and capsules, allowing them to stick tenaciously to the fur of an animal. This gives some species of *Mentzelia* the common name "stickleaf." The capsules are weakly connected to the stem by a short peduncle, so the capsules, or sometimes larger portions of the plant, can break off and stick to an animal brushing by. This is an effective means of seed dispersal.

Phenotypic plasticity

There is nothing in the literature to suggest that *Mentzelia* species are phenotypically plastic. Weigend et al. (2000) noted that some species of *Nasa* (Loasaceae) have highly variable leaf shapes. This is probably an adaptive response to insect attack since some insects use leaf shape as a cue to identify their desired host plants. The specific response of *M. chrysantha* to browsing by herbivores has not been studied. Stowe et al. (2000) presents an overview of plant tolerance to consumer damage. *Mentzelia chrysantha* individuals vary in size, stature, and reproductive effort, probably due to year-to-year variations in climate and local availability of resources.

Mycorrhizal relationships

Roots of *Mentzelia chrysantha* have not been assayed for the presence of mycorrhizal symbionts. Information on the mycorrhizae of *Mentzelia* and the Loasaceae is sparse to non-existent. In general, members of the Magnoliophyta (flowering plants), including the Violales and Cornales (depending on whose taxonomic treatment of the Loasaceae is used) but excluding the orders Amborellales, Nymphaeales, and Austrobaileyales, may have arbuscular mycorrhizal (AM) symbioses (Stevens 2002). AM fungi belong to a group of non-descript soil fungi (Glomales) that are difficult to identify because they seldom sporulate (Fernando and Currah 1996). They are the most abundant type of soil fungi (Harley 1991) and infect up to 90 percent of all angiosperms (Law 1985). AM fungi are generally thought to have low host specificity, but there is increasing evidence for some degree of specificity between some taxa (Rosendahl et al. 1992, Sanders et al. 1996). While this group has not previously been thought of as particularly diverse, recent studies suggest that there is unexpectedly high diversity at the genetic (Sanders et al. 1996, Varma 1999) and single plant root (Vandenkoornhuyse et al. 2002) levels. As root endophytes, the hyphae of these fungi enter the cells of the plant roots where water and nutrients are exchanged in specialized structures.

Hybridization

While hybridization events appear to be uncommon among members of *Mentzelia*, they have been observed occasionally. Taxonomic difficulties in the genus *Mentzelia* may be the result of past hybridization events (Holmgren and Holmgren 2002). Among members of section *Bartonia*, natural hybrids have been reported between *M. decapetala* and *M. laevicaulis* (Thompson 1963) and between *M. multiflora* and *M. saxicola* (Thompson and Zavortink 1968). Artificial hybrids have also been induced by crossing *M. candelariae* with *M. laevicaulis* (Thompson 1963), *M. candelariae* with *M. albescens* (Thompson and Prigge 1984), and *M. marginata* with *M. cronquistii* (Thompson and Prigge 1986). All of these hybrids produced very little viable pollen and no seed, suggesting that hybridization events that result in stable hybrid populations are rare in section *Bartonia*

(Thompson and Zavortink 1968, Thompson and Prigge 1984, Thompson and Prigge 1986). There are probably strong barriers to interbreeding in section *Bartonia*, and extensive gene exchange among its members is unlikely (Christy 1995).

Mentzelia nuda and *M. reverchonii* are sympatric with *M. chrysantha*; these species are potential parents of hybrids with *M. chrysantha*. *Mentzelia densa*, which like *M. chrysantha* has a base chromosome number of 10 (Thompson 1963), also may be capable of hybridizing with *M. chrysantha*; however, there have been no observations of apparent hybrids reported. Occurrences of *M. chrysantha* and *M. densa* are not sympatric, but they are close enough for some gene exchange to occur, and both species are members of section *Bartonia* (Gilg 1894, Darlington 1934). There are no reports in the literature of any hybridization between *M. chrysantha* and other species of *Mentzelia*.

Demography

Three occurrences of *Mentzelia chrysantha* are small enough to be negatively affected by demographic and genetic stochasticity. Demographic stochasticity results from chance variation in vital rates such as survival and reproduction, and it becomes a concern in populations of 50 or fewer individuals (Menges 1991). Genetic stochasticity includes founder effects, inbreeding depression, loss of genetic variation due to genetic drift, and the accumulation of deleterious mutations (Matthies et al. 2004); it generally becomes a concern in effective populations of fewer than 500 individuals. As an obligate outcrossing species, *M. chrysantha* is vulnerable to inbreeding depression in small populations or in populations with limited pollinator activity. It is likely that some genetic diversity is being lost due to fragmentation and disturbance of *M. chrysantha* habitat.

Because of its limited global range, environmental stochasticity could threaten the persistence of *Mentzelia chrysantha*. Environmental stochasticity includes temporal variation in reproduction and survival as a consequence of environmental conditions and catastrophic local events, and it could lead to extinction (Lande 1998, Oostermeijer et al. 2003). Environmental stochasticity can operate at many scales and thus may impact large or small populations. Maintaining the largest occurrences possible is most likely to reduce potential negative consequences of environmental stochasticity.

The lifespan of *Mentzelia chrysantha* has not been determined. Members of section *Bartonia* are short-lived monocarpic perennials, but some may be capable of successfully reproducing in a single year (Keeler 1987, Christy 1995). Monocarpic species produce seeds one time, and then the entire plant dies. *Mentzelia chrysantha* has been characterized as a biennial or monocarpic perennial (Darlington 1934, Colorado Natural Heritage Program 2006), but there has been some speculation that it may occasionally be capable of bolting more than once (Coles personal communication 2003). It may also be capable of reproducing in its first year (Kelso personal communication 2006). *Mentzelia chrysantha* can flower at the end of its second growing season, but it can also persist for years as a rosette. There are no data regarding the proportion of individuals within a population that reproduce in a given year. There are also no demographic data from which a life cycle graph can be produced. **Figure 9** is a hypothetical life cycle graph for *M. chrysantha*. Identifying critical life history stages that contribute most to population or metapopulation dynamics is crucial to developing recovery strategies for rare plants (Schemske et al. 1994). Critical life history stages have not been identified for *M. chrysantha*.

The authors were unable to find any evidence of a population viability analysis (PVA) for *Mentzelia chrysantha*, any other member of the genus *Mentzelia* or the Loasaceae from which inferences could be drawn for this assessment. One species of *Mentzelia* (*M. leucophylla*) is currently listed as endangered (U.S. Fish and Wildlife Service 1985, U.S. Fish and Wildlife Service 1986), but there has been no PVA of this species to date. Monitoring and preliminary quantitative assessment of population viability have been conducted for this species (Reveal 1978).

The limited lifespan of short-lived species such as *Mentzelia chrysantha* results in a rapid turnover of populations, requiring new individuals to be recruited into populations at frequent intervals (Spira and Pollak 1986). Reproductive output is much higher in favorable years than in unfavorable years, when very little reproductive effort occurs (Spackman Panjabi personal communication 2003). Seed production may be copious during wet years (Kelso personal communication 2006). The optimal conditions for reproduction are not known for *M. chrysantha*, but observations suggest that it responds positively to high soil moisture during wet summers, and remains in the rosette form during dry summers.

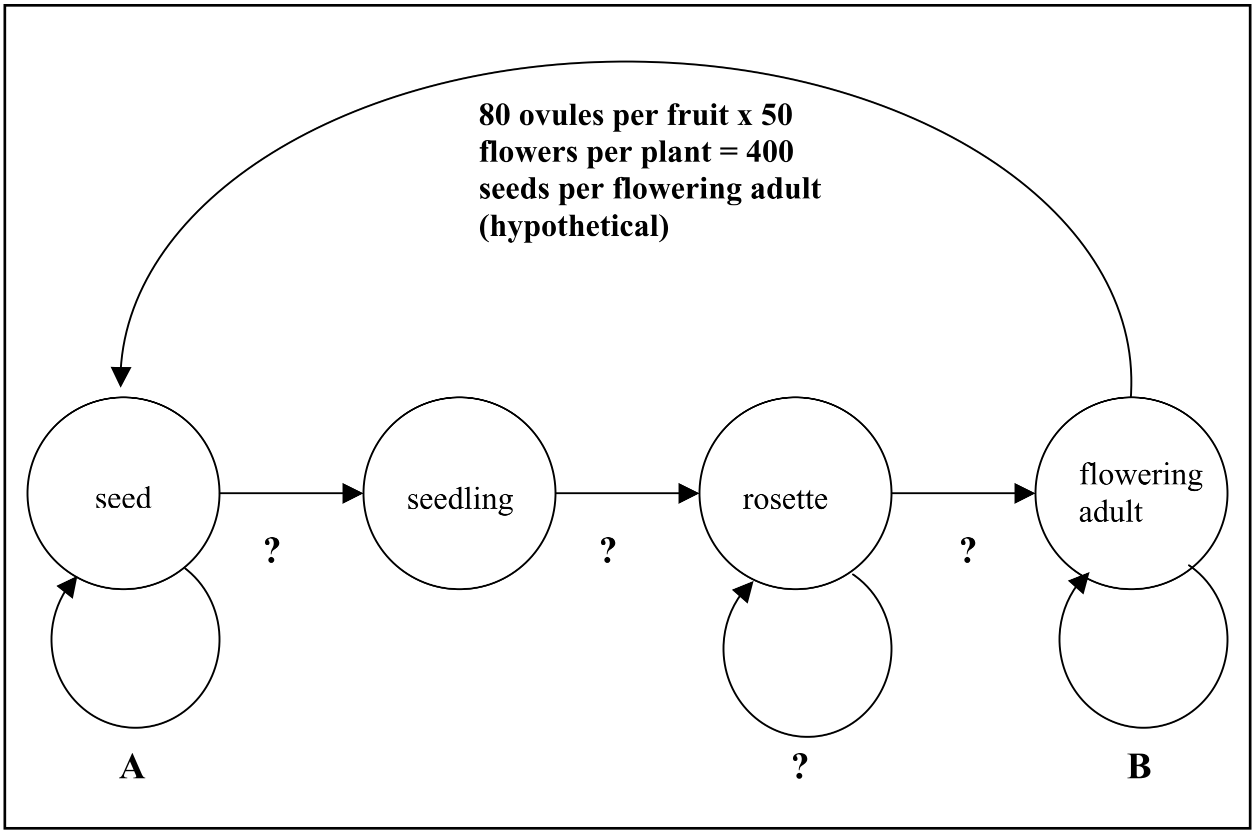

Figure 9. Hypothetical lifecycle graph (after Caswell 2001) for *Mentzelia chrysantha*, including the known life history stages gleaned from limited observations and from information from other members of section *Bartonia*. No transition probabilities are known for *M. chrysantha*, and there has been no demographic monitoring of other species of *Mentzelia* from which inferences can be drawn. The hypothetical transition rate for flowering adult to seed is for a hypothetical plant with 80 viable seeds per fruit (Harrington 1954). Seed longevity is limited for species of *Mentzelia*, typically not exceeding two years (Brown 1971), suggesting that (A) is probably small. However, 48 percent of seeds of *M. densa* remained viable after two years (Coles 1990), suggesting that the seeds of *M. chrysantha* may also remain viable for two or more years. As a monocarpic species, there would be no return arrow in the flowering adult stage (B), but Coles (personal communication 2003) suggested that plants may occasionally be capable of bolting more than once.

As a habitat specialist, *Mentzelia chrysantha* is naturally limited by the availability of its habitat. Experiments on other shale endemics have shown lower germination rates in soils from outside the native range of the species (e.g., Collins 1995); this may preclude the establishment of occurrences on substrates derived from other parent materials. However, other rare shale endemics such as *Mirabilis rotundifolia* and *Physaria bellii* are able to thrive in gardens or greenhouses in richer soils (personal communication Kelso 2006, personal communication Kothera 2006). It is not known if *Mentzelia chrysantha* is seed-limited or what factors control seedling recruitment. Habitat destruction and fragmentation are occurring rapidly throughout the area occupied by *M. chrysantha*. Intensive land use practices such as strip mining preclude colonization or persistence of occurrences in these locations.

Community ecology

The Arkansas River Valley supports a rich flora, including eight plant species endemic to the valley and surrounding areas (**Table 8**; Kelso 1995, Colorado Natural Heritage Program 2006). The middle Arkansas Valley has been identified as a priority area for biodiversity conservation due to its high global biodiversity significance (The Nature Conservancy 1998, Neely et al. 2001, Spackman Panjabi et al. 2003, The Nature Conservancy 2005, Colorado Natural Heritage Program 2006).

On the eastern mountain front in Colorado, strata were tilted eastward by the uplift during the Laramide Orogeny (Huber 1993). Subsequent erosion exposed many different strata, creating a complex mosaic of

Table 8. Other rare plant species tracked by the Colorado Natural Heritage Program occurring in the middle Arkansas Valley (Colorado Natural Heritage Program 2006).

Species	G/S Rank	Endemic or nearly endemic to middle Arkansas Valley	Occurs with *Mentzelia chrysantha*
Asclepias uncialis ssp. *uncialis*	G3G4T2T3 S2		×
Bolophyta tetraneuris	G3 S3	×	
Eriogonum brandegeei	G1G2 S1S2		
Grindelia inornata	G2? S2?	×	
Lesquerella calcicola	G2 S2	×	
Mentzelia densa	G2 S2	×	
Mirabilis rotundifolia	G2 S2	×	×
Oenothera harringtonii	G2 S2		×
Oönopsis puebloensis	G2 S2	×	×
Penstemon degeneri	G2 S2	×	

different substrates. This, along with the resulting complex topography, has resulted in a high degree of endemism in the flora of the Front Range. Endemism is particularly high in the middle Arkansas Valley, where shale substrates, low precipitation and high summer temperatures create a stressful environment for plants. Such areas are called shale barrens, so-named because of their characteristically sparse vegetation. Shale barrens have been referred to as the "cradle for evolutionary diversification and edaphic adaptation" (Kruckeberg 2002, p. 152), and they often support occurrences of narrowly endemic species. **Table 9** is a list of species documented with *Mentzelia chrysantha*.

Vegetation

Coarse-scale vegetation types in which *Mentzelia chrysantha* is found include pinyon juniper-woodland and juniper woodland communities (Colorado Division of Wildlife 1998). While a few occurrences have been documented in pinyon-juniper woodland vegetation, the most commonly associated species are *Frankenia jamesii* and *Atriplex canescens*. This vegetation type, referred to as a marlstone barrens community, is itself rare and is tracked by the Colorado Natural Heritage Program (Colorado Natural Heritage Program 2006). *Frankenia jamesii* is a distinctive short shrub that is disjunct in the Arkansas Valley. It is also known from the badlands and barrens habitats in Montezuma County, Colorado and in Texas and New Mexico. This community has southern floristic affinities, primarily with the Chihuahuan Desert (Naumann 1990, Kelso 2004). Plant cover is usually less than 25 percent on the Niobrara Shale barrens of the Arkansas Valley (Kelso et al. 1999a).

Pinyon-juniper woodlands are widely distributed throughout the western United States (West and Young 2000), and they comprise approximately 11 percent of the Southern Rocky Mountain Ecoregion (Rondeau 2000). In the Arkansas River Valley, *Pinus edulis* and *Juniperus monosperma* are the dominant overstory species (Chumley 1998). This is the northernmost extent of this community, which is more common in northern New Mexico and West Texas (Peet 2000).

Herbivores

No evidence of browsing or grazing of *Mentzelia chrysantha* has been observed (Coles personal communication 2003). Some evidence of browsing by a large vertebrate was observed infrequently on *M. multicaulis* (Christy 1995). Observations of insect herbivores on *Mentzelia* have included aphids, spidermites, weevil and moth larvae eating developing seeds, and grubs eating the roots (Christy 1995). The capsules of *M. nuda* are attacked by several insects (Keeler 1981). The weevil *Orthoris crotchi* Lec and the larvae of the moth *Strymon melinus* Hubner account for most of the damage to seeds observed by Keeler (1981). Beetles and an unidentified green larva also were observed feeding on capsules of *M. nuda*.

Weigend et al. (2000) offer some hypotheses regarding herbivore defense mechanisms in the Loasaceae. Most members of this family are heavily armed, both physically and chemically. The authors suggest that the synthesis and sequestration of iridoid compounds is a mechanism for repelling large herbivores. These compounds are not effective against insects; their presence suggests that taxa replete with

Table 9. Associated species that have been documented with *Mentzelia chrysantha*. Sources include herbarium specimen labels (UC, CS, RM, CC), Colorado Natural Heritage Program element occurrence records, and Anderson et al. (2001). C= common associate, E= exotic, and R= rare plant tracked by the Colorado Natural Heritage Program.

Associated Species	**Common Name**		**Associated Species**	**Common Name**	
Achnatherum hymenoides	Indian ricegrass	R	*Juniperus scopulorum*	Rocky Mountain juniper	
Aristida purpurea	purple threeawn		*Melampodium leucanthum*	plains blackfoot	
Artemisia bigelovii	Bigelow sage		*Melilotus officinalis*	yellow sweetclover	E
Asclepias uncialis	wheel milkweed	R	*Mentzelia decapetala*	tenpetal blazingstar	
Atriplex canescens	fourwing saltbush	C	*Mentzelia nuda*	bractless blazingstar	
Atriplex confertifolia	shadscale saltbush		*Mentzelia reverchonii*	Reverchon's blazingstar	
Atriplex sp.	saltbush		*Mirabilis rotundifolia*	roundleaf four o'clock	R
Bromus tectorum	cheatgrass	E	*Oenothera harringtonii*	Colorado Springs evening-primrose	R
Cercocarpus montanus	alderleaf mountain mahogany		*Oligosporus pacificus*	field sagewort	
Chrysothamnus nauseosus	rubber rabbitbrush		*Opuntia* spp.	pricklypear	
Clematis ligusticifolia	western white clematis		*Oreocarya* sp.	cryptantha	
Conyza canadensis	Canadian horseweed		*Oryzopsis hymenoides*	Indian ricegrass	
Cylindropuntia imbricata	tree cholla		*Penstemon auriberbis*	Colorado beardtongue	
Eriogonum effusum	spreading buckwheat		*Pinus edulis*	twoneedle pinyon	
Frankenia jamesii	James' seaheath	C	*Psoralidium* sp.	scurfpea	
Grindelia squarrosa	curlycup gumweed		*Salsola iberica*	prickly Russian thistle	E
Hesperostipa neomexicana	New Mexico feathergrass		*Sporobolus airoides*	alkali sacaton	
Hilaria jamesii	James' galleta		*Yucca glauca*	soapweed yucca	
Juniperus monosperma	oneseed juniper		*Zinnia grandiflora*	Rocky Mountain zinnia	

iridoids evolved under intense pressure from large herbivores. Leaf hairs are more effective at repelling insect pests, so taxa with a heavy armament of trichomes are probably the product of evolution under heavy insect herbivory. The hairs of *Mentzelia* species are effective at trapping and killing insects (Eisner et al. 1998). Iridoids have been isolated from members of section *Bartonia*, including *M. decapetala* (Danielson et al. 1973, Danielson et al. 1975); iridoid concentrations in *M. chrysantha* have not been measured.

Members of the genus *Mentzelia* are noted for their selenium uptake, but none have been cited for toxicity to livestock (Burrows and Tyrl 2001). Members of this genus are generally avoided by livestock and mammalian herbivores (Coles personal communication 2003), most likely due to their dense vesture of unpalatable hairs and the iridoid compounds produced by members of this genus (Weigend et al. 2000).

Competitors

There has been no formal study of the community ecology and interspecific relationships of *Mentzelia chrysantha*. As a habitat specialist, *M. chrysantha* may be a poor competitor, which may mean that it is vulnerable to competition from introduced species. Many reports have reported that it is typically found in barren habitats with little competition from other species (Colorado Natural Heritage Program 2006). This is typical of stress-tolerant species as described by Grime (2001). Sites such as wasting slopes, badlands, and road cuts are chronically disturbed and maintained in a state of arrested succession; this probably excludes many potential competitors that are poorly adapted to these sites. *Mentzelia chrysantha* is seldom found in close association with grass species, and it is rarely seen in areas with high grass cover (Coles personal communication 2003). This is possibly due to the highly competitive nature of many grasses (Grime 2001).

There has been no investigation or documentation of the relationship of *Mentzelia chrysantha* with biological soil crusts. These crusts are relatively uncommon in the shale-dominated habitats occupied by *M. chrysantha*. While the presence of biological soil crusts enhances the available soil nitrogen and other essential nutrients for plants (Belnap et al. 2001), biological soil crusts compete vigorously for phosphorus with *M. multiflora* in southeastern Utah (Belnap and Harper 1995). Clayey soils derived from shale due are generally too mobile to support the development of biological soil crusts.

Parasites and disease

There are no reports of parasites or disease for *Mentzelia chrysantha* or other species of *Mentzelia*. Two aphids, *Macrosiphum mentzeliae* and *Pleotrichophorus wasatchii*, attack species of *Mentzelia* in the Rocky Mountain Region (Palmer 1952). The protective hairs covering most *Mentzelia* species are apparently not very effective at repelling aphid attacks, but they do incapacitate a coccinellid beetle (*Hippodamia convergens*) that preys on aphids. Thus the benefit to the plant from its defensive hairs is offset by a cost (Eisner et al. 1998). Eisner et al. (1998) observed that numerous other harmless insects were found stuck to the trichomes.

CONSERVATION

Threats

There are several threats to the persistence of *Mentzelia chrysantha*. In order of decreasing priority, these include residential and commercial development, mining, recreation, right-of-way management, exotic species, grazing, effects of small population size, climate change, and pollution. These threats and the hierarchy ascribed to them are speculative, and more complete information on the biology and ecology of this species may reveal other threats. Not all threats apply equally to all occurrences, and the priority of threats may vary among occurrences. The various threats tend to interact and compound one another; thus a separate discussion of each of these effects is not warranted. Because *M. chrysantha* is not known to occur on any National Forest System land, the threats discussed in this section are based on observations of occurrences on BLM, state, and private lands; the potential for these threats to affect occurrences that might exist on National Forest System land is discussed where relevant. Assessment of threats to this species is an important component of future inventories and monitoring.

Influence of management activities or natural disturbances on habitat quality and individuals

Residential and commercial development

Residential development is the greatest threat to the quality and availability of habitat for *Mentzelia chrysantha*. Urban growth rates are higher in the Colorado Front Range than anywhere else in the United States (US Census Bureau 2003). The population of Fremont County grew 43 percent from 1990 to 2000, and it is among the fastest growing counties in the United States (U.S. Census Bureau 2003). Residential development throughout the Arkansas Valley has resulted in a significant decline in the amount of available habitat for *M. chrysantha*. Exurban development such as subdivision of property into ranchettes and construction of second homes is accelerating in the region and represents a greater threat to *M. chrysantha* than high-density development at the peripheries of Cañon City, Pueblo, and Florence. Low and medium-density development fragment large areas of natural habitat (Knight et al. 2002). The proliferation of roads and disturbance from construction directly threatens occurrences of *M. chrysantha*; secondary impacts include blocking pollinators that the species requires in order to produce seed (Forman and Alexander 1998) and encouraging the spread of noxious weeds into *M. chrysantha* habitat.

Mining

Mining for gravel and for raw materials from which to make cement is widespread in the area occupied by *Mentzelia chrysantha* (Colorado Natural Heritage Program 2006). Removal of bedrock in mined areas also removes the native vegetation. It is not known if *M. chrysantha* can recolonize these sites. This species' presence on road cuts suggests that recolonization is possible, but it is unlikely if mining removes all suitable geologic substrate for *M. chrysantha*. If grass is used to revegetate reclaimed areas, it is unlikely that *M. chrysantha* will be able to compete. At present, mining activities are concentrated on private lands; there is no mining or proposals to mine shale or gravel on the San Isabel National Forest near *M. chrysantha*.

Recreation and off-highway vehicle use

Several element occurrence records note the presence of off-highway vehicle and mountain bike impacts in *Mentzelia chrysantha* occurrences. Shale barrens are frequently exploited for off-highway vehicle recreation because of their challenging slopes and the lack of interference from vegetation (Lyon and Denslow 2001). Management attention is needed for many occurrences, including those at Garden Park where mountain bike activity and the potential for unauthorized off-highway vehicle travel are increasing (Anderson et al. 2001). Unauthorized use of off-highway vehicles is a potential threat to occurrences that might occur on the San Isabel National Forest.

Christo and Jeanne-Claude are planning a massive art installation along 4 to 6 miles of the Arkansas River in 2009, called "Over the River" (Christo and Jeanne-Claude 2005). This project will involve the installation of fabric curtains that will be anchored to the canyon walls and cover the river. The BLM Royal Gorge Field Office and Colorado Division of Parks and Outdoor Recreation are analyzing the potential impacts to *Mentzelia chrysantha* and other rare plant species from this project (Billerbeck personal communication 2006, Brekke personal communication 2006). For *M. chrysantha*, the primary concern is the impact of visitors who will come to see the installation, which is expected to draw 250,000 to 1,000,000 visitors during the two-week period that it is installed (Brekke personal communication 2006). Occurrences of *M. chrysantha* that are either in areas that offer good vantage points or easily accessed from Highway 50 are most likely to be impacted. The use of heavy equipment could impact *M. chrysantha* locally during the three years over which it will be constructed, displayed, and disassembled. An Environmental Impact Statement for this proposal is currently being drafted (Christo and Jeanne-Claude 2005).

At Fort Carson Military Reservation, training take place within the range of *Mentzelia chrysantha* (Colorado Natural Heritage Program 2006). Maneuvers involve driving tanks and other military vehicles cross-country to practice military maneuvers and artillery use. Although the practice maneuvers occur in the southern portion of the reservation where *M. chrysantha* is found, threats from this activity are low (Kelso personal communication 2006). *Mentzelia chrysantha* is found on steep, barren slopes and road cuts in this area where tanks cannot drive, so the use of military vehicles is unlikely to cause direct mortality. Artillery fire may cause local disturbances that result in mortality of *M. chrysantha*, but periodic disturbance of this sort is unlikely to result in large impacts to occurrences. Artillery fire may even benefit *M. chrysantha* by locally decreasing the prevalence of competitors (Kelso personal communication 2006).

Right-of-way management

Occurrences within right-of-ways are susceptible to road maintenance activities such as mowing, spraying for weeds, installing and maintaining underground utilities, and widening of roads. Although plans have been formulated to mitigate these threats (Grunau et al. 2003), full mitigation will be difficult. Plants within 23 ft. of the pavement (or 15 ft., depending on the size of the mower used) will probably be mowed repeatedly through the growing season (Powell personal communication 2003). Utility installation and maintenance is likely to result in repeated ground disturbance in right-of-way occurrences.

Fort Carson Military Reservation will be expanding its role as a training facility and will probably add approximately 5,000 troops beginning in 2006. It is likely that roads accessing the southern part of the installation will be widened, and all plants on road cuts will likely be destroyed. This will affect approximately 1/3 of the plants known on Fort Carson, with the greatest impacts to the Pierce Gulch occurrence (Rifici personal communication 2006). If individuals and a source of seeds remain after road widening, it is likely that *Mentzelia chrysantha* will recolonize these areas.

Exotic species

Non-native species have not been reported as negatively impacting *Mentzelia chrysantha*. Kelso et al. (1999a) observed very little evidence of exotic species in shale barrens, even where anthropogenic disturbance had reduced vegetation cover. However, three exotic species have been documented with *M. chrysantha*: cheatgrass (*Bromus tectorum*), Russian thistle (*Salsola australis*), and yellow sweetclover (*Melilotus officinale*). These species threaten occurrences of *Mentzelia chrysantha* in both natural and human-impacted habitat. The most pervasive weeds in the habitat of *M. chrysantha* at the Garden Park ACEC are yellow sweetclover and Russian thistle, and a monitoring program has been initiated to study the behavior of these species and their impacts on *M. chrysantha* and *Eriogonum brandegeei* (Anderson et al. 2001). Other exotic species present in the vicinity of Garden Park but not yet within occurrences of *M. chrysantha* include bindweed (*Convolvulus arvensis*), tumblemustard (*Sisymbrium altissimum*), and timothy (*Phleum pratense*). The most frequent exotic species on shale barrens observed by Kelso et al. (1999a) were Russian thistle, smooth brome, and herb sophia (*Descurainia sophia*).

Yellow sweetclover has invaded occurrences of *Astragalus ripleyi*, a rare Colorado and New Mexico endemic, and it apparently results in decreased density of *A. ripleyi* (Colorado Natural Heritage Program 2006). The behavior of this species in the Arkansas Valley should be monitored at Garden Park (where a monitoring study has already been established by Anderson et al. (2001)) and other sites to determine the degree to which it threatens *Mentzella chrysantha*.

Cheatgrass aggressively invades native plant habitat, and its spread throughout the Intermountain West is well documented (Young and Blank 1995). Cheatgrass has spread through pinyon-juniper woodlands throughout the Intermountain West, resulting in increased erosion as perennial understory species are outcompeted (West and Young 2000). The dramatic changes invoked by cheatgrass on the fire ecology of woodland ecosystems are also a cause for concern if it becomes widespread in the shale barrens habitats of *Mentzelia chrysantha*. However, cheatgrass is likely to have competitively excluded *M. chrysantha* before it becomes sufficiently dense to alter the fire regime.

Yellow starthistle (*Centaurea solstitialis*) is present on Colorado's western slope (Dillon 1999), and a population was identified and eradicated on the Colorado Front Range. It poses a very real threat to *Mentzelia chrysantha* and many other native plant species if ongoing efforts to contain it fail. It has a wide ecological amplitude and the potential to spread widely in Colorado. It currently infests 10 million acres in California (Colorado Weed Management Association 2002).

Two exotic species that have spread widely elsewhere and have recently been documented in the Arkansas Valley for the first time include alkali swainsonpea (*Sphaerophysa salsula*) and elongated mustard (*Brassica elongata*) (Elliott personal communication 2006). Other exotic species of concern for *Mentzelia chrysantha* include halogeton (*Halogeton glomeratus*), Russian knapweed (*Acroptilon repens*), and medusa head rye (*Taeniatherum caput-medusae*). Although these species have not yet been documented with *Mentzelia chrysantha*, they are aggressive species that have invaded large areas of native plant habitat throughout the West. Russian knapweed has spread to the southern Front Range area and is extremely difficult to control (Colorado Weed Management Association 2002). Although it can grow in poor soils, Russian knapweed tends to prefer roadside ditches and swales while *M. chrysantha* is found in better-drained, upland settings (Coles personal communication 2003).

Use of herbicides for right-of-way weed management and for range management threatens *Mentzelia chrysantha*. Because roadsides support a large percentage of the known occurrences, their careful management with respect to *M. chrysantha* is important to ensure the continued survival of this species. Care must be taken with the application of herbicides in habitat for *M. chrysantha*, and use of herbicides within known occurrences should be limited to hand application to the target species.

Grazing

At appropriate stocking rates, animals will not tend to enter shale barrens occupied by *Mentzelia chrysantha* since these areas have very low forage value. Impacts to this species from grazing are likely to be greatest with respect to habitat degradation, since *M. chrysantha* is probably not palatable to livestock. In fragile soils such as those inhabited by *M. chrysantha*, grazing enhances erosion, which may benefit or harm *M. chrysantha* depending on its intensity. Other impacts from grazing, particularly those cited by West and Young (2000) in pinyon juniper woodlands, include the introduction of exotics such as cheatgrass.

Small population size

Three occurrences of *Mentzelia chrysantha* reportedly consist of 50 or fewer individuals and are thus susceptible to stochastic processes. Small occurrences are vulnerable to environmental stochasticity (temporal variation in reproduction and survival as a consequence of changing environmental conditions such as weather, herbivory, pollinator availability, and other biotic or abiotic factors), which may lead to local extinction (Lande 1998, Oostermeijer et al. 2003). In small populations of obligate outcrossing species, population viability and fitness may be compromised by shortage of potential mates (House 1993, Murawski et al. 1990), low pollinator visitation rates (Sih and Baltus 1987), and inbreeding depression (Aizen and Feinsinger 1994).

Climate change

Global climate change is likely to have wide-ranging effects in the near future on all habitats, but the direction of projected trends is yet to be determined, and predictions vary based on environmental parameters used in predictive models. For example, Manabe and Wetherald (1986) demonstrate projections based on current atmospheric CO_2 trends that suggest that average temperatures will increase while precipitation will decrease in the West. However, Giorgi et al.

(1998) showed that temperature and precipitation both increased under simulated doubling of atmospheric CO_2 levels. Either scenario could significantly affect the distribution of suitable habitats for *Mentzelia chrysantha*. Temperature increase, predicted by both models, could cause vegetation zones to climb 350 ft. in elevation for every 1 ºF of warming (U.S. Environmental Protection Agency 1997). Because the habitat for *M. chrysantha* is already xeric, lower soil moistures during the growing season induced by decreased precipitation could have serious impacts.

Pollution

Atmospheric nitrogen deposition is one of the most important agents of vegetation change in densely populated regions (Köchy and Wilson 2001). Nitrogen loading and vegetation change are greatest near large metropolitan areas (Schwartz and Brigham 2003). Measurable impacts from nitrogen pollution might therefore be expected within the range of *Mentzelia chrysantha*. Nitrogen enrichment experiments show that nitrogen is limited in undisturbed habitats (Gross et al. 2000). An increase in soil nitrogen tends to cause a few species to increase in abundance while many others decline (Schwartz and Brigham 2003). The degree to which nitrogen pollution has resulted in vegetation change in the habitats of *M. chrysantha* is unknown. Acid deposition, which has increased markedly in Colorado through the 20th century, may have already changed soil chemistry and affected habitat quality for *M. chrysantha* locally or regionally (Burns 2002). However, many sites are buffered by the high pH of their residual soils.

Threats from over-utilization

There are no known commercial uses for *Mentzelia chrysantha*, and there are no reports of over-utilization of the species. There is some limited use of members of the Loasaceae for gardening. There is a long history of traditional medical usage of at least two South American species of *Mentzelia*, *M. chilensis* (Bucar et al. 1998) and *M. cordifolia* (Villegas et al. 1997). *Mentzelia chilensis* shows strong action as an anti-inflammatory while *M. cordifolia* has been used to treat wounds. There has been biomedical research on other taxa of *Mentzelia* as well (El-Naggar et al. 1980, El-Naggar et al. 1982, Nicoletti et al. 1995). There has been no biomedical investigation of *M. chrysantha*, but it is vulnerable to potential impacts from harvesting wild populations if for some reason it became sought after as a medicinal herb. Because of its small population size, collection for botanical specimens and scientific research is cited as a potential threat to the federally listed threatened *M. leucophylla* (Ash Meadows blazing star) (Conservation Management Institute 1996). However, collection is unlikely to present a serious threat to *M. chrysantha*. In collecting plants for scientific purposes, collectors should take care not to remove plants from small occurrences (Wagner 1991, Pavlovic et al. 1992).

Archaeological research found that prehistoric peoples such as the Chemehuevi of the Great Basin made stews with the fruits of numerous plants, including *Mentzelia* (Lawlor 1995). Seeds of *M. albicaulis* and other *Mentzelia* species have been found at many archeological sites in Utah, Nevada, and New Mexico, and it was apparently part of the diet of many Native American peoples (Hill 1976). Some use of *Mentzelia* seeds was documented by ethnographers in the late 19th century (e.g., Fewkes 1896), but it is uncertain whether these uses continue today. *Mentzelia chrysantha* is probably not currently impacted by this sort of utilization.

Conservation Status of Mentzelia chrysantha in Region 2

Is distribution or abundance declining in all or part of its range in Region 2?

Given the changes that have taken place within the range of *Mentzelia chrysantha*, it can be assumed that the distribution and abundance of this species have been diminished, and there has been a reduction of suitable habitat. While the net human impact on the distribution and abundance of *M. chrysantha* is difficult and complicated to assess, the cumulative impact of construction, mining, dam building, recreation, grazing, and habitat fragmentation wrought by a rapidly growing human presence is almost certainly resulting in a decline of *M. chrysantha*. Because the pre-settlement population of *M. chrysantha* is not known, it is difficult to assess precisely the effects of infrastructure, extractive use, and management regimes on abundance. While prolonged or constant disturbance is not compatible with *M. chrysantha*, periodic light to moderate disturbance may be beneficial. However, plants that benefit from human disturbance are also imperiled by it. Reliance on human disturbances such as road maintenance and grazing would be an extremely tenuous existence for *M. chrysantha* since areas thus disturbed are not managed on its behalf. Inventories and monitoring will help to determine the population trend of this species.

Do habitats vary in their capacity to support this species?

Variation in the capacity of habitats to support occurrences of *Mentzelia chrysantha* is probably due to geochemistry/ soil chemistry, slope/ aspect, disturbance regime, pollinator availability, and competing vegetation. These variables are not independent of one another, and key environmental variables have not yet been identified. At this time very little is known about the specific habitat requirements of *M. chrysantha*. Clearly, geologic substrate is important, possibly because the edaphic conditions to which *M. chrysantha* is adapted are contingent on it. As a putative calciphile, alkaline soil conditions are likely to be an important requirement for *M. chrysantha*. Lack of natural or quasi-natural disturbance or other types of habitat amelioration probably leads to dominance by more competitive species, which is likely to result in the exclusion of *M. chrysantha*.

Many of the known occurrences of *Mentzelia chrysantha* are in sites maintained by anthropogenic disturbance. Changes in transportation or weed management could have dramatic impacts on occurrences of *M. chrysantha*. Reliance on human disturbance is an insecure mode of existence that will need to be addressed in conservation plans for *M. chrysantha*.

Vulnerability due to life history and ecology

Mentzelia chrysantha's narrow tolerance of edaphic conditions appears to limit it to very specific substrates in the Arkansas River Valley that are also suitable for residential development, cement and gravel mining, and off-highway vehicle and mountain bike recreation. As a short-lived species, *M. chrysantha* may be vulnerable to environmental stochasticity. The degree to which it can survive dry years will depend largely on how long it can persist as a rosette or remain dormant as seeds. The high population turnover of annuals and biennials leaves them more vulnerable to seasonal environmental stochasticity than perennials.

The minimum viable population size is not known for *Mentzelia chrysantha*, but even small populations by the standards of the 50/500 rule of Soulé (1980) may still be viable and of conservation importance. The Colorado Natural Heritage Program considers occurrences of *M. chrysantha* containing 10 or more plants as viable, but this threshold will be revised when a minimum viable population size is determined (Colorado Natural Heritage Program 2006).

Evidence of populations in Region 2 at risk

Evidence suggests that *Mentzelia chrysantha* is at risk due to the overlap of its narrow range with incompatible land uses. Known and potential habitat is desirable for purposes other than conservation. Limestone and shale mining, road construction, residential and commercial development, and reservoir creation have all decreased the quantity and quality of habitat for *M. chrysantha*. Fremont and Pueblo counties are growing rapidly; Fremont County has one of the highest human population growth rates in the United States (**Table 10**; U.S. Census Bureau 2003). The development pressures exerted on *M. chrysantha*'s habitat are unlikely to decrease before most or all of it is gone. Mining of shale, bentonite, and gravel within the range of *M. chrysantha* has resulted in significant loss of habitat; these activities are likely to continue.

Although quantitative abundance data are not available, the total estimated population of *Mentzelia chrysantha* is not large (approximately 5,400 individuals). Six occurrences document the presence of 100 or fewer individuals. An unknown but probably significant number of occurrences of *M. chrysantha* are predicted to be vulnerable to extirpation due to human impacts and stochastic processes. Fragmentation of its habitat suggests that geneflow between occurrences may be obstructed, leading to smaller effective population sizes while increasing the risk of inbreeding depression.

Most *Mentzelia chrysantha* occurrences occupy sites maintained by an anthropogenic disturbance regime. Fifteen occurrences are entirely or partly within railroad or road right-of-ways. While *M. chrysantha* appears to benefit to some extent from this type of disturbance, these sites are unreliable for ensuring the long-term viability of this species. It is likely that with increased urbanization of the sites where *M. chrysantha* is currently found, these areas will no longer be used as

Table 10. 1990 and 2000 census data for Fremont and Pueblo counties, Colorado (U.S. Census Bureau 2003).

County	April 1, 1990 population	April 1, 2000 population	Population increase	Percent increase
Fremont	32,273	46,145	13,872	43.0
Pueblo	123,051	141,472	18,421	15.0

they are now, and *M. chrysantha* might be excluded by changes in land use.

Three occurrences of *Mentzelia chrysantha* have not been visited and assessed in more than 20 years. If these records represent occurrences that are extant, the occurrences cannot benefit substantially from any conservation actions on their behalf until they are relocated and better geographic data are available.

Management of Mentzelia chrysantha in Region 2

Implications and potential conservation elements

Current data suggest that *Mentzelia chrysantha* is a narrowly endemic species that is imperiled due to a small number of occurrences, high level of endemism, and threats to its habitat. Thus, the loss of an occurrence or a portion thereof is significant and is likely to result in the loss of important components of the genetic diversity of the species. Conservation easements, acquisition of habitat or occurrences by Federal Agencies through land exchange, public education, and development of management strategies and protective regulations offer the best chance for the conservation of this species. Without strong conservation efforts, *M. chrysantha* and other narrow endemics of the Arkansas Valley may eventually warrant listing under the Endangered Species Act (U.S.C. 1531-1536, 1538-1540). Restoration policies need to address appropriate restoration of native plant communities, grazing regimes, human and natural disturbance regimes, and pollinator resources. The Tools and practices and Threats sections include information on mitigating threats resulting from management.

Because *Mentzelia chrysantha* has not been documented on National Forest System land, the role of the USFS in conserving *M. chrysantha* is limited. However, surveys for this species are needed on the San Isabel National Forest and the Comanche National Grassland (see the following Species and habitat inventory section for details).

Tools and practices

Species and habitat inventory

Inventory is among the highest priorities for *Mentzelia chrysantha*. Collecting baseline information and developing a detailed map of the species' distribution and abundance will provide a starting point from which population trend can be assessed. Recent discoveries of occurrences suggest that further searching could yield new occurrences. Inventories are simple, inexpensive, effective, and necessary for developing an understanding sufficient for developing a monitoring program.

Inventories for *Mentzelia chrysantha* are complicated by taxonomic difficulties and uncertainties of field identification. Plants appearing to be *M. chrysantha* must be verified by a skilled botanist since they can easily be misidentified. It is not possible to identify *M. chrysantha* confidently during the rosette stage. Surveys during late summer may be required to obtain mature seeds, which are needed to distinguish *M. chrysantha* from *M. reverchonii*.

Areas with the highest likelihood of new occurrences are those with the appropriate geologic substrate near known occurrences. Aerial photography, topographic maps, and vegetation maps are highly effective for refining survey areas for *Mentzelia chrysantha*. Many areas within the known range of *M. chrysantha* remain to be searched because of the difficulties in obtaining permission to visit private land.

Mentzelia chrysantha is known to occur within 1 mile of the San Isabel National Forest boundary south of Cañon City. Surveys are needed to search the northern and eastern edges of the Wet Mountains on the San Isabel National Forest where it is possible that small patches of habitat for *M. chrysantha* may exist. Southeast of the town of Greenwood there are sedimentary deposits within the forest boundary that may support *M. chrysantha*. *Mentzelia chrysantha* has never been documented east of Pueblo State Park, but other endemic species with which it occurs (*Mirabilis rotundifolia* and *Oenothera harringtonii*) are known from the Comanche National Grassland and the Piñon Canyon Maneuver Site. Since there are outcrops of suitable geologic substrates in these areas, they should be the target of searches.

Areas on suitable geological formations in the area surrounding the known range of *Mentzelia chrysantha* have not been searched thoroughly and are a high priority for inventory (Coles personal communication 2003). High priority survey areas include outcrops of Greenhorn shale southeast of Pueblo Reservoir, small outcrops of Niobrara shale to the north and west of Cañon City along Skyline Drive, and on the south side of the Royal Gorge, where there are some hogbacks and outcrops of Niobrara shale (Coles personal communication 2003). Given strong similarities in habitat affinities between *Mirabilis rotundifolia* and *Mentzelia chrysantha*, any known location of *Mirabilis rotundifolia* is a good location to search for *Mentzelia chrysantha*. Even though botanical field work at the Piñon Canyon Maneuver Site identified two shale barrens that included *Frankenia jamesii*, but not *M. chrysantha* (Shaw et al. 1989), locations near the Front Range where *F. jamesii* is found warrant searches for *M. chrysantha*.

Surveys targeting *Mentzelia chrysantha* and other rare plant species of the Arkansas Valley are planned for 2006 to support the development of an Environmental Impact Statement for the proposed "Over the River" Project, a massive art installation to be constructed in 2008 or 2009 (Billerbeck personal communication 2006, Brekke personal communication 2006; see the Recreation section under Threats for further details). A survey of rare plants of the Fort Carson Military Reservation is also planned for 2006 and 2007. Although *M. chrysantha* is not a target species of this survey, it is likely that there will be an opportunity to reassess known occurrences at Fort Carson. No surveys for *M. chrysantha* are planned for National Forest System land.

Surveys for *Mentzelia chrysantha* could be aided by predictive distribution modeling using deductive and inductive techniques. The availability of fine-scale Geographic Information System (GIS) data with high predictive value for *M. chrysantha* suggests that these techniques could generate useful models for guiding and focusing future surveys. Techniques for predicting species distributions are reviewed by Scott et al. (2002). Species distribution modeling has been done for other sensitive plant species in Wyoming (Fertig and Thurston 2003) and Colorado (Decker et al. 2005), and these methods are applicable to *M. chrysantha* as well. Species distribution modeling is an effective means of prioritizing areas to survey for this species on National Forest System land.

Population monitoring

Population monitoring could provide valuable information to assist with the management and conservation of *Mentzelia chrysantha*. Lesica (1987) described a technique for monitoring populations of non-rhizomatous perennial plant species that may be applicable to *M. chrysantha*. Demographic monitoring of populations in which marked individuals are followed through the growing season over a number of years is needed to understand the life cycle of *M. chrysantha*. The species appears to be opportunistic and may be able to complete its life cycle in one year, but individuals have not been tracked to verify this. Standard monitoring methods generally employ the use of randomly arrayed systematic sampling units (quadrats). Within each quadrat, plants are marked and tracked using an aluminum tag or other field marker. During annual visits, data are gathered for each marked plant including life history stage, fecundity (the number of fruits or some other measure of reproductive output), and mortality. Recruitment within each quadrat is measured by counting seedlings. To reduce the chance of missing seedlings, a quadrat frame subdivided with tight string can help observers search each quadrat systematically. Elzinga et al. (1998) offers additional suggestions regarding this method. Seed viability and longevity can be estimated using small buried bags containing known numbers of live seeds that are collected and tested periodically using tetrazolium chloride and germination trials on subsets of each bag. Suitable methods for monitoring pollinators, which are a critical autecological factor for *M. chrysantha*, are discussed in Kearns and Inouye (1993).

Data from these studies could provide insight into the rate of change among the life history stages of seeds, seedlings, juveniles, and reproductive individuals and would allow transition probabilities to be determined. They would also yield insight into the longevity, fecundity, seed bank dynamics, and recruitment rate of *Mentzelia chrysantha*, and would permit the use of modeling in which critical life history stages, minimum viable population size, and probability of long-term persistence could be determined.

Simpler and less labor-intensive approaches to demographic monitoring, in which individuals are not marked and tracked, can still yield valuable data. However, these methods do not provide specific information on life history and the fate of individuals. For example, such methods cannot be used to determine the lifespan of *Mentzelia chrysantha*, but they would provide information on recruitment, recruitment success, and population age/stage structure.

Selection of monitoring sites is an important consideration in developing a monitoring program. Including locations under varying degrees of anthropogenic disturbance regimes will provide information useful to the management of *Mentzelia chrysantha*. It will be important to define *a priori* the changes that the sampling regime intends to detect, and the management actions that will follow from the results (Schemske et al. 1994, Elzinga et al. 1998).

Elzinga et al. (1998) recommend several methods of monumentation, depending on the site physiography and frequency of human visitation to the site. Establishing monumentation can be difficult in the naturally disturbed, unstable soils where *Mentzelia chrysantha* grows.

Estimating cover and/or abundance of associated species within the plots described above could permit the investigation of interspecific relationships through ordination or other statistical techniques. In very sparsely vegetated plots this can be difficult, but it can be done accurately using appropriate cover classes or subdivided quadrat frames. Gathering data on edaphic characteristics (i.e., moisture, texture, and soil chemistry, particularly pH, if possible) from the permanent plots described above would permit the canonical analysis of species-environment relationships. These data would facilitate hypothesis generation for further studies of the ecology of this species.

Adding a photo point component to this work, following recommendations in Elzinga et al. (1998), could facilitate the tracking of individuals and add valuable qualitative information. A handbook on photo point monitoring (Hall 2002) offers detailed instructions on establishing photo point monitoring plots. Monitoring sites should be selected carefully, and a sufficient number of sites should be selected if the data are intended to detect population trends.

Gathering abundance data through plot sampling methods can be done rapidly and can require only a small amount of additional time and effort (Elzinga et al. 1998). Approaches and challenges in applying ecological census techniques in the quantification of plant population sizes are discussed by Bullock (1996).

The best time for inventory and monitoring of *Mentzelia chrysantha* is from July to early September when plants are flowering and fruiting; late August through September is optimal because mature seeds are needed to distinguish *M. chrysantha* from *M. reverchonii*. A monitoring program for *M. chrysantha* would begin by targeting robust occurrences in both natural and unnatural (roadside) settings. Monitoring sites under a variety of land management scenarios will help to identify appropriate management practices for *M. chrysantha* and will help to understand its population dynamics and structure.

Documenting habitat attributes, disturbance regime, and associated species during population monitoring will augment our understanding of *Mentzelia chrysantha*'s habitat requirements and management needs. Habitat monitoring of occurrences will alert managers of new impacts such as weed infestations and damage from human disturbance and grazing. Change in environmental variables might not cause observable demographic repercussions for several years, so resampling the environmental variables may help to identify underlying causes of population trends. Evidence of current land use practices and management is important to document while monitoring occurrences.

Observer bias is a significant problem with habitat monitoring (Elzinga et al. 1998). Thus, habitat monitoring is usually better at identifying new impacts than at tracking change in existing impacts. For estimating weed infestation sizes, using broad size classes helps to reduce the effects of observer bias, as does careful training and calibration of the field crews that are estimating cover. To assess trampling impacts, using photographs of impacts to train field crews will help them to consistently rate the severity of the impact.

Beneficial management actions

Establishing areas to be managed for *Mentzelia chrysantha* is the best conservation strategy for this species. Actions of this sort taken in the near future will increase the probability of protecting robust occurrences before they are lost to development or fragmentation. Conservation easements and other land trust activities are useful conservation tools to protect occurrences on private land (Colorado Natural Heritage Program 2006). Although *M. chrysantha* is not known from any existing conservation easements, there remain many opportunities for Pueblo or Fremont counties or other entities to purchase the development rights to parcels that support robust occurrences of *M. chrysantha*. While larger acreages are ideal, purchasing conservation easements even on small properties may confer significant benefits to the species. State Natural Area designation would confer some degree of protection for targeted occurrences. Land exchanges that bring sites on private land into federal ownership, such as the BLM, are another useful conservation tool. Continuing management practices that favor the persistence of *M. chrysantha* will help to ensure the long-term persistence of occurrences at these locations.

The implementation of best management practices (**Table 1**) developed by Grunau et al. (2003) will help to ensure that occurrences within right-of-ways are not impacted by road improvements and other projects. Voluntary implementation of these practices by municipalities, counties, and federal agencies would prevent impacts to occurrences adjacent to roads not managed by the Colorado Department of Transportation.

Aggressive management of noxious weeds in and near *Mentzelia chrysantha* occurrences is a high priority. In occurrences of the federally listed *M. leucophylla*, controlling and removing non-native vegetation is recommended (U.S. Fish and Wildlife Service 1986). Any management strategies that work to prevent the infestation of *M. chrysantha* occurrences are likely to confer the greatest benefits.

Mowing and noxious weed control activities have the potential to affect occurrences of *Mentzelia chrysantha*, but right-of-way management practices can be modified to mitigate these impacts. Hand-pulling is the preferred method of managing weeds within occurrences of *M. chrysantha*. Use of herbicides within occurrences should be limited to direct application to target species. Avoiding right-of-way mowing in *M. chrysantha* occurrences from June until late August or September (after fruit has dried and seeds are released) will also be beneficial. The Colorado Natural Heritage Program provides distribution data for *M. chrysantha* in highway right-of-ways to the Colorado Department of Transportation to help avoid impacts to occurrences. Surveys of suitable habitat prior to road projects, such as utility line installation and alterations or widening of roads, will help to minimize impacts to occurrences.

Direct impacts to *Mentzelia chrysantha* from livestock are probably limited. Management practices that minimize impacts to fragile shale soils from livestock are likely to benefit *M. chrysantha*. Research is needed to better understand the impacts of grazing on *M. chrysantha*, and grazing regimes that are compatible with *M. chrysantha* must then be implemented. Given our limited knowledge based solely on observations, exclusion of grazing within occurrences from June through September (when the plant is growing and reproducing) is most likely to be compatible with the persistence of *M. chrysantha*. Other approaches that might be considered on a site-by-site basis include using exclosures and reducing stocking rates, but it is not known what stocking rates are compatible with *M. chrysantha*.

Inventory and monitoring would benefit *Mentzelia chrysantha*. Identifying occurrences with high-quality habitat and large numbers of plants within an intact landscape will help managers to prioritize conservation efforts. Although as much as 80 percent of the known suitable habitat in the Arkansas Valley has been searched (Colorado Natural Heritage Program 2006), additional areas (cited in the Tools and practices section under Species and habitat inventory) remain to be searched, especially on private land.

Seed banking

No seeds or genetic material for *Mentzelia chrysantha* are in storage at the National Center for Genetic Resource Preservation (Miller personal communication 2003). This species is not among the National Collection of Endangered Plants maintained by the Center for Plant Conservation (Center for Plant Conservation 2002). *Mentzelia densa* is currently grown at the Denver Botanic Garden under this program, suggesting that growing *M. chrysantha* would also be feasible, given their close relationship. Collecting seeds for long-term storage will be useful if restoration is necessary, but the longevity of seeds, even under highly controlled conditions, is questionable.

Information Needs and Research Priorities

Distribution

The greatest information need for *Mentzelia chrysantha* is species surveys to complete the picture of its distribution. Inventory of habitat on private land throughout its range is the highest priority and a first step towards developing a complete understanding of this species' distribution. Places to focus searches are included in the Tools and practices section under Species and habitat inventory. Little is known about most occurrences of *M. chrysantha*; population size has not been estimated for 14 occurrences, and there are limited descriptive data for most occurrences (Colorado Natural Heritage Program 2006).

Taxonomic status

Molecular genetic and cytogeographic research is needed to clarify the relationship between *Mentzelia chrysantha* and *M. reverchonii* (Kelso personal communication 2006); these two species are certainly closely related and *M. chrysantha* may be an incipient species not yet fully differentiated from *M. reverchonii*. Investigating haplotypes of these taxa where they are sympatric will provide insight into the taxonomic distinctness of these taxa.

Life cycle, habitat, and population trend

Research is needed to understand the population ecology of *Mentzelia chrysantha*. Although some inferences can be made from other taxa, they cannot take the place of research. Information on longevity, seed viability, and seed germinability on different substrates, including non-calcareous soils, would help to establish basic life history parameters that would be useful in population models and restoration efforts.

Although basic descriptive information is available for the habitat of *Mentzelia chrysantha*, more detailed information is needed. Information on the ecological amplitude of *M. chrysantha* with respect to pH, calcium concentration, soil texture, soil moisture, and disturbance would be useful to scientists and land managers, and it is needed to understand species-environment relationships for *M. chrysantha*. Studies of the physiological and community ecology of *M. chrysantha* will be valuable in the event that a population needs to be restored, they and will help scientists to determine biotic and abiotic factors that contribute to the species' survival. Understanding plant-environment relationships for *M. chrysantha* will help to model its potential distribution and explain why it is rare.

Mentzelia chrysantha reproduction and seedling establishment rates, as well as the effects of environmental variation on these parameters, have not been thoroughly investigated. Rates of emigration and immigration, and the ability to migrate are likewise unknown. *Mentzelia chrysantha* could be expected to respond quickly to environmental impacts since it is a short-lived, ruderal species, and populations turn over rapidly. This will also be important for understanding any metapopulation dynamics relevant to the conservation of *M. chrysantha*.

Because *Mentzelia chrysantha* is an obligate outcrosser, investigation of its reproductive biology is needed to ensure that conservation actions include protecting its pollinators. Research is needed to determine which insect visitors to *M. chrysantha* are most effective as pollinators (Spackman Panjabi 2004). Change in the amount of residential development and infrastructure in the habitat of *M. chrysantha* may decrease the availability and diversity of pollinators, and pollinators capable of persisting in disturbed habitats are likely to be favored. Further study of the effects of disturbance on pollinator species richness will help to reduce the loss of genetic diversity of *M. chrysantha*.

Understanding the specific responses of *Mentzelia chrysantha* to disturbance is important for determining appropriate management practices, but these responses are poorly understood and need further investigation. Studying the effects of grazing on the survival and population ecology of *M. chrysantha* will assist with the development of compatible land management practices. See the Reproductive Biology and Ecology section of this document for further discussion of disturbance.

Demography and population monitoring

A replicated demographic monitoring study comparing vital rates of *Mentzelia chrysantha* in naturally vs. anthropogenically disturbed, grazed vs. ungrazed, and in the presence and absence of competitors would answer many questions about this species. Growth and survival rates are unknown, and the rate of reproduction is poorly understood. It is uncertain whether *M. chrysantha* is an annual, biennial, or short-lived perennial, or to what extent its life history responds to annual climatic variation. Short-term demographic studies can provide misleading guidance for conservation purposes, so complementary information, such as historical data and experimental manipulations, should be included whenever possible (Lindborg and Ehrlén 2002). However, the value of demographic data for conservation planning and species management cannot be overstated. Demographic data are far more useful for assessing status and developing recovery efforts than genetic information (Schemske et al. 1994). Determining the critical life history stages of *M. chrysantha* will allow managers to focus efforts on implementing management protocols that minimize impacts on those stages.

Selection of monitoring sites from a variety of ecological settings and land use scenarios will be necessary to monitor overall population trends. Monitoring threats by tracking road maintenance activities, housing density, grazing, spread of noxious weeds, and off-highway vehicle use would provide valuable feedback to managers of this species. Continuing the monitoring established by Anderson et al. (2001) at Garden Park and conducting similar monitoring elsewhere will help to mitigate impacts from exotic species by identifying problem species and infestations.

Restoration methods

There have been no known attempts to restore habitat or occurrences of *Mentzelia chrysantha*. Given the ruderal nature of this species, it is likely that propagation in a greenhouse by seed would not be difficult, but it may be difficult to transfer plants successfully into a natural or quasi-natural (restored) setting. Fresh seed would be required due to the possible short longevity of the seeds of *Mentzelia* (Brown 1971, Coles 1990). Although there have been no known attempts to establish or re-establish wild populations of members of this genus, the successful colonization of road cuts by *M. chrysantha* suggests that occurrences of this species could be successfully restored or introduced simply by seeding. Introduced populations are of lesser conservation value than populations in their known range (Given 1994).

DEFINITIONS

Calciphile – A plant that grows best in soils rich in calcium carbonate (Art 1993).

Conservation Status Rank - The Global (G) Conservation Status (Rank) of a species or ecological community is based on the *range-wide* status of that species or community. The rank is regularly reviewed and updated by experts, and takes into account such factors as number and quality/condition of occurrences, population size, range of distribution, population trends, protection status, and fragility. A subnational (S) rank is determined based on the same criteria applied within a subnation (state or province). The definitions of these ranks, which are not to be interpreted as legal designations, are as follows:

GX	<u>Presumed Extinct:</u> Not located despite intensive searches and virtually no likelihood of rediscovery.
GH	<u>Possibly Extinct:</u> Missing; known only from historical occurrences but still some hope of rediscovery.
G1	<u>Critically Imperiled:</u> At high risk of extinction due to extreme rarity (often five or fewer occurrences), very steep declines, or other factors.
G2	<u>Imperiled:</u> At high risk of extinction due to very restricted range, very few populations (often 20 or fewer), steep declines, or other factors.
G3	<u>Vulnerable:</u> At moderate risk of extinction due to a restricted range, relatively few populations (often 80 or fewer), recent and widespread declines, or other factors.
G4	<u>Apparently Secure:</u> Uncommon but not rare; some cause for long-term concern due to declines or other factors.
G5	<u>Secure:</u> Common; widespread and abundant.

Isosyntype – Copy of a syntype.

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

Monumentation - The process of marking permanent sampling units by installing rebar, stakes, or other markers, or by using landmark references. Anything that is used to relocate a plot is called a monument (Elzinga et al. 1998).

Papillose - Having short, rounded nipple-like bumps or projections on the surface (papillae) (Harris and Harris 1999).

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

Potential Conservation Area – A best estimate of the primary area supporting the long-term survival of targeted species or natural communities; PCAs are circumscribed for planning purposes only (Colorado Natural Heritage Program Site Committee 2001).

Sere – The characteristic sequence of developmental stages occurring in plant succession (Allaby 1998).

Staminode (staminodia=plural) – A modified, sterile stamen that produces no pollen (Harris and Harris 1999).

Suffrutescent – Somewhat shrubby; slightly woody at the base (Harris and Harris 1999).

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

Syntype – All specimens in a type series in which no type specimen was designated (Allaby 1998).

Trichome – A hair or hairlike outgrowth of the epidermis of plants (Mauseth 1988).

Type – The specimens from which the original description of a species is made (Harrington and Durrell 1957).

References

Aizen, M. and P. Feinsinger. 1994. Forest fragmentation, pollination, and plant reproduction in a Chaco dry forest, Argentina. Ecology 75: 320-341.

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

Anderson, D., P. Lyon, S. Spackman, and J. Handwerk. 2001. Weed and Rare Plant Assessments on Selected BLM ACECs. Unpublished report prepared for the Bureau of Land Management by the Colorado Natural Heritage Program, Fort Collins, CO.

Art, H.W. 1993. The Dictionary of Ecology and Environmental Science. Henry Holt and Company, New York, NY.

Ayensu, E.S. and R.A. DeFilipps. 1978. Endangered and Threatened Plants of the United States. Smithsonian Institution and World Wildlife Fund, Inc., Washington, D.C.

Bailey, R.G. 1995. Description of the Ecoregions of the United States. Second edition. Miscellaneous Publication No. 1391. USDA Forest Service, Washington, D.C.

Barbour, M.G., J.H. Burk, and W.D. Pitts. 1987. Terrestrial Plant Ecology. Benjamin/Cummings Publishing Company, Inc., Menlo Park, CA.

Beattie, A.J., C. Turnbull, R.B. Know, and E.G. Williams. 1984. Ant inhibition of pollen function: A possible reason why ant pollination is rare. American Journal of Botany 71:421-426.

Bell, C.R. 1971. Breeding systems and floral biology of the Umbelliferae, or evidence for specialization in unspecialized flowers. Pages 93-107 *in* V.H. Heywood, editor. The Biology and Chemistry of the Umbelliferae. Botanical Journal of the Linnean Society 64, Suppl. 1.

Belnap, J. and K.T. Harper. 1995. Influence of cryptobiotic soil crusts on elemental content of tissue of two desert seed plants. Arid Soil Research and Rehabilitation 9:107-115.

Belnap, J., J.H. Kaltenecker, R. Rosentreter, J. Williams, S. Leonard, and D. Eldridge. 2001. Biological Soil Crusts: Ecology and Management. Technical Reference 1730-2. Bureau of Land Management, Denver, CO.

Billerbeck, R. 2006. Personal communication with Program Manager of the Colorado Natural Areas Program regarding *Mentzelia chrysantha*.

Bliss, C.A., T.J. Danielson, and R.A. Abramovi. 1968. Investigations on Genus *Mentzelia*. I. Mentzeloside - a New Iridoid Glycoside. Lloydia 31:424.

Borror, D.J., C.A. Triplehorn, and N.F. Johnson. 1989. An Introduction to the Study of Insects. Sixth edition. Harcourt Brace College Publishers, Fort Worth, TX.

Brekke, E. 2006. Personal communication with Bureau of Land Management Wildlife Biologist regarding *Mentzelia chrysantha*.

Brown, D.K. 1971. A study of floral morphology in the Loasaceae with emphasis on relationships among the subfamilies. PhD. Dissertation. University of Nebraska Department of Botany, Lincoln, NE.

Brown, D.K. and R.B. Kaul. 1981. Floral structure and mechanism in Loasaceae. American Journal of Botany 68: 361-372.

Bucar, F., E. Knauder, and M. Schubert-Zsilavecz . 1998. Studies on the anti-inflammatory principle of *Mentzelia chilensis*. Phytotherapy Research 12:275-278.

Bullock, J. 1996. Plants. Chapter 3 *in* W.J. Sutherland, editor. Ecological Census Techniques: a Handbook. Cambridge University Press, Cambridge, UK.

Bureau of Land Management. 2000. Colorado BLM State Director's Sensitive Species List. Accessed via the Internet at at http://www.co.blm.gov/botany/sens_species.htm.

Bureau of Land Management. 2001. Manual 6840- Special Status Species Management. United States Department of the Interior, Bureau of Land Management, Washington, D.C.

Bureau of Land Management. 2005. BLM Handbook H-1601-1. Land Use Planning Handbook (Public). United States Department of the Interior, Bureau of Land Management, Washington, D.C.

Burns, D.A. 2002. The Effects of Atmospheric Nitrogen Deposition in the Rocky Mountains of Colorado and Southern Wyoming - a Synthesis and Critical Assessment of Published Results. U.S. Geological Survey Water Resources Investigations Report 02-4066.

Burrows, G.E. and R.J. Tyrl. 2001. Toxic Plants of North America. Iowa State University Press, Ames, IA.

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

Catalano, S., G. Flamini, A.R. Bilia, I. Morelli, and M. Nicoletti. 1995. Iridoids from *Mentzelia cordifolia*. Phytochemistry 38:895-897.

Center for Plant Conservation. 2002. National Collection of Endangered Plants. Accessed via the Internet at http://www.mobot.org/CPC/NC_Choice.html.

Center for Plant Conservation. 2003. National Collection of Endangered Plants. Accessed via the Internet at http://ridgwaydb.mobot.org/cpcweb/CPC_NCList_Find.asp. Missouri Botanical Garden.

Christo and Jeanne-Claude. 2005. Over the River- Project for the Arkansas River (in Progress). Accessed via the Internet at http://www.christojeanneclaude.net/otr2.html.

Christy, C.M. 1995. Systematics of the *Mentzelia* (Section *Bartonia*) *multiflora* (Nutt.) A. Gray complex. PhD. Dissertation. Arizona State University, Phoenix, AZ.

Chumley, T.W. 1998. A floristic inventory of the East Slope, Central Colorado. Masters Thesis. University of Wyoming, Laramie, WY.

Coles, J. 1990. Status Report for *Mentzelia densa*. Unpublished report produced for the U.S. Fish and Wildlife Service by the Colorado Natural Areas Program, Denver, CO.

Coles, J. 2003. Personal communication with botanist and expert on *Mentzelia chrysantha.*

Collins, C. 1995. The Natural History and Reproductive Biology of the Pagosa Gilia, *Ipomopsis polyantha* (Rydberg) V. Grant var. *polyantha* (Polemoniaceae). M.A. Thesis. California State University, Fullerton, CA.

Colorado Division of Wildlife. 1998. Colorado GAP Analysis Land Cover Map. Colorado Division of Wildlife, Denver, CO.

Colorado Native Plant Society. 1997. Rare Plants of Colorado. Second edition. Falcon Press, Helena, MT.

Colorado Natural Heritage Program. 2006. Biodiversity Tracking and Conservation System. Colorado State University, Fort Collins, CO.

Colorado Natural Heritage Program Site Committee. 2001. Recommendations for Development and Standardization of Potential Conservation Areas and Network of Conservation Areas. Colorado Natural Heritage Program, Fort Collins, CO.

Colorado Weed Management Association. 2002. Yellow Starthistle (*Centaurea solstitialis*). Accessed via the Internet at http://www.cwma.org/yellow_starthistle.html.

Conservation Management Institute. 1996. Ash Meadows Blazing Star (Draft). Accessed via the Internet at http://fwie.fw.vt.edu/www/esis/lists/e701034.htm. Blacksburg, VA.

Coulter, J.M. and A. Nelson. 1909. New Manual of Botany of the Central Rocky Mountains (Vascular Plants). American Book Company, New York, NY.

Cronquist, A. 1981. An Integrated System of Classification of Flowering Plants. Columbia University Press, New York, NY.

Danielson, T.J., E.M. Hawes, and C.A. Bliss. 1973. Iridoids of *Mentzelia decapetala* (Pursh) .1. Mentzeloside. Canadian Journal of Chemistry 51:760-766.

Danielson, T.J., E.M. Hawes, and C.A. Bliss. 1975. Identification of Iridoids of *Mentzelia decapetala* by 2-Dimensional Paper Chromatography. Journal of Chromatography 103:216-218.

Darlington, J. 1934. A monograph of the genus *Mentzelia*. Annals of the Missouri Botanical Garden 21:103-227.

Decker, K., A. Lavender, and D.G. Anderson. 2005. Modeling the Potential Distribution of *Phacelia scopulina* var. *submutica* (Debeque Phacelia) and *Astragalus debequaeus* (Debeque Milkvetch) in Western Colorado. Prepared for U.S. Fish and Wildlife Service and Colorado State Parks by Colorado Natural Heritage Program, Fort Collins, CO.

Dillon, B. 1999. Yellow Starthistle Threatens Local Rangeland, Livestock. Newspaper article published August 12, 1999. Montrose Daily Press, Montrose, CO.

Doyle, G., J. Armstrong, J. Gionfriddo, D. Anderson, J. Stevens, and R.A. Schorr. 2001. Survey of Critical Biological Resources, El Paso County, Colorado. Unpublished report prepared for El Paso County Parks and Leisure Services by the Colorado Natural Heritage Program, Fort Collins, CO.

Eisner, T., M. Eisner, and E.R. Hoebeke. 1998. When defense backfires: Detrimental effect of a plant's protective trichomes on an insect beneficial to the plant. Proceedings of the National Academy of Sciences of the United States of America 95:4410-4414.

El-Naggar, L.J., J.L. Beal, and R.W. Doskotch. 1980. Iridoid Glycosides from *Mentzelia decapetala*. Planta Medica 39:266.

El-Naggar, L.J., J.L. Beal, and R.W. Doskotch. 1982. Iridoid Glycosides from *Mentzelia decapetala*. Journal of Natural Products 45:539-550.

Elliott, B. 2006. Personal communication with San Isabel National Forest Botanist regarding exotic species in the Arkansas Valley.

Ellstrand, N.C. 1992. Gene flow by pollen - Implications for plant conservation Genetics. Oikos 63:77-86.

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

Engelmann, G. 1876. Description of *Mentzelia chrysantha*. Page 237 *in* T.S. Brandegee. Flora of Southwestern Colorado. Bulletin of the Geological and Geographical Survey of the Territories 2.

Fahn, A. 1979. Secretory Tissues in Plants. Academic Press, New York, NY.

Fernando, A.A. and R.S. Currah. 1996. A comparative study of the effects of the root endophytes *Leptodontidium orchidicola* and *Phialocephala fortinii* (Fungi Imperfecti) on the growth of some subalpine plants in culture. Canadian Journal of Botany 74:1071-1078.

Fertig, W. and R. Thurston. 2003. Modeling the Potential Distribution of BLM sensitive and USFWS Threatened and Endangered Plant Species. Wyoming Natural Diversity Database, Laramie, WY.

Fewkes, J.W. 1896. A contribution to ethnobotany. American Anthropology 9:14-21.

Finnamore, A.T. and C.D. Michener. 1993. Chapter 9. Superfamily Apoidea. Pages 279-357 *in* H. Goulet and J.T. Huber, editors. Hymenoptera of the World: An Identification Guide to Families. Publication 1894/E. Centre for Land and Biological Resources Research, Research Branch, Agriculture Canada, Ottawa, Ontario.

Forman, R.T.T. and L.E. Alexander. 1998. Roads and their major ecological effects. Annual Reviews of Ecological Systems 29:207-231.

Frederiksen, L.B., S. Damtoft, and S.R. Jensen. 1999. Biosynthesis of Iridoids Lacking C-10 and the Chemotaxonomic Implications of Their Distribution. Phytochemistry 52:1409-1420.

Gilg, E. 1894. Loasaceae. Pages 522-543 *in* A. Engler and K. Prantl. Die Natürlichen Pflanzenfamilien, Ed. 2. Vol. 21.

Giorgi, F., L.O. Mearns, C. Shields, and L. McDaniel. 1998. Regional nested model simulations of present day and 2 x CO_2 climate over the central plains of the U.S. Climatic Change 40:457-493.

Given, D.R. 1994. Principles and Practice of Plant Conservation. Timber Press, Portland, OR.

Grant, V. 1949. Pollination systems as isolating mechanisms in Angiosperms. Evolution 3:82-97.

Great Plains Flora Association. 1986. Flora of the Great Plains. University Press of Kansas, Lawrence, KS.

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

Gross, K.L., M.R. Willig, and R. Gough. 2000. Patterns of species density and productivity at different spatial scales in herbaceous plant communities. Oikos 89:417-427.

Grunau, L., A.K. Ruggles, M. Venner, C. Pague, R. Rondeau, and J.M. Powell. 2003. Programmatic Biological Assessment, Conference Report, and Conservation Strategy for Impacts from Transportation Improvement Projects on Select Sensitive Species on Colorado's Central Shortgrass Prairie. Unpublished report prepared for the U.S. Fish and Wildlife Service.

Hall, F.C. 2002. Photo Point Monitoring Handbook- Parts A and B. General Technical Report PNW-GTR 526. USDA Forest Service Pacific Northwest Research Station, Portland, OR.

Harley, J.L. 1991. Introduction: The state of the art. Pages 1-24 *in* J.R. Norris, D.J. Read, and A.K. Varma, editors. Methods in Microbiology, Vol. 23. Academic Press, London, England.

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

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

Harrington, H.D. and L.W. Durrell. 1957. How to Identify Plants. Swallow Press, Chicago, IL.

Harris, J.G. and M.W. Harris. 1999. Plant Identification Terminology- an Illustrated Glossary. Spring Lake Publishing, Spring Lake, UT.

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

Hickman, J.C. 1974. Pollination by ants: a low energy system. Science 184:1290-1292.

Hill, R.J. 1976. Taxonomic and phylogenetic significance of seed coat microsculpturing in *Mentzelia* (Loasaceae) in Wyoming and adjacent western states. Brittonia 28:86-112.

Hill, R.J. 1977. Variability of soluble seed proteins in populations of *Mentzelia* L. (Loasaceae) from Wyoming and adjacent states. Bulletin of the Torrey Botanical Club 104:93-101.

Holmgren, P. 2003. Personal communication with expert on *Mentzelia* regarding *M. chrysantha*.

Holmgren, N.H. and P.K. Holmgren. 2002. New *Mentzelias* (Loasaceae) from the Intermountain Region of Western United States. Systematic Botany 27:747-762.

Holmgren, N.H., P.K. Holmgren, and A. Cronquist. 2005. Loasaceae, the Loasa Family. Pages 81-118 *in* N.H. Holmgren, P.K. Holmgren, and A. Cronquist, editors. Intermountain Flora: Vascular Plants of the Intermountain West, U.S.A.. Volume 2, Part B: Subclass Dilleniidae. The New York Botanical Garden, Bronx, NY.

House, S. M. 1993. Pollination success in a population of dioecious rain forest trees. Oecologia 96: 555-561.

Huber, T.P. 1993. Colorado: The Place of Nature, the Nature of Place. University Press of Colorado, Niwot, CO.

Jensen, S.R., C.B. Mikkelsen, and B.J. Nielsen. 1981. Iridoid in Loasaceae .1. Iridoid Mono-Dylcosides and Di-Glycosides in *Mentzelia*. Phytochemistry 20:71-83.

Johnston, B.C. 2002. Personal communication with USDA Forest Service Botanist regarding sampling methodology for rare plants.

Jordan, L. 1992. Listing Priority Number Assignment Form for *Mentzelia chrysantha*.

Kartesz, J.T. 1999. A Synonymized Checklist and Atlas with Biological Attributes for the Vascular Flora of the United States, Canada, and Greenland. First Edition. *In*: J.T. Kartesz and C.A. Meacham. Synthesis of the North American Flora [computer program]. Version 1.0. North Carolina Botanical Garden, Chapel Hill, NC.

Kearns, C.A. and D.W. Inouye. 1993. Techniques for Pollination Biologists. University Press of Colorado, Niwot, CO.

Keeler, K.H. 1981. Function of *Mentzelia nuda* (Loasaceae) Post-floral nectaries in seed defense. American Journal of Botany 68:295-299.

Keeler, K.H. 1987. Survivorship and fecundity of the polycarpic perennial *Mentzelia nuda* (Loasaceae) in Nebraska Sandhills Prairie. American Journal of Botany 74:785-791.

Kelso, S. 2006. Personal communication with Botanist and Curator of the Carter Herbarium regarding *Mentzelia chrysantha*.

Kelso, S. 2004. Botany of the Pikes Peak Region. Unpublished report. Department of Biology, Colorado College, Colorado Springs, CO.

Kelso, S. 2003. Personal communication with Botanist and Curator of the Carter Herbarium regarding *Mentzelia chrysantha*.

Kelso, S., N.W. Bower, K.E. Heckmann, P.M. Beardsley, and D.G. Greve. 2003. Geobotany of the Niobrara Chalk Barrens in Colorado: a study of edaphic endemism. Western North American Naturalist 63(3):299-313.

Kelso, S., K. Heckmann, J. Lawton, and G. Maentz. 1995. The Ecology and Distribution of *Oxybaphus rotundifolia* and *Penstemon versicolor*: Geobotany and Endemism in the Arkansas Valley, Colorado. Department of Biology, Colorado College, Colorado Springs, CO.

Kelso, S., G. Maentz, and C. Hall. 1999a. A Comparative Study of the Shale Barrens Flora on the Niobrara Formation in Southeastern Colorado. Flora, Phytogeography, and Response to Disturbance. Project Dates: May 1998-September 1998. Unpublished report for the Colorado Natural Areas Program.

Kelso, S., G. Maentz, C. Hall, H. Carson, and T. Forester. 1999b. Rare Plants of the Pikes Peak Region. Department of Biology, Colorado College, Colorado Springs, CO.

Knight, R., W.C. Gilgert, and E. Marston. 2002. Ranching West of the 100th Meridian: Culture, Ecology, and Economics. Island Press, Washington, D.C.

Köchy, M. and S.D. Wilson. 2001. Nitrogen deposition and forest expansion in the northern Great Plains. The Journal of Ecology 89:807-817.

Kothera, L. 2006. Personal communication with doctoral candidate regarding *Physaria bellii*.

Kruckeberg, A. R. 2002. Geology and Plant Life- the Effects of Landforms and Rock Types on Plants. University of Washington Press, Seattle, WA.

Lande, R. 1998. Anthropogenic, ecological and genetic factors in extinction and conservation. Researches on Population Ecology 40:259-269.

Larsen, R.J., T.J. Wiggins, D.L. Holden, M.B. McCulloch, and R.E. Preator. 1979. Soil Survey of Pueblo Area, Colorado- Parts of Pueblo and Custer Counties. U.S. Department of Agriculture, Soil Conservation Service, in cooperation with the Colorado Agricultural Experiment Station.

Law, R. 1985. Evolution in a mutualistic environment. Pages 145-170 *in* D.H. Boucher, editor. The Biology of Mutualism, Ecology and Evolution. Oxford University Press, New York, NY.

Lawlor, E.J. 1995. Archaeological Site-Formation Processes Affecting Plant Remains in the Mojave Desert. PhD. Dissertation. University of California, Riverside, CA.

Leopold, A. 1936. Wildlife Crops: Finding Out How to Grow Them. American Wildlife Institute, Washington, D.C.

Lesica, P. 1987. A technique for monitoring nonrhizomatous, perennial plant species in permanent belt transects. Natural Areas Journal 7:65-68.

Lindborg, R. and J. Ehrlén. 2002. Evaluating the extinction risk of a perennial herb: demographic data versus historical records. Conservation Biology 16:683-690.

Little, R.J. 1985. Breeding System and Floral Utilization by Solitary Bees in *Mentzelia involucrata* ssp. *megalantha* (Loasaceae). American Journal of Botany 72:857-858.

Lyon, P. and M. Denslow. 2001. Gunnison Gorge Natural Conservation Area Survey of Impacts on Rare Plants. Unpublished report prepared for the Bureau of Land Management, Montrose, CO by the Colorado Natural Heritage Program, Fort Collins, CO.

Mabberley, D.J. 1997. The Plant-Book. A Portable Dictionary of the Vascular Plants. Second edition. Cambridge University Press, Cambridge, UK.

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

Manabe, S. and R.T. Wetherald. 1986. Reduction in summer soil wetness induced by an increase in atmospheric carbon dioxide. Science 232:626-628.

Matthies, D., I. Bräuer, W. Maibom, and T. Tscharntke. 2004. Population size and the risk of local extinction: empirical evidence from rare plants. Oikos 105:481-488.

Mauseth, J. 1988. Plant Anatomy. Benjamin/Cummings Publishing Company, Inc., Menlo Park, CA.

McKee, J.P. 2002. Region 2 Sensitive Species Evaluation Form - *Mentzelia chrysantha*. Accessed via the Internet at http://www.fs.fed.us/r2/projects/scp/index.shtml.

Menges, E.S. 1991. Predicting the future of rare plants: demographic monitoring and modeling. Natural Areas Journal 6:13-25.

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

Mills, C.E. 1999-2000. *Nuttallia obscurata*, the purple varnish clam or the purple mahogany-clam. Accessed via the Internet at http://faculty.washington.edu/cemills/Nuttallia.html. Published by the author, web page established March 1998, last updated 23 August 2000.

Muller, A.A., J.K. Kufer, K.G. Dietl, and M. Weigend. 1998. A dimeric iridoid from *Loasa acerifolia*. Phytochemistry 49:1705-1707.

Murawski, D. A., J. L. Hamrick, S. P. Hubbell, and R. B. Foster. 1990. Mating systems of two bombacaceaous trees of a neotropical moist forest. Oecologia 82:501-506.

Musick, H.B. 1976. Phosphorus toxicity in seedlings of *Larrea divaricata* grown in solution culture. Botanical Gazette 139:108-111.

NatureServe. 2006. NatureServe Explorer: an Online Encyclopedia of Life. Accessed via the Internet at http://www.natureserve.org/explorer/.

Naumann, T. 1990. Status Report for *Oxybaphus rotundifolius*. Unpublished report produced for the U.S. Fish and Wildlife Service by the Colorado Natural Areas Program, Fort Collins, CO.

Neely, B., P. Comer, C. Moritz, M. Lammert, R. Rondeau, C. Pague, G. Bell, H. Copeland, J. Humke, S. Spackman, T. Schulz, D. Theobald, and L. Valutis. 2001. Southern Rocky Mountains: An Ecoregional Assessment and Conservation Blueprint. Prepared by The Nature Conservancy with support from the USDA. Forest Service, Rocky Mountain Region, Colorado Division of Wildlife, and Bureau of Land Management.

New York Botanical Garden. 2003. Image of isosyntype specimens of *Mentzelia chrysantha*. Accessed via the Internet at http://scisun.nybg.org:8890/searchdb/owa/wwwspecimen.searchform.

Nicoletti, M., L. Tomassini, and S. Foddai. 1995. An unusual C-skeleton type glucoside from *Mentzelia incisa*. Planta Medica 61:88-89.

Oostermeijer, J.G.B., S.H. Luijten, and J.C.M. den Nijs. 2003. Integrating demographic and genetic approaches in plant conservation. Biological Conservation 113:389-398.

Palmer, M.A. 1952. Aphids of the Rocky Mountain Region. Hirschfeld Press, Denver, CO.

Parenti, R.L., Jr. A.F. Robinson, and J. Kagan. 1993. Bradshaw's Lomatium Recovery Plan. Portland, OR, Unpublished report prepared for the U.S. Fish and Wildlife Service.

Pavlovic, N.B., M. DeMauro, and M. Bowles. 1992. Perspectives on plant competition- Plant collection rate should be positively correlated with plant population size. Plant Science Bulletin 38:8.

Peet, R.K. 2000. Forests and Meadows of the Rocky Mountains. Pages 75-122 *in* M.G. Barbour and W.D. Billings, editors. North American Terrestrial Vegetation. Cambridge University Press, New York, NY.

Pianka, E.R. 1970. On *r*- and *K*-selection. American Naturalist 104:592-597.

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

Potter, L.D., R.C. Reynolds, and E.T. Louderbough. 1985. Mancos shale and plant community relationships: Field observations. Journal of Arid Environments 9:137-145.

Powell, J. 2003. Personal communication with Colorado Department of Transportation threatened and endangered species specialist regarding management of *Mentzelia chrysantha*.

Prigge, B. 1986. New species of *Mentzelia* (Loasaceae) from Grand County, Utah. Great Basin Naturalist 46:361-363.

Proctor, J. No Date. Region 2 Individual Species Recommendations: *Mentzelia chrysantha*. Accessed via the Internet at http://www.fs.fed.us/r2/projects/scp/evalrationale/rationales/dicots/mentzeliachrysantha.pdf.

Reveal, J.L. 1978. *Mentzelia leucophylla* Brandegee (Ash Meadows stick-leaf). Status Report. U.S. Fish and Wildlife Service, Nevada.

Rees, M. 1994. Delayed germination of seeds: a look at the effects of adult longevity, the timing of reproduction, and population age/stage structure. American Naturalist 144:43-64.

Reveal, J.L. 2003. Indices Nominum Supragenericorum Plantarum Vascularium- Alphabetical Listing by Family of Validly Published Suprageneric Names. Accessed via the Internet at http://www.life.umd.edu/emeritus/reveal/PBIO/fam/sgindex.html.

Rickett, H.W. 1973. Wildflowers of the United States. Volume 6, Part 1. McGraw-Hill Book Company, New York, NY.

Rifici, C. 2006. Personal communication with Fort Carson Military Reservation Botanist regarding *Mentzelia chrysantha*.

Rondeau, R. 2000. Pinyon-Juniper Woodland Ecological System- Matrix. Community Characterization Abstract produced for the Colorado Natural Heritage Program and The Nature Conservancy.

Rosendahl, S., C.N. Rosendahl, and U. Sochting. 1992. Distribution of VA mycorrhizal endophytes amongst plants from a Danish grassland community. Agric Ecosystem and Environment 29:329-335.

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

Rydberg, P.A. 1922. Flora of the Rocky Mountains and Adjacent Plains. Hafner Publishing Co., New York, NY.

Sanders, I.R., J.P. Clapp, and A. Wiemken. 1996. The genetic diversity of arbuscular mycorrhizal fungi in natural ecosystems - a key to understanding the ecology and functioning of the mycorrhizal symbiosis. New Phytologist 133:123-134.

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

Schwartz, M.W. and C.A. Brigham. 2003. Why plant population viability assessment? Chapter 1 *in* C.A. Brigham and M.W. Schwartz, editors. Population Viability in Plants. Springer-Verlag, Berlin, Germany.

Scott, G.R. 1977. Reconnaissance Geologic Map of the Cañon City Quadrangle, Fremont County, Colorado. U.S. Geological Survey, Denver, CO.

Scott, G.R. and R.B. Taylor. 1974. Reconnaissance Geologic Map of the Rockvale Quadrangle, Custer and Fremont Counties, Colorado. U.S. Geological Survey, Denver, CO.

Scott, M.J., P.J. Heglund, M.L. Morrison, J.B. Haufler, M.G. Raphael, W.A. Wall, and F.B. Samson. 2002. Predicting Species Occurrences- Issues of Accuracy and Scale. Island Press, Washington, D.C.

Scott, G.R. and W.A. Cobban. 1964. Stratigraphy of the Niobrara Formation at Pueblo, Colorado. U.S.G.S. Professional Paper 454-L. U.S. Government Printing Office, Washington, D.C.

Scott, M.J., P.J. Heglund, M.L. Morrison, J.B. Haufler, M.G. Raphael, W.A. Wall, and F.B. Samson. 2002. Predicting Species Occurrences- Issues of Accuracy and Scale. Island Press, Washington, D.C.

Shaw, R.B., S.L. Anderson, K.A. Schulz, and V.E. Diersing. 1989. Plant Communities, Ecological Checklist, and Species List for the U.S. Army Pinyon Canyon Maneuver Site, Colorado. Colorado State University Department of Range Science, Fort Collins, CO.

Sih, A. and M. S. Baltus. 1987. Patch size, pollinator behavior, and pollinator limitation in catnip. Ecology 68: 1679-1690.

Silvertown, J. 1993. Introduction to Plant Population Ecology. Second edition. Longman Scientific and Technical, New York, NY.

Smith, N. 2006. Personal communication with The Nature Conservancy expert regarding *Mentzelia chrysantha*.

Soulé, M.E. 1980. Thresholds for survival: maintaining fitness and evolutionary potential. Pages 151-169 *in* M.E. Soule and B.A. Wilcox, editors. Conservation Biology: an Evolutionary Perspective. Sinauer Associates, Sunderland, MA.

Spackman Panjabi, S. 2003. Personal communication with Colorado Natural Heritage Program botanist regarding *Mentzelia chrysantha*.

Spackman Panjabi, S. 2004. Visiting Insect Diversity and Visitation Rates for Seven Globally Imperiled Plant Species in Colorado's Middle Arkansas Valley. Prepared for the Native Plant Conservation Alliance and the National Fish and Wildlife Foundation by the Colorado Natural Heritage Program, Fort Collins, CO.

Spackman Panjabi, S., J. Sovell, G. Doyle, D. Culver, and L. Grunau. 2003. Survey of Critical Biological Resources of Pueblo County, Colorado. Unpublished report prepared for the Pueblo County Planning Department by the Colorado Natural Heritage Program, Fort Collins, CO.

Spackman, S. 2001a. Rare Plant Survey of the Blue Heron Property. Unpublished report prepared for the Bureau of Land Management, Royal Gorge Field Office by the Colorado Natural Heritage Program, Fort Collins, CO.

Spackman, S. 2001b. Raw data from investigations of the pollination biology of *Mentzelia chrysantha* (Unpublished).

Spackman, S. and S. Floyd. 1996. Conserving the Globally Imperiled Brandegee Wild Buckwheat, *Eriogonum brandegeei* Rydb. Unpublished report prepared for the Bureau of Land Management Colorado Office by the Colorado Natural Heritage Program, Fort Collins, CO.

Spackman, S., B. Jennings, J. Coles, C. Dawson, M. Minton, A. Kratz, and C. Spurrier. 1997. Colorado Rare Plant Field Guide. Prepared for the Bureau of Land Management, the U.S. Forest Service and the U.S. Fish and Wildlife Service by the Colorado Natural Heritage Program, Fort Collins, CO.

Spira, T.P. and O.D. Pollak. 1986. Comparative reproductive biology of alpine biennial and perennial gentians (Gentiana: Gentianaceae) in California. American Journal of Botany 73:39-47.

Standley, L.A. 1992. Taxonomic issues in rare species protection. Rhodora 74:218-242.

Stevens, P.F. 2002. Angiosperm Phylogeny Website. Version 3, May 2002. Accessed via the Internet at http://www.mobot.org/MOBOT/research/APweb/.

Stowe, K.A., R.J. Marquis, C.G. Hochwender, and E.L. Simms. 2000. The evolutionary ecology of tolerance to consumer damage. Annual Review of Ecology and Systematics 31:565-595.

Takhtajan, A. 1997. Diversity and Classification of Flowering Plants. Columbia University Press, New York, NY.

The Nature Conservancy. 1998. Ecoregion-based Conservation in the Central Shortgrass Prairie. The Nature Conservancy, Boulder, CO.

The Nature Conservancy. 2005. Central Shortgrass Prairie Assessment and Partnership Initiative - Interim Report, Summary of Phase 1 (July 2004 - July 2005).

Thompson, H.J. 1963. Cytotaxonomic observations on *Mentzelia*, section *Bartonia* (Loasaceae). Madroño 17:16-23.

Thompson, H.J. and B.A. Prigge. 1984. A new species of *Mentzelia* section *Bartonia* (Loasaceae) from western Nevada. Phytologia 55:281-287.

Thompson, H.J. and B. Prigge. 1986. New species and a new combination of *Mentzelia* Section *Bartonia* (Loasaceae) from the Colorado Plateau. Great Basin Naturalist 46:549-554.

Thompson, H.J. and J.E. Zavortink. 1968. Two new species of *Mentzelia* in Texas. Wrightia 4:21-24.

Thorne, R.F. 1983. Proposed new realignments in the angiosperms. Nordic Journal of Botany 3:85-117.

Tweto, O. 1979. Geologic Map of Colorado. Compiled by the U.S. Geological Survey with technical assistance by the Colorado Geological Survey.

U.S. Census Bureau. 2003. 1990 and 2000 census data for Fremont and Pueblo Counties. Accessed via the Internet at www.census.gov.

U.S. Department of Agriculture, Soil Conservation Service. 1994. State Soil Geographic (STATSGO) Database for Colorado Publication Information. U.S. Department of Agriculture, Soil Conservation Service, Fort Worth, TX.

U.S. Fish and Wildlife Service. 1985. Final rule for seven plants and one insect in Ash Meadows, Nevada and California. Federal Register 50:20777-20794.

U.S. Fish and Wildlife Service. 1986. Recovery Plan for the Endangered and Threatened Species of Ash Meadows, NV. Agency Draft. U.S. Fish and Wildlife Service, Portland, OR.

U.S. Environmental Protection Agency. 1997. Climate Change and Colorado. EPA 230-F-97-008f. Office of Policy, Planning, and Evaluation, Climate and Policy Assessment Division, Washington, D.C.

Urban, I. and E. Gilg. 1900. Monographia Loasacearum. Nova Acta Akad. Leop.-Carol. German. Nat. Cur 76:1-370.

USDA Forest Service Region 2. 2003a. Forest Service Manual Rocky Mountain Region. Chapter 2670. Threatened, Endangered, and Sensitive Plants and Animals. USDA Forest Service Region 2, Lakewood, CO.

USDA Forest Service Region 2. 2003b. Matrix of “Listed” Species in the Great Plains of North America and their Occurrence on National Grasslands. Available via the Internet at http://www.fs.fed.us/r2/nebraska/gpng/matrix/plantmo.html.

USDA Natural Resources Conservation Service. 2006. The PLANTS Database, 6 March 2006 (http://plants.usda.gov). National Plant Data Center, Baton Rouge, LA.

Vandenkoornhuyse, P., S.L. Baldauf, C. Leyval, J. Straczek, and J.P.W. Young. 2002. Extensive fungal diversity in plant roots. Science 2051-2052.

Varma, A. 1999. Functions and application of arbuscular mycorrhizal fungi in arid and semi-arid soils. Pages 521-556 *in* A. Varma and B. Hock, editors. Mycorrhiza. Second edition. Springer-Verlag, Berlin, Germany.

Villegas, L.F., I.D. Fernandez, H. Maldonado, R. Torres, A. Zavaleta, A.J. Vaisberg, and G.B. Hammond. 1997. Evaluation of the wound-healing activity of selected traditional medicinal plants from Peru. Journal of Ethnopharmacology 55:193-200.

Wagner, D.H. 1991. The 1 in 20 rule for plant collectors. Plant Science Bulletin 37:11.

Weber, W.A. and R.C. Wittmann. 2001a. Colorado Flora: Eastern Slope. Third edition. University Press of Colorado, Boulder, CO.

Weigend, M. 1997. *Nasa* and the conquest of South America. Weigend Eigenverlag, Munich, Germany.

Weigend, M. 2003. The Loasaceae web page. Accessed via the Internet at http://www.nybg.org/bsci/res/loas/index.htm.

Weigend, M., J. Kufer, and A.A. Muller. 2000. Phytochemistry and the systematics and ecology of Loasaceae and Gronoviaceae (Loasales). American Journal of Botany 87:1202-1210.

West, N.E. and J.A. Young. 2000. Intermountain valleys and lower mountain slopes. *In*: M.G. Barbour and W.D. Billings, editors. North American Terrestrial Vegetation. Second Edition. Cambridge University Press, New York, NY.

Western Regional Climate Center. 2003. Colorado Climate Summaries. Accessed via the Internet at http://www.wrcc.dri.edu/summary/climsmco.html.

Wheeler, T.J., D.L. Anderson, S. Engel, A.M. Hogan, L.S. Larsen, L.A. Neve, and R.R. Romano. 1995. Soil Survey of Fremont County Area, Colorado. U.S. Department of Agriculture, Natural Resources Conservation Service, in cooperation with the Colorado Agricultural Experiment Station and the U.S. Department of the Interior, Bureau of Land Management.

Xiang, Q.Y., M. Moody, D.E. Soltis, C.Z. Fan, and P.S. Soltis. 2002. Relationships within Cornales and circumscription of Cornaceae - matK and rbcL sequence data and effects of outgroups and long branches. Molecular and Phylogenetics and Evolution 24:35-57.

Xiang, Q.Y. and D.E. Soltis. 1998. *RbcL* sequence data define a cornaceous clade and clarify relationships of Cornaceae *sensu lato*. *In*: D.E. Boufford and H. Ohba, editors. Sino-Japanese Flora- Its Characteristics and Diversification. University of Tokyo, Tokyo, Japan.

Xiang, Q.Y., D.E. Soltis, D.R. Morgan, and P.S. Soltis. 1993. Phylogenetic relationships of *Cornus* L. *sensu lato* and putative relatives inferred from *rbcL* sequence data. Annals of the Missouri Botanical Garden 80:723-734.

Young, J.A. and R.R. Blank. 1995. Cheatgrass and wildfires in the Intermountain West. California Exotic Pest Plant Council Symposium Proceedings 1-3.