

***Eriogonum brandegeei* Rydberg  
(Brandegee's buckwheat):  
A Technical Conservation Assessment**



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

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## COVER PHOTO CREDIT

*Eriogonum brandegeei* (Brandegee's buckwheat). Photograph by Susan Spackman Panjabi, used with permission.

# SUMMARY OF KEY COMPONENTS FOR CONSERVATION OF *ERIOGONUM BRANDEGEEI*

## *Status*

*Eriogonum brandegeei* (Brandegees' buckwheat) is an extremely narrow endemic whose global distribution is limited to nine verified occurrences in Fremont and Chaffee counties, Colorado. An additional occurrence has been reported on National Forest System lands in Chaffee County, but the exact location of this report is uncertain. The total area of known occupied habitat is 1.27 square miles in two areas near the Arkansas River, separated from each other by approximately 50 miles. The total population size of *E. brandegeei* is unknown, but estimates range between 35,000 and several million plants. NatureServe ranks this species as globally critically imperiled (G1G2), and the Colorado Natural Heritage Program ranks it critically imperiled in the state (S1S2). The USDA Forest Service Region 2 considers *E. brandegeei* to be a sensitive species, and the Colorado State Office of the Bureau of Land Management includes it on the Sensitive Species List for the Royal Gorge Field Office. *Eriogonum brandegeei* is not listed as threatened or endangered under the Federal Endangered Species Act, but it is a former candidate for listing.

## *Primary Threats*

Observations and quantitative data identify several threats to the persistence of *Eriogonum brandegeei*. In order of decreasing priority, these threats include off-road vehicle use and other recreation, residential and commercial development, timber thinning and extraction, mining, right-of-way management, exotic species invasion, grazing, effects of small population size, rust, fire, global climate change, and pollution. Some threats are more urgent at some sites than at others; this hierarchy of threats may be different for each site. All sites are threatened by recreational impacts, particularly off-road vehicle use. Fremont County is among the fastest growing counties in the United States, and low-density development is proceeding rapidly throughout the Arkansas River valley.

## *Primary Conservation Elements, Management Implications and Considerations*

Six occurrences of *Eriogonum brandegeei* are located completely or partially on lands managed by the Bureau of Land Management, where they are somewhat protected due to this species' status as a sensitive species. However, off-road vehicle use and mountain biking threaten some of these occurrences. Curtailment of off-road vehicle use in occurrences is likely to confer the greatest benefits to *E. brandegeei*. All or part of nine occurrences are found on private lands where they are threatened by residential development or mining. Designating a new Area of Critical Environmental Concern, pursuing conservation easements on private properties and other protective land status changes are likely to be highly effective in achieving conservation goals for *E. brandegeei*. Inventories focusing on private lands may lead to the discovery of new occurrences, but it is unlikely that large occurrences remain undiscovered. Research is needed to investigate the population biology and autecology of *E. brandegeei* so that conservation efforts on its behalf can be most effective.

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## INTRODUCTION

This assessment is one of many being produced to support the Species Conservation Project for the Rocky Mountain Region (Region 2), USDA Forest Service (USFS). *Eriogonum brandegeei* is the focus of an assessment because it is designated a sensitive species by Region 2. Within the National Forest System, a sensitive species is a plant or animal whose population viability is identified as a concern by a Regional Forester because of significant current or predicted downward trends in abundance and/or in habitat capability that would reduce its distribution (FSM 2670.5(19)). A sensitive species requires special management, so knowledge of its biology and ecology is critical. This assessment addresses the biology of *E. brandegeei* throughout its range in Region 2. The broad nature of the assessment leads to some constraints on the specificity of information for particular locales. This introduction defines the goal of the assessment, outlines its scope, and describes the process used in its production.

### *Goal of Assessment*

Species conservation assessments produced as part of the Species Conservation Project are designed to provide forest managers, research biologists, and the public with a thorough discussion of the biology, ecology, conservation status, and management of certain species based on available scientific knowledge. The assessment goals limit the scope of the work to critical summaries of scientific knowledge, discussion of broad implications of that knowledge, and outlines of information needs. The assessment does not seek to develop specific management recommendations. Rather, it provides the ecological background upon which management must be based and focuses on the consequences of changes in the environment that result from management (i.e., management implications). Furthermore, this assessment 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 *Eriogonum brandegeei* with specific reference to the geographic and ecological characteristics of the USFS Rocky Mountain Region, to which it is endemic. This assessment is concerned with reproductive behavior, population dynamics, and other characteristics of *E. brandegeei* in

the context of the current environment rather than under historical conditions. The evolutionary environment of the species is considered in conducting the synthesis, but placed in a current context.

In producing the assessment, I reviewed refereed literature, non-refereed publications, research reports, and data accumulated by resource management agencies. All known publications, reports, and element occurrence records on *Eriogonum brandegeei* are referenced in this assessment, and most of the experts on this species were consulted during its synthesis. All known specimens of *E. brandegeei* were viewed to verify occurrences and to incorporate specimen label data. Specimens were searched for at University of Colorado Herbarium (COLO), CSU 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). Specimen data from other institutions were obtained via the Internet and from Reveal (1967a). While this assessment emphasizes refereed literature, non-refereed publications, personal communications, and reports were used when additional information was unavailable elsewhere. Unpublished data (e.g., Natural Heritage Program records) contain the vast majority of the useful information known on *E. brandegeei* and were important in estimating its geographic distribution. However, these data required special attention because of the diversity of persons and methods used in collection.

### *Treatment of Uncertainty*

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, so we must often rely on observations, inference, good thinking, and models 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.

Overall, our knowledge of *Eriogonum brandegeei* is sparse and incomplete. To the author's knowledge, there have been no quantitative or qualitative studies into the autecology of *E. brandegeei*. The existing information is mostly from herbarium labels, field surveys, and anecdotal observations. The paucity of information on *E. brandegeei* has forced the author to rely heavily on personal communications with botanists that have had some experience with the species, and to draw inferences from other members of the genus *Eriogonum* 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 the revision of assessments, which will be accomplished based on guidelines established by Region 2.

### ***Peer Review of This Document***

Assessments developed for the Species Conservation Project have been peer reviewed prior to release on the Web. This assessment was reviewed through a process administered by the Center for Plant Conservation employing two recognized experts on this or related taxa. Peer review was designed to improve the quality of communication and to increase the rigor of the assessment.

## **MANAGEMENT STATUS AND NATURAL HISTORY**

### ***Management Status***

USDA Forest Service Region 2 (2003) has designated *Eriogonum brandegeei* as a sensitive species. Although its merits for sensitive status were not evaluated during the revision of the sensitive species list, it was recommended for inclusion because of its global rarity (Kratz and Warren 2002). It is also listed on the Bureau of Land Management (BLM) Colorado State Sensitive Species List for the Royal Gorge Field Office (Bureau of Land Management 2000). *Eriogonum brandegeei* currently has no status under the federal Endangered Species Act of 1973 (U.S.C. 1531-1536, 1538-1540). It was formerly a candidate for listing (U.S. Fish and Wildlife Service 1993) but was removed

from Candidate status in 1996 (U.S. Fish and Wildlife Service 1996). Prior to 1993, it was a Category 2 candidate, for which "proposing to list as threatened is possibly appropriate, but for which sufficient data on biological vulnerability and threats are not currently available to support proposed rules" (U.S. Fish and Wildlife Service 1993). *Eriogonum brandegeei* has been listed as threatened by the International Union for Conservation of Nature and Natural Resources (Ayensu and DeFilipps 1978).

NatureServe (2005) considers *Eriogonum brandegeei* to be globally critically imperiled (G1G2). The Colorado Natural Heritage Program (2005) also considers this species to be critically imperiled (S1S2) in the state because it is known from only nine verified occurrences, and all of them are immediately threatened by human activities. Four additional locations are documented, but these occurrences are questionable. If more of the known occurrences were secure and demonstrably viable, *E. brandegeei* would warrant a rank of G2, but the split rank of G1G2 better reflects its degree of rarity and imperilment (see the **Definitions** section for explanations of conservation status ranks).

### ***Existing Regulatory Mechanisms, Management Plans, and Conservation Strategies***

Adequacy of current laws and regulations

*Eriogonum brandegeei* has no known enforceable laws, regulations, protective designations, conservation agreements, or management plans that would prevent the destruction of individuals or their habitat. It is included on the USFS Region 2 sensitive species list (USDA Forest Service Region 2 2003), but there are currently no well-documented occurrences known from National Forest System lands. The BLM, which manages land that contains all or part of six occurrences, must consider *E. brandegeei* in its planning activities because it is included on the Sensitive Species List by the BLM Royal Gorge Field Office. Efforts must be made to maintain individuals and their habitat on BLM lands.

The BLM recently drafted a travel management plan for an area that includes Garden Park in Fremont County, Colorado. The preferred option in this plan will reduce traffic impacts on *Eriogonum brandegeei* by an estimated 49 acres (Bureau of Land Management 2004a). A travel management plan will soon be drafted to address areas of the upper Arkansas River in Chaffee County that will include most of the occurrences of *E.*



*brandegeei*. It is anticipated that this plan will also result in decreased impacts on *E. brandegeei* (Brekke personal communication 2004). No management plans have been written for the BLM Areas of Critical Environmental Concern (ACEC) in which *E. brandegeei* is found (Brekke personal communication 2004). However, actions have been taken in an effort to decrease human impacts to *E. brandegeei* occurrences on BLM land. Some roads have been closed to vehicle traffic at Droney Gulch ACEC to prevent trash disposal and to protect *E. brandegeei* (Brekke personal communication 2004). Land ownership patterns complicate protection for some occurrences of *E. brandegeei* on BLM lands.

*Eriogonum brandegeei* is a conservation target in the Arkansas Valley Barrens Site Conservation Plan (The Nature Conservancy 2001). The goal of this plan is to ensure the protection of all plants in the Garden Park area. Specifically, this plan outlines a strategy for the conservation of the three occurrences of *E. brandegeei* at Garden Park through the purchase of property or easements and through cooperative efforts with federal agencies (The Nature Conservancy 2001).

The Chaffee County Comprehensive Plan (Chaffee County 2000) does not explicitly cite the protection of *Eriogonum brandegeei* among its planning goals. However, the plan's emphasis on preventing scattered rural development and development on steep slopes and ridgelines may afford some protection to *E. brandegeei*.

#### Adequacy of current enforcement of laws and regulations

Current legal protections that apply to *Eriogonum brandegeei* pertain only to occurrences on public lands managed by the USFS (if any) or the BLM. There are no known cases in which an occurrence of this species was extirpated due to the failure to enforce any existing regulations. However, this does not necessarily indicate that current regulations or their enforcement are adequate for the protection of *E. brandegeei*. Human impacts such as residential development and recreational use of habitat may have diminished the abundance of this species. Enforcement of existing off-road vehicle use restrictions on BLM lands is very difficult. Users frequently pull down barriers and breach fences to gain access to off-limits areas (Brekke personal communication 2004). Illegal trash disposal is a problem on public lands near municipalities and has occurred at Droney Gulch in Chaffee County. This practice is also very difficult to prevent (Brekke personal communication 2004).

Federal agencies lack sufficient human resources to patrol the vast areas that they manage, and given the current human population growth trends within the global range of this species, future impacts to occurrences of *E. brandegeei* are inevitable.

### ***Biology and Ecology***

#### Classification and description

*Eriogonum brandegeei* is a member of the buckwheat family (Polygonaceae). This large family, composed mainly of herbs, includes about 30 genera and 750 species worldwide (Heywood 1993). It is a cosmopolitan family but is more common in the north temperate regions (Zomlefer 1994). The Polygonaceae family is in the Eudicot group, order Caryophyllales (Stevens 2001 onwards). *Eriogonum* is in the subfamily Eriogonoideae (**Table 1**).

Frye and Kron (2003) used chloroplast DNA from the *rbcL* gene to construct a molecular phylogeny of the Polygonaceae. While the focus of this study was the genus *Polygonum*, two species of *Eriogonum* were included, and the family appears to be monophyletic. No comparable analysis has been done to investigate the relationships throughout the genus *Eriogonum*.

The genus *Eriogonum* includes about 250 species, all but two of which are endemic to North America (Reveal 1981, Reveal 1985). The greatest diversity can be found in the western United States (Shields and Reveal 1988). The center of distribution for *Eriogonum* appears to be the Rocky Mountains and surrounding areas of the interior western United States (Reveal 1967b). The combination of isolated mountain ranges and many unusual soil types in the Intermountain West has resulted in a high degree of adaptive radiation and endemism in this relatively recently evolved genus (Shields and Reveal 1988, The Nature Conservancy and the Association for Biodiversity Information 2000). Forty-nine species of *Eriogonum* are known from Colorado (Weber and Wittmann 2000, Weber and Wittmann 2001a, 2001b), and many of these are rare. The Colorado Natural Heritage Program tracks 16 rare species of *Eriogonum*. One Colorado species, *E. pelinophilum*, is a federally listed endangered species (U.S. Fish and Wildlife Service 1983).

*Eriogonum* species have long been considered among the most difficult to resolve taxonomically. Dr. James Reveal, monographer of the genus *Eriogonum*, has described the taxonomic status of *E. brandegeei*, which will be included in his treatment of the Polygonaceae in

**Table 1.** Classification of *Eriogonum brandegeei* after USDA Natural Resources Conservation Service 2003, with sources (not necessarily the original source) of particular portions cited below. \* The taxonomic level of the Eudicots group has not yet been determined (Stevens 2001 and onwards).

Kingdom	Plantae (Plants)
Subkingdom	Tracheobionta (Vascular Plants)
Superdivision	Spermatophyta (Seed Plants)
Division	Magnoliophyta (Flowering Plants)
Class*	Eudicots <sup>3</sup>
Subclass	Caryophyllidae
Order	Caryophyllales <sup>3</sup>
Family	Polygonaceae (Buckwheat Family)
Subfamily	Eriogonoideae <sup>1</sup>
Tribe	Eriogoneae <sup>1</sup>
Subtribe	Eriogoninae <sup>1</sup>
Genus	<i>Eriogonum</i> (buckwheat)
Subgenus	<i>Eucycla</i> <sup>2</sup>
Section	<i>Aphelogonum</i> <sup>2</sup>
Subsection	<i>Aphelogonum</i> <sup>2</sup>

<sup>1</sup>Reveal 2000

<sup>2</sup>Reveal 1969

<sup>3</sup>Stevens 2001 onwards

a forthcoming volume of the Flora of North America. He considers *E. brandegeei* to be a valid species. The closest relative of *E. brandegeei* is *E. spathulatum*, which has a branched inflorescence rather than a capitate inflorescence but is otherwise very similar to *E. brandegeei*. *Eriogonum spathulatum* is endemic to Utah. Like *E. canum*, the nearest relatives of *E. brandegeei* are in distant locations. *Eriogonum brandegeei* is part of the *E. spathulatum* complex in the *E. brevicaulis* group. This is a variable group, which includes one member currently being described whose leaves consist only of midveins (Reveal personal communication 2004). As a narrow endemic, *Eriogonum brandegeei* is a distinctive element of the flora of the southern Rocky Mountains and is important in the taxonomic study of the genus (Johnston et al. 1981).

#### History of knowledge

*Eriogonum brandegeei* was collected several times in the 1870s from Garden Park north of Cañon City (Johnston et al. 1981). It was first collected by Townshend Stith Brandegee in September 1872 (#B427 at NY). He collected it again on September 1, 1873 (*s.n.*) as *E. multiceps*, a wide-ranging species, under which it was included in Rydberg 1907. T. S. Brandegee was stationed in Cañon City in 1871 as county surveyor and city engineer when he made these collections. Marcus E. Jones made another early collection in the

Arkansas River gorge above Cañon City in 1878. These collections were made around the time that Garden Park, a fossil bed containing well-preserved specimens of numerous dinosaur species, was discovered (Colorado Natural Areas Program 2004). Brandegee's 1873 collection (housed at New York Botanical Garden) became the type specimen for *E. brandegeei* when it was formally described by Per Axel Rydberg in his *Flora of the Rocky Mountains and Adjacent Plains* (Rydberg 1922), naming it after its original collector. An image of this specimen can be viewed at the New York Botanical Garden website (New York Botanical Garden 2004).

In her 1936 monograph of the genus *Eriogonum*, Susan Stokes reduced *E. brandegeei* to varietal status under *E. spathulatum*, as *E. spathulatum* A. Gray var. *brandegeei* [sic] (Rydberg) S. Stokes (Stokes 1936). Stokes' treatment is reflected in Harrington's *Manual of the Plants of Colorado* (Harrington 1954), where it is given a cursory discussion since Harrington had not seen the specimens. There were no further monographic treatments of the genus until that of James Reveal in 1969. Reveal restored *E. brandegeei* to a full species; it is this treatment that is universally recognized today.

After the collections of the 1870s, no further collections of *Eriogonum brandegeei* were made until 1947 when it was collected by George W. Kelly at an

uncertain location (see the Distribution and abundance section of this assessment). It was not until 1967, nearly a century after its discovery, that *E. brandegeei* was collected again with reliable location data. James Reveal and Garrett Davidse collected *E. brandegeei* at a new location at Garden Park and discovered a small occurrence near Salida in Chaffee County. Since then, several large occurrences have been documented around Salida.

It was these recent collections that raised the profile of *Eriogonum brandegeei* in the botanical community, and its rarity and narrow endemism were recognized. After the passage of the Endangered Species Act in 1973, *E. brandegeei* was considered for its potential to be an endangered or threatened species. It was reviewed as a candidate for Threatened status in 1975 (U.S. Fish and Wildlife Service 1975, as cited in Johnston et al. 1981). In 1980 it was designated a Category 2 candidate species, as it appeared to merit listing but insufficient information was available (U.S. Fish and Wildlife Service 1980). In 1981 Barry Johnston, J. Scott Peterson, and William Harmon wrote a status report for the species in which they recommended a Category 2 status (Johnston et al. 1981).

*Eriogonum brandegeei* was collected numerous times in the 1980s by O’Kane, Johnston, Jennings, and others, and several times by Spackman in the 1990s and 2000s. O’Kane (1988) provided a brief overview of *E. brandegeei* as known at that time, in the only treatment of its distribution and threats published in a peer-reviewed journal. Surveys were done by Coles and Naumann in 1989, 1992, and 1993 that “resulted in population estimates between 100,000 and several million individuals” (U.S. Fish and Wildlife Service 1996). Susan Spackman and Sandra Floyd conducted a survey of *E. brandegeei* on lands administered by the BLM in July of 1995. This survey, funded by the BLM, identified and surveyed 19 areas containing potential habitat for *E. brandegeei* and resulted in the discovery of two new occurrences. No more occurrences have been discovered since 1995. The total population estimated by Spackman and Floyd (1996) was 35,000 individuals.

*Eriogonum brandegeei* was elevated to Candidate (C1) status in 1993 (U.S. Fish and Wildlife Service 1993) but was removed from any consideration for protection under the Endangered Species Act in 1996 (U.S. Fish and Wildlife Service 1996), based on the surveys of Coles and Naumann. However, no mention of the results of Spackman and Floyd (1996) was made. It is quite possible that the author of the document was

not aware of Spackman and Floyd’s research, but the delisting of *E. brandegeei* was premature since it did not give adequate consideration to available information.

In 2004, the BLM funded the installation of monitoring plots at two sites at Garden Park and one at Cleora (Grant and DePrenger-Levin 2005). The plots at Garden Park were resampled in 2005, but the plot at Cleora was not due to concern for the impacts of monitoring at this location, which is on steep slopes with soft soils. The goals of this study include documenting demographic variables (including reproduction, recruitment, and longevity) and assessing the impacts of fungal rust and off-road vehicle disturbance. Data from this study are included in this assessment where relevant, and their methods are described in the Population monitoring section of this assessment.

### *Eponymy*

*Eriogonum brandegeei* is named after Townshend Stith Brandegee, the first collector of this species. T.S. Brandegee (1843-1925) had a remarkable career as a botanist, having participated in numerous botanical expeditions. His wife, Kate Brandegee, also had an illustrious career as a botanist. Together they made an enormous contribution to the description and documentation of the flora of western North America. As a result, they have been honored by numerous authors; at least 120 species include some form of their last name as an eponym (The Plant Names Project 1999, Frazier and Allred 2000). The eponym “*brandegei*” has been applied by most authors for this purpose, as used by Rydberg for naming *E. brandegeei*. However, as noted by Frazier and Allred (2000), recommendation 60C.3 of the 1994 International Code of Botanical Nomenclature states “In forming new epithets based on personal names, the original spelling of the personal name should not be modified unless it contains letters foreign to Latin plant names or diacritical signs.” In deference to this recommendation, most contemporary treatments are shifting to the spelling “*brandegeei*” for these eponyms. The conflict between these treatments (e.g., Kartesz 1999, USDA Natural Resources Conservation Service 2003, NatureServe 2005 where “*E. brandegeei*” is used) and sources where the original spelling is used (e.g., Colorado Native Plant Society 1997, Spackman et al. 1997, and Weber and Wittmann 2001a) is a possible source of confusion.

### *Non-technical description*

The genus *Eriogonum* is distinguished from other members of the Polygonaceae in that its members do

not have an ocrea at the leaf base (Harrington 1954). The ocrea is a sheath around the stem formed from the stipules that is common throughout most of the Polygonaceae (Harris and Harris 1999). *Eriogonum* species also have distinctive wood anatomy when compared with other members of the Polygonaceae (Carlquist 2003).

*Eriogonum brandegeei* is a mat-forming perennial herb (**Figure 1**). It is typically 10 to 25 cm tall (Spackman et al. 1997), and mats have been observed from 1 inch in diameter (Spackman Panjabi personal communication 2004) to more than 2 ft. in diameter (O’Kane specimen #2208). *Eriogonum brandegeei* has an deep, woody taproot that, along with its spreading habit, leaves it well adapted to surviving on steep, unstable slopes (Coles personal communication 2004, Reveal personal communication 2004). Plants have been observed on “pedestals,” with much of their woody root exposed. Its leaves are erect (NatureServe 2005) and densely hairy on both sides (Reveal 1969,

Spackman et al. 1997). The hairs of the leaves and other parts of the plant have been described as tomentose (Reveal 1969) or floccose, with loose tufts of wool-like hair that are not uniformly distributed over all surfaces (Rydberg 1922, Reveal 1969, Ellis and Fay 1978). The dense tomentum gives the plant a blue-green appearance (Johnston et al. 1981). *Eriogonum brandegeei* produces leafless, unbranched flowering stalks that are 10 to 25 cm tall (Reveal 1969, NatureServe 2005). The flowering stalk bears a terminal cluster of white to pink or rose-colored flowers that are 3 to 3.5 mm long (Colorado Native Plant Society 1997, Spackman et al. 1997, NatureServe 2005). The stamens are slightly exerted from the flower (**Figure 2**; Reveal 1969).

*Eriogonum brandegeei* is distinguished from other local *Eriogonum* species by its leaves, which are densely tomentose on both sides, and by its unbranched flowering stalk (Spackman et al. 1997). *Eriogonum brandegeei* shares many similarities with *E. coloradense* (Colorado Natural Heritage Program



**Figure 1.** *Eriogonum brandegeei*. Photograph by Susan Spackman Panjabi (From Spackman et al. 1997), used with permission.



**Figure 2.** The capitulate inflorescence of *Eriogonum brandegeei*. Photograph by Susan Spackman Panjabi, used with permission.

2005), but these species do not occur together. The leaves of *E. brandegeei* are tomentose on both sides, while those of *E. coloradense* are only tomentose below. The stature of *E. coloradense* is generally shorter than that of *E. brandegeei*, but taller individuals that approach the maximum height of *E. brandegeei* have been documented in favorable sites.

There have been no cytological investigations of *Eriogonum brandegeei*. It has been suggested that members of *Eriogonum* have a base chromosome number of 10, and that members whose base chromosome number is 20 or 40 are the descendants of an ancestral allopolyploid (Stokes 1936, Stokes and Stebbins 1955). *Eriogonum allenii* is  $n = 20$  (Bellmer 1969) while *E. umbellatum* ssp. *polyanthum* is  $n = 40$  (Reveal and Holmgren 1965). Chromosome numbers of 18, 22, 24, 32, and 34 have also been reported within the genus, suggesting that some aneuploid events have also occurred in the evolution of the species (Stokes and Stebbins 1955).

#### *Technical description*

The following technical description of *Eriogonum brandegeei* is taken from Reveal (1969, p. 149):

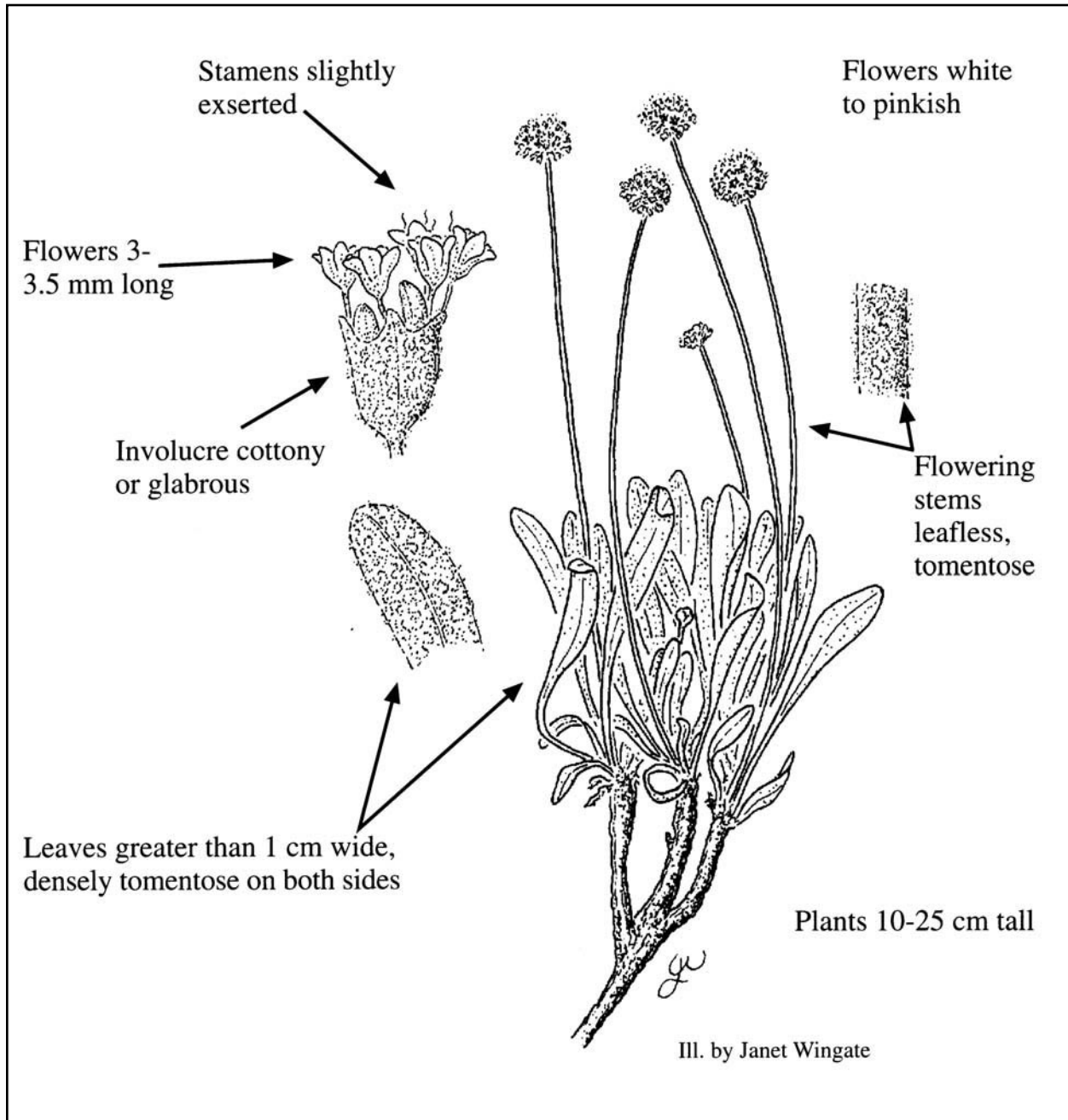
Low spreading herbaceous perennials 1 to 2.5 dm high and 1 to 2 dm across; leaves basal, the leaf-blades oblanceolate to elliptic, 1.5 to 3 (4) cm long, 4 to 8 mm wide, tomentose, the margins entire and plane, the petioles long, 1 to 1.5 cm long, tomentose; flowering stems erect, 1 to 2.5 dm long, tomentose to floccose; inflorescences capitulate or nearly so; bracts scale-like, ternate, 2 to 5 mm long, 0.5 to 1.2 mm wide; peduncles lacking or up to 3 mm long, thinly floccose to glabrous; involucre congested, 4 to 8 per head, turbinate, 3.5 to 5 mm long, 3 to 4 mm wide, floccose to glabrous, 5-lobed; flowers white, 3 to 3.5 mm long, glabrous, the tepals essentially similar; stamens slightly exerted, 3 to 3.5 mm long, the filaments sparsely pubescent basally,

the anthers reddish; achenes brown, 3 to 3.5 mm long.

*Sources for photographs, illustrations, and descriptions*

There are several sources of photographs and illustrations of *Eriogonum brandegeei*. The best is Spackman et al. (1997), which includes a high-quality

illustration (**Figure 3**), photographs of the plant (**Figure 1**) and its habitat (**Figure 4**), a description of diagnostic characters, and a distribution map. An online version of this source is available at [www.cnhp.colostate.edu](http://www.cnhp.colostate.edu). Johnston et al. (1981) includes plant and habitat photographs, but this source is not readily available. Colorado Native Plant Society (1997) also includes photographs of *E. brandegeei*. This species is mentioned in Rickett (1973), but no photograph is



**Figure 3.** Illustration of *Eriogonum brandegeei* by Janet Wingate (from Spackman et al. 1997), used with permission.



**Figure 4.** Habitat of *Eriogonum brandegeei*. Photograph by Susan Spackman Panjabi, used with permission.

provided. A photograph of the type specimen, housed at the New York Botanical Garden, is available on their website (New York Botanical Garden 2004). Detailed anatomical investigations of the wood anatomy of members of the Polygonaceae including *Eriogonum* were done by Carlquist (2003); this reference includes numerous SEM photographs of the microstructure of several *Eriogonum* species (but not *E. brandegeei*).

Technical descriptions of *Eriogonum brandegeei* are found in Rydberg (1922) and Reveal (1969). Of the two, the latter is more thorough. Weber and Wittmann (2001a) provide a key but no technical description. *Eriogonum brandegeei* is mentioned in Harrington (1954), but no description is included. Ellis and Fay (1978) include a brief description.

#### Distribution and abundance

*Eriogonum brandegeei* is narrowly endemic to two counties (Fremont and Chaffee) in Colorado. It has been reported from 13 locations, nine of which have been verified by subsequent field surveys, and four of which (three from Colorado and one from New Mexico)

are questionable or their location is not known. Six of the nine verified occurrences are located within a 5 by 15 mile area along the Arkansas River in Chaffee County. The other three are about 50 miles away at Garden Park, north of Cañon City in Fremont County. In Chaffee County, the species is limited primarily to outcrops of the Dry Union Formation while in Fremont County it is found on sites underlain by the Morrison Formation (Johnston et al. 1981, O’Kane 1988, Spackman and Floyd 1996, Colorado Natural Heritage Program 2005). See **Figure 5** and **Figure 6** for maps that show the distribution of *E. brandegeei* occurrences in Region 2 and **Table 2** for descriptions of each occurrence.

Spackman and Floyd (1996) recognized five areas in which occurrences are found, and they delineated each as a Potential Conservation Area (PCA; **Figure 7**). The Colorado Natural Heritage Program uses PCAs to describe the primary area needed to support the long-term survival of a targeted species. Four PCAs (Droney Gulch, Cleora, Harrington Gulch, and Hecla Junction) fall within the 5 by 15 mile area in Chaffee County; a fifth PCA, Garden Park, includes the occurrences in Fremont County.

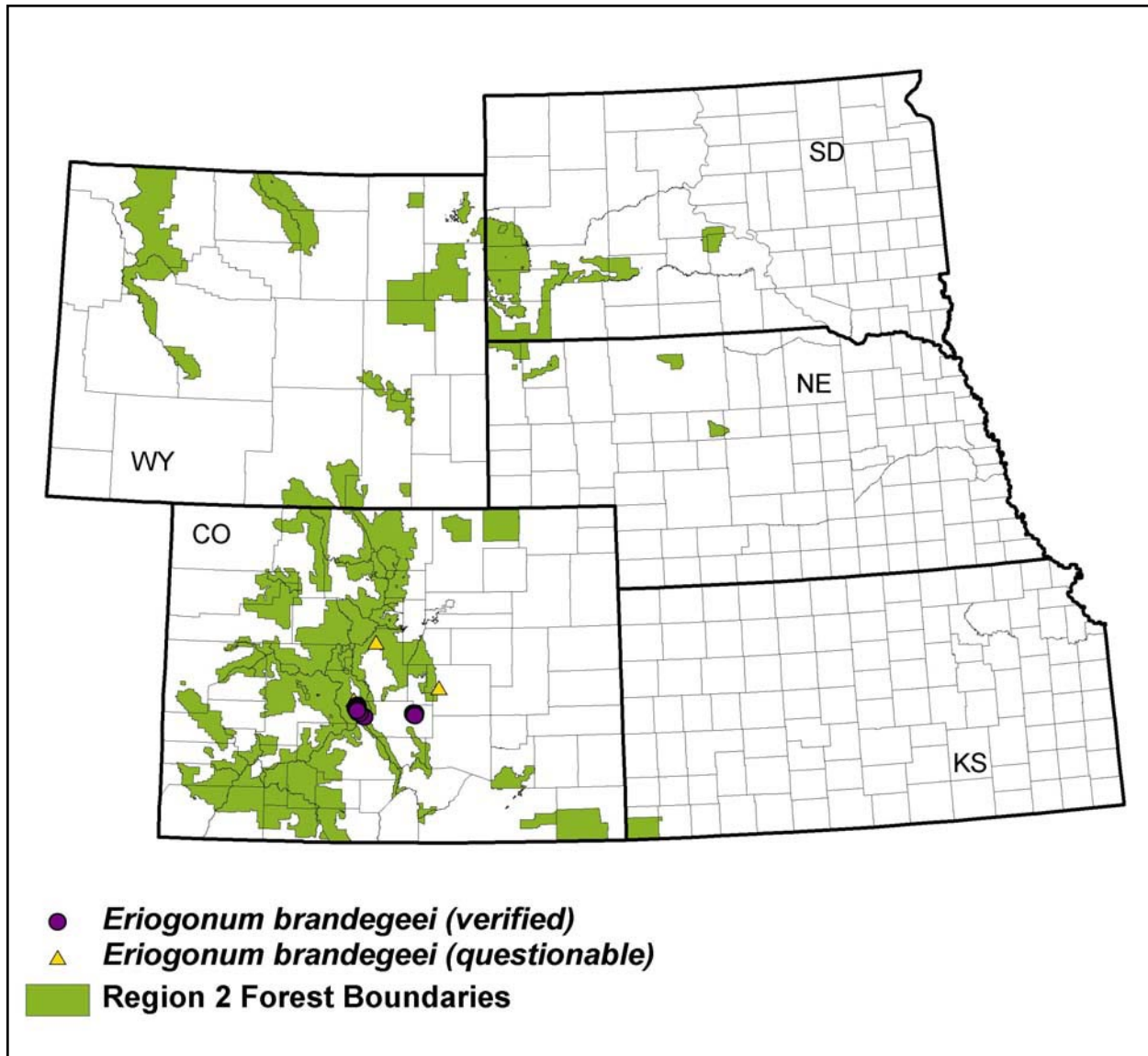


Figure 5. The distribution of *Eriogonum brandegeei* in the states of USDA Forest Service Region 2.

Of the four questionable reports of *Eriogonum brandegeei*, three are from Colorado while the fourth is from New Mexico. Reveal (personal communication 2004) examined the specimen, collected by Edward Lee Greene (1843-1915) and labeled as being from New Mexico. The specimen was indeed *E. brandegeei*, but Reveal questions its location, since Greene's label data are often mistaken. Greene lived for a time in Pueblo, where he officiated as an Episcopal minister (Ewan and Ewan 1981). He probably collected the specimen at one of the known sites in the Arkansas Valley, or it was given to him. Reveal has not seen *E. brandegeei* or similar species in New Mexico.

A herbarium specimen reportedly collected from "Colorado Springs" in 1884 (Letterman s.n.) is also

questionable. This specimen (EO#4 in **Table 2**) was verified as *Eriogonum brandegeei*, but it was probably mislabeled since there is no suitable habitat near Colorado Springs (Colorado Natural Heritage Program 2005). O'Kane (1988) noted that this is a particularly wooly-pubescent specimen.

Of the 1947 collection of *Eriogonum brandegeei* in South Park, Park County (EO#9 in **Table 2**; Kelly #507 at COLO), O'Kane (1988) wrote: "A specimen taken from 'South Park,' Park County probably has an incorrect location. Repeated searches in South Park have located neither the species nor suitable habitat. Kelly, passing through South Park on his way to Cortez, probably collected the species near Salida."



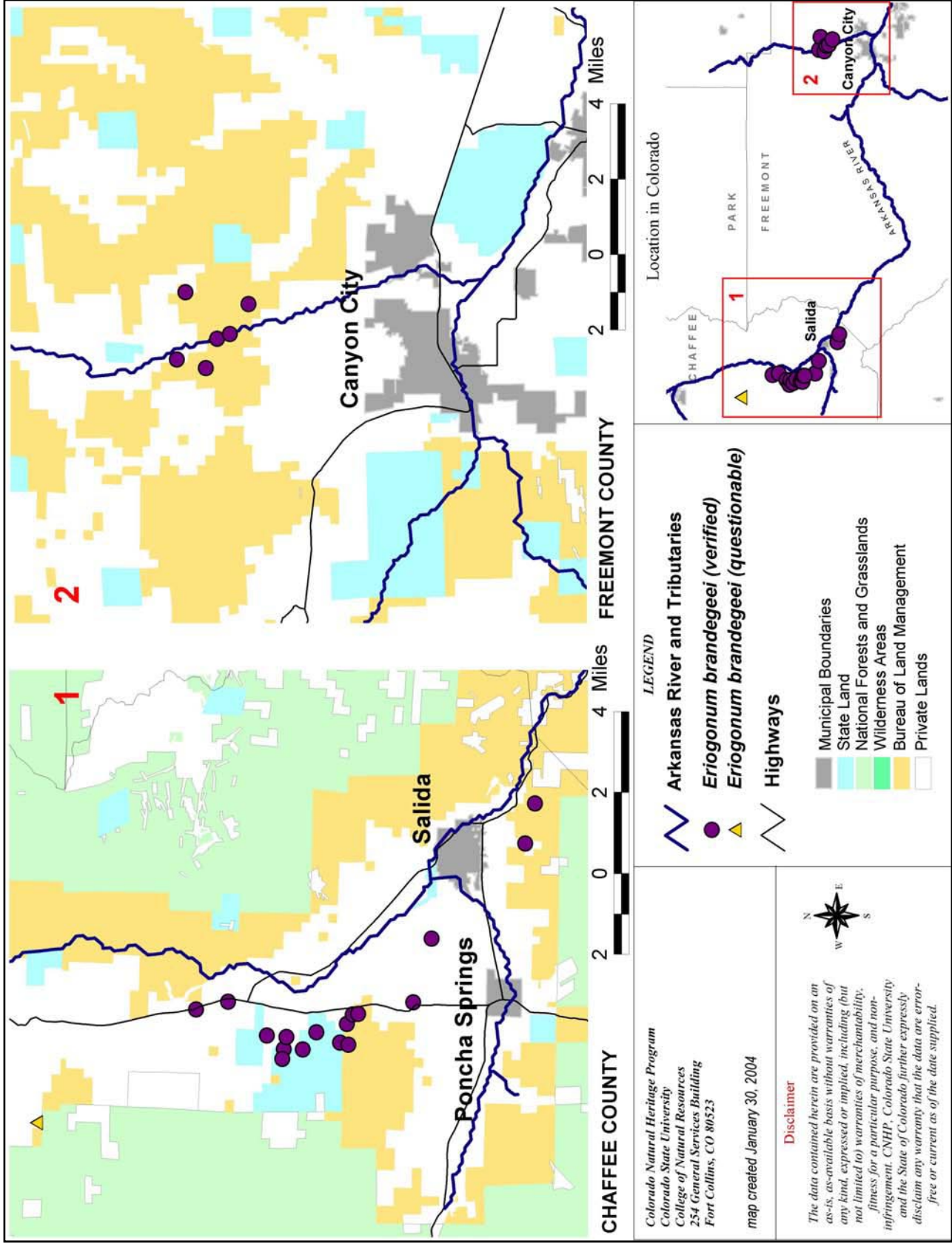


Figure 6. Land ownership status of the occurrences of *Eriogonum brandegeei* in Fremont and Chaffee counties, Colorado.

**Table 2.** Summary information for the 12 occurrences of *Eriogonum brandegeei* in Colorado. Questionable reports are shaded in the table.

EO# <sup>1</sup>	County	Location	Precision <sup>2</sup>	Date First Observed	Date Last Observed	EO Rank <sup>3</sup>	Elevation (ft.)	Abundance	Owner	Habitat
1	Chaffee	Hecla Junction	S	22-Aug-1967	13-Aug-2003	C	7,400 to 7,560	1,000 or more	Private, Highway right-of-way	Actively colonizing a road cut in powdery, gray, tuffaceous clay; slope 0 to 40 degrees, also in Pinyon-Juniper stand above the road cut.
2	Fremont	Garden Park Fossil Site (Garden Park West)	S	1872	31-Aug-2005	B	5,800	est. 1,000	Bureau of Land Management (some in an Area of Critical Ecological Concern), Private (some in a State Natural Area)	On barren clay-loam escarpment of the Morrison Formation. Plants on the east bank of a road cut; occurrence bisected by highway. Aspect: variable. Soil: Rocky, silty (tuffaceous?) clay matrix; plants growing on gray or white powdery clay. Slope: 0 to 50 degrees. Habitat limited, much of it disturbed.
3	Fremont	Garden Park Fossil Site (Garden Park East)	S	18-Jul-1984	31-Aug-2005	B	6,200 to 6,510	1,500	Bureau of Land Management (some in an Area of Critical Ecological Concern), Private (some in a State Natural Area)	On steep or moderate slopes in clay hills and on old roadbeds in a variety of plant associations. 80 acres of potential habitat; 20 to 30 percent occupied. A partially excavated quarry occurs in the site on private land. Habitat is in good shape; some roads and old roads cross the site. Adjacent to a mine; catchment pond also present in the element occurrence. Geology: Morrison Formation. Slope: 5 to 75 percent. Aspect: All. Soil: light gray to whitish barren clay; easily erodible; alkaline; clay and silty clay with gypsum crystals.
4	El Paso	Colorado Springs	G	25-Jul-1884	24-Jul-1884	H	unknown	not reported	Unknown	Not reported.

Table 2 (cont.).

EO# <sup>1</sup>	County	Location	Precision <sup>2</sup>	Date First Observed	Date Last Observed	EO Rank <sup>3</sup>	Elevation (ft.)	Abundance	Owner	Habitat
5	Chaffee	Droney Gulch	S	31-Jul-1985	13-Aug-2003	A	7,200 to 7,840	1,500	Bureau of Land Management (some in an Area of Critical Ecological Concern), State of Colorado, Private (some in a State Natural Area)	On highly erodible bluffs. The plants occur on all aspects and slopes and are the dominant plant of the barren soils as they seem to prefer little competition from other species and occur on the harshest substrate. Plants colonizing eroded areas and man-disturbed areas, common especially in small arroyos, also on road cut. Trash disposal and off-road vehicle use is occurring; weeds are present. Geology: Riverine sediments of the Dry Union Formation. Soil: Gravelly clay barren soils; tan clay-loam. Slope: 5 to 90 percent.
7	Chaffee	Harrington Gulch	S	01-Aug-1985	08-Aug-1991	B	7,440	approx. 7,000 to 10,000	Private	middle slope; dry (xeric). Geology: Riverine alluvium of the Dry Union Formation. Soil: tan loam.
8	Chaffee	Cleora (Castle Gardens)	S	02-Aug-1985	31-Aug-2004	B	7,000 to 7,520	10,000 to "tens of thousands"	BLM, Private	Plants mostly restricted to barren eroded slopes of the Dry Union Formation. A few plants occur in more rocky soils in pinyon-juniper woodlands at the tops of the barren slopes. Off-road vehicle use is disturbing habitat. Residential development has encroached on this occurrence. Slope: 0 to 7 percent. Aspect: All. Soil: Gravelly. Of ca. 320 acres of potential habitat, 90 percent is occupied. Off-road vehicle impacts are widespread within this occurrence.
9	Park	Jefferson	G	28-Jun-1947	28-Jun-1947	H	9,620	not reported	Unknown	Dry hillside.

Table 2 (concluded).

EO# <sup>1</sup>	County	Location	Precision <sup>2</sup>	Date First Observed	Date Last Observed	EO Rank <sup>3</sup>	Elevation (ft.)	Abundance	Owner	Habitat
10	Chaffee	Loggie Gulch	S	21-Jul-1995	2003	A	7,230 to 7,620	“thousands”	Bureau of Land Management, Private	Barren slopes of fine-textured soils with cobbles; Dry Union Formation. 75 to 95 percent bare ground. Site appears to receive little human use. No weed problems evident. A few little-used roads and trails through occurrences; impacts appear insignificant.
11	Fremont	Cope Quarry in Garden Park	S	Sep-1872	09-Jul-2003	B	5,960 to 6,320	“hundreds”	Bureau of Land Management, Private	On outcrop of gray to chocolate brown clay soils in a northwest facing drainage. Plants growing mostly on more gentle slopes (approximately 20 percent) with <i>Frankenia jamesii</i> . Also on edges of pinyon-juniper woodlands and on completely barren slopes up to 40 percent. Bare ground: 70 to 90 percent. About 80 acres of habitat in excellent condition.
12	Chaffee	Raspberry Gulch	M	1982	1982	E	8,360	not reported	USDA Forest Service or Private	Not reported.

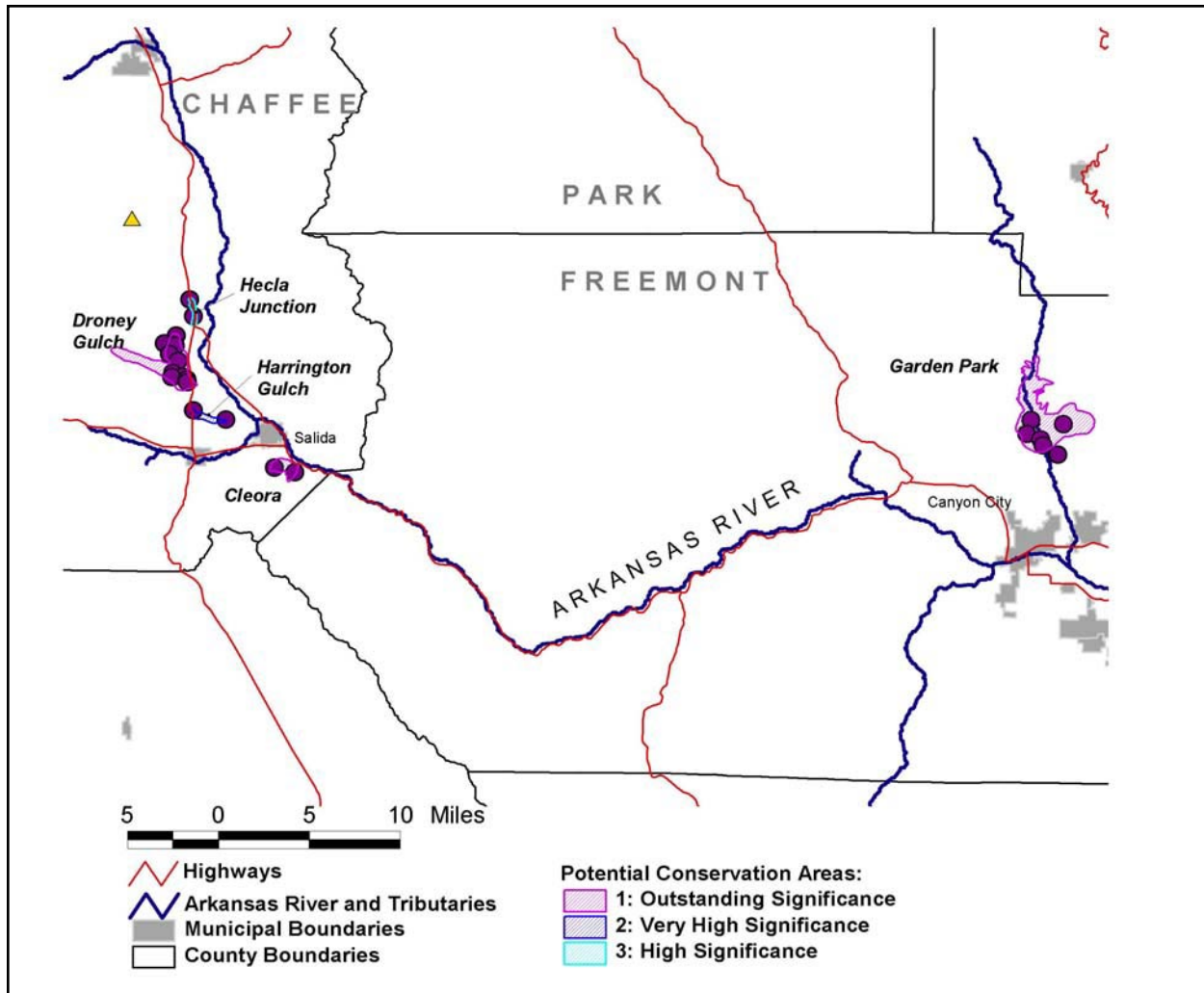
<sup>1</sup>Colorado Natural Heritage Program Element Occurrence Number

<sup>2</sup>Precision:

- S Seconds record- precise location known
- M Minutes record- vicinity of location known within one square mile
- G General record- vicinity of location is vague; i.e. “Colorado Springs”

<sup>3</sup>EO (Element Occurrence) Rank:

- A Excellent estimated viability
- B Good estimated viability
- C Fair estimated viability
- D Poor estimated viability
- E Verified extant (viability not assessed)
- H Historical- not seen in more than 20 years



**Figure 7.** Potential Conservation Areas for *Eriogonum brandegeei*, circumscribed by Spackman and Floyd (1996) and Colorado Natural Heritage Program (2004). Please see the **Definitions** section of this document for an explanation of Potential Conservation Areas and their ranks.

A report of *Eriogonum brandegeei* from Raspberry Gulch (EO#12) is the only known occurrence possibly on National Forest System lands. The location of this occurrence is uncertain, and it may or may not actually be on the San Isabel National Forest. This occurrence was reported in 1982 by Barry Johnston, who was given a plant fragment by a crew that was delineating a timber sale. It is not known how far up Raspberry Gulch the plant was collected, but they reported finding the plant just above the forest boundary. Johnston verified the identity of the fragment as *E. brandegeei*, but the specimen was not of sufficient quality to preserve (Johnston personal communication 2004, Colorado Natural Heritage Program 2005). This area was searched by Spackman and Floyd (1996), but no plants were found. They did note the presence of barren, chalky outcrops in the area, but these seemed inappropriate for *E. brandegeei* since they did not

consist of bentonite clay (Spackman Panjabi personal communication 2004). Elliott (personal communication 2004) noted that most National Forest System lands in the Arkansas Valley are too high in elevation for *E. brandegeei* and are not underlain by the right geologic formations. However, further searching is needed in this area.

#### *Microscale distribution patterns*

Microscale distribution patterns of *Eriogonum brandegeei* are probably influenced by microtopography and other microhabitat attributes. *Eriogonum ovalifolium* var. *depressum* occurs in tight clumps at Craters of the Moon National Monument. This association is probably the result of seed trapping by the prostrate canopy of *E. ovalifolium* var. *depressum* and more favorable conditions for seedling establishment under its canopy

(Day and Wright 1989). Because *E. brandegeei* has a similar habit to *E. ovalifolium* var. *depressum*, such distribution patterns are plausible for *E. brandegeei* as well, but there have been no studies to investigate this. Because *E. brandegeei* is a poor competitor, it is likely that seed trapping would be deleterious.

### *Abundance*

There has been no rigorous attempt to assess the total population of *Eriogonum brandegeei* using quantitative census methods, and estimates of the total population size of *E. brandegeei* range widely. Early population size estimates based on the first two occurrences known (Garden Park and Hecla Junction) were 700 individuals (Johnston et al. 1981, Spackman and Floyd 1996, U.S. Fish and Wildlife Service 1996). Total population size estimates for the nine verified occurrences have ranged from 35,000 (Spackman and Floyd 1996) to “100,000 to several million individuals” (U.S. Fish and Wildlife Service 1996). The latter report references surveys done in 1989, 1992, and 1993. These estimates were used to justify the removal of *E. brandegeei* from Candidate status. Attempts by the U.S. Fish and Wildlife Service to find the documents supporting these estimates were not successful (Davis personal communication 2004, Mayo personal communication 2004, Morgan personal communication 2004), and there is no documentation of these population size estimates in the Colorado Natural Heritage Program files. However, the surveys referenced were probably those conducted by Tamara Naumann and Janet Coles, whose estimates were based mainly on visits to Droney Gulch and the occurrence at Cleora (Coles personal communication 2004). They did not use quantitative methods in these determinations. Coles (personal communication 2004) noted that the densities observed were high.

The total area occupied by *Eriogonum brandegeei* is 1.27 square miles (3,289,285 m<sup>2</sup>). Thus, for there to be one million plants within this area, the average density rangewide must be 0.304 plants per m<sup>2</sup>. Johnston et al. (1981) noted densities of 300 plants in 800 m<sup>2</sup> at an unnamed occurrence north-northwest of Salida (probably EO#1) and 400 plants in 1,155 m<sup>2</sup> “north of Cañon City” in the Garden Park Area, yielding densities of 0.375 plants per m<sup>2</sup> and 0.346 plants per m<sup>2</sup>, respectively (the densities presented in Johnston et al. 1981 had been miscalculated). Extrapolating a density of 0.346 plants per m<sup>2</sup> yields a hypothetical total population size of 1,138,093 plants while 0.375 plants per m<sup>2</sup> yields 1,233,482 plants.

In 2004 and 2005, rosettes were counted within three 600 m<sup>2</sup> macroplots (two plots at Garden Park and one at Cleora) by Grant and DePringer-Levin (2005). The highest density was observed at Garden Park West, where approximately 2000 rosettes were observed within the macroplot. This extrapolates to a total population of 10,964,283 rosettes rangewide. The lowest density was observed in 2004 at the Garden Park East site, approximately 750 individuals in 600 m<sup>2</sup>, which gives a total population of 4,111,606 rosettes rangewide. Because rosettes within 10 cm are often connected underground, the number of genets within the macroplots is probably considerably less, but no attempt was made to quantify the number of genets (genetic individuals) due to the obvious difficulties of such an undertaking. Nonetheless, the available quantitative data from these two studies support a hypothetical population size within the range estimated by Naumann and Coles.

Although a population size of 1,000,000 plants or more is plausible, some evidence suggests that this may be an overestimate. Several experts expressed that they thought the population of *Eriogonum brandegeei* is unlikely to be that high (Dawson personal communication 2004, Jennings personal communication 2004, Reveal personal communication 2004, Spackman Panjabi personal communication 2004). Population size estimates based on Colorado Natural Heritage Program Element Occurrence Records support a conservative population estimate of 35,000 (as noted by Spackman and Floyd 1996) to 45,000 plants, but these numbers are also based largely on ocular estimates and are often vague (e.g., “thousands”). Because of the uneven, clumped distribution of *E. brandegeei* that has been reported at Droney Gulch and elsewhere (Dawson personal communication 2004, Colorado Natural Heritage Program 2005), extrapolations of density measurements taken in a limited area are of questionable validity. The distribution of *E. brandegeei* is highly discontinuous within the mapped occurrences, with areas of higher density and many areas of lower density as well. *Eriogonum brandegeei* is restricted largely to steep terrain within an occurrence. Observers (Dawson personal communication 2004, Grant personal communication 2004) have noted that there is also much unoccupied space within a mappable occurrence, suggesting that density extrapolations are likely to produce overestimates of population size. The tendency for proximal rosettes to be connected to each other underground probably results in inflated estimates of the number of genets. The great disparity between existing estimates of population size demonstrates the need for a

robust assessment using quantitative sampling methods to determine the actual population size of this species.

#### Population trend

There are no quantitative data that could be used to infer the long-term population trend of *Eriogonum brandegeei*. Population size is not known for many occurrences, and there has been no monitoring at most occurrences of this species. Preliminary results of monitoring efforts started in 2004 suggest a slight population increase at both Garden Park study sites in 2005, but these results are not statistically significant, and no recruitment was observed in either year (Grant and DePringer-Levin 2005). Jennings noted that there was no change in population size from 1989 to 1993 at Hecla Junction (EO#1) (Colorado Natural Heritage Program 2005). Johnston et al. (1981) suggested that occurrences appeared stable and were “perhaps increasing slightly in response to the small amount of disturbance that has been introduced.” This supposition was based on the observation of plants colonizing road cuts at two sites, which at the time were the only two sites known for *E. brandegeei*. The current viability of *E. brandegeei* has been assessed to be “very good” (The Nature Conservancy 2001). As long-lived perennials, changes in population size may occur slowly and be difficult to detect.

Ongoing human activities are certainly resulting in a loss of individuals. These include residential and commercial development near Salida, and off-road vehicle use at all occurrences. Development of transportation infrastructure has probably removed some plants in occurrences bisected by roads. Resource extraction and grazing may also have caused localized population decreases. Population decline may also result from rust attack (Spackman and Floyd 1996) (see the Community ecology and Threats sections of this assessment for details). However, the degree to which these impacts are decreasing the population size of occurrences and the species as a whole is not known.

#### Habitat

##### *General habitat description*

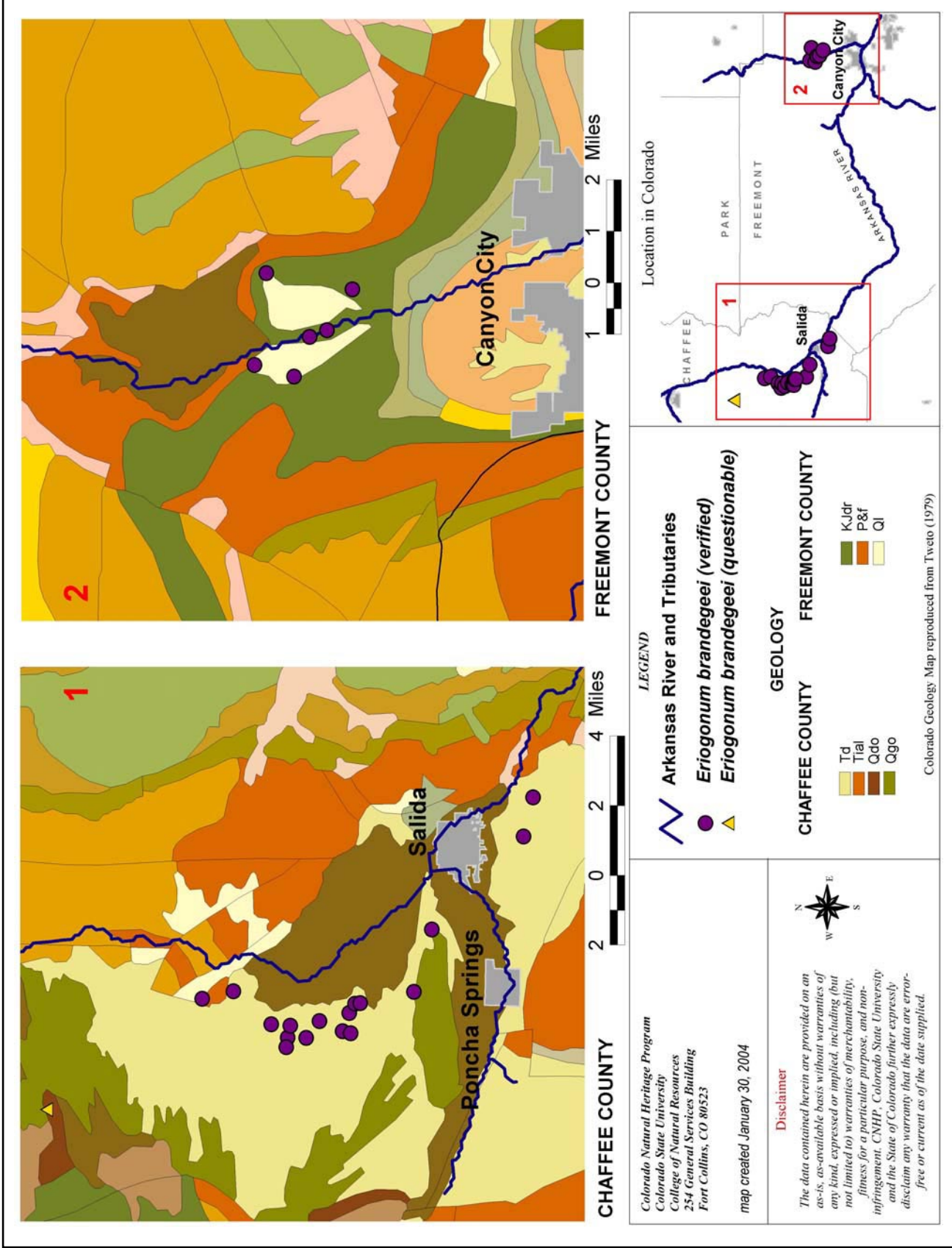
The genus *Eriogonum* has exhibited a propensity for adaptive radiation and specialization throughout the Intermountain West (Shields and Reveal 1988). Like *E. brandegeei*, many other *Eriogonum* species are narrowly endemic to restricted habitat types, including *E. diatomaceum* (Reveal et al. 2002), *E. codium*

(Reveal et al. 1995), *E. robustum* (Morefield 2000), *E. gypsophilum* (Limerick 1984), *E. pelinophilum* (U.S. Fish and Wildlife Service 1983), and numerous others.

*Eriogonum brandegeei* 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 in the Southern Rocky Mountain Steppe-Open Woodland-Coniferous Forest-Alpine Meadow Province.

The climate of the Arkansas Valley around Cañon City is arid, with low humidity, low annual precipitation, and hot summer temperatures. Prevailing weather patterns mean that this area is in the rain shadow of the Sangre de Cristo, Mosquito, and Collegiate ranges. Temperature and precipitation data are available from the Arkansas Valley at Cañon City (1948 to 2002) and Salida (1947 to 2003) within the range of *Eriogonum brandegeei* (Western Regional Climate Center 2003). Total average annual precipitation at Cañon City is 12.75 inches, with much of this falling as snow in the winter (36.1 inches average). At Salida, total average annual precipitation is slightly lower (10.2 inches average), with a greater proportion (46.9 inches) as snowfall. In typical years, July and August are the wettest months of the year at Cañon City and Salida. This pattern corresponds favorably with the timing of high reproductive effort for *E. brandegeei*. These months average approximately 2 inches of rain at each location from monsoonal thundershowers. They are also the hottest of the year, with maximum daily temperatures often exceeding 100 °F at Cañon City.

Geology and soil are important habitat variables for *Eriogonum brandegeei*. Occurrences of *E. brandegeei* are limited mostly to outcrops of the Dry Union Formation (in Chaffee County) and lower members of the Morrison Formation (in Fremont County), or to Quaternary strata that are derived from these formations (O’Kane 1988, Spackman et al. 1997). Both of these formations are highly heterogeneous, and there are portions of each that weather into soils composed of sand, silt, or clay. The unifying feature of all the known occurrences is the presence of a significant fraction of bentonite clay in the soil. Bentonite is derived from the decomposition of volcanic ash. Bentonite swells when wetted, so it is widely used in drilling wells and sealing canals, in addition to many other uses (Lohman 1976). These soils are often barren because only specialized or particularly stress-tolerant plants can establish and survive on them. See **Figure 8** for geology maps of occurrences in Chaffee and Fremont counties.



**Figure 8.** Bedrock geology underlying occurrences of *Eriogonum brandegeei* in Fremont and Chaffee counties, Colorado (from Tweto 1979).



### *Geomorphology, slope, aspect, and elevation*

*Eriogonum brandegeei* is most commonly found on active slopes that can be as steep as 90 percent. It has been also been documented on flat sites, particularly where erosion has deposited clay soil in small basins. On the Dry Union Formation, *E. brandegeei* is often found on the steep, barren eroding slopes below a cap of glacial outwash. The outwash consists of gravels and cobbles and serves to stabilize the underlying fine-textured substrate (Coles personal communication 2004). Pinyon-juniper woodlands typically occupy the outwash mesas. Disturbance of the outwash cap has potential consequences for *E. brandegeei* on the slopes below, since the barren slopes where it occurs are highly susceptible to erosion.

*Eriogonum brandegeei* is not typically found in the pinyon-juniper woodland above the wasting slopes, or where outwash has sloughed down the slope. It is often reported growing with pinyon and juniper (both *Juniperus osteosperma* and *J. monosperma*), but this is usually on rocky or gravelly slopes, and on the edges of pinyon-juniper woodlands. Most sites where *E. brandegeei* occurs are barren and open. *Eriogonum brandegeei* has been reported from north, south, southeast, and southwest aspects. At one location in Droney Gulch, density and abundance were observed to be highest on south and southeast aspects. The dense tomentum of *E. brandegeei* leaves it well suited to sites where insolation is high but may be maladaptive under even moderate shade.

The elevation range of *Eriogonum brandegeei* is 5,800 to 7,840 ft. (**Table 2**). The Raspberry Gulch site is at approximately 8,360 ft., and the Jefferson site in Park County is at 9,620 ft., but it is not known if these sites fall within the elevational limits of *E. brandegeei*. The occurrences at Garden Park are somewhat lower (5,800 to 6,320 ft.) than those in Chaffee County (7,000 to 7,840 ft.) (Colorado Natural Heritage Program 2005).

#### *Fremont County: Garden Park*

At Garden Park in Fremont County, *Eriogonum brandegeei* is found on an outcrop of the Morrison Formation (O’Kane 1988). This formation was deposited during the Jurassic period and covers vast areas of the central and western interior of North America (Webster 1956). Like the Dry Union Formation, it is often very heterogeneous with few beds being traceable for more than 200 yards along an outcrop (Webster 1956). In Fremont County, it consists primarily of variegated shales, siltstones, and siliceous sandstones (Wynne

1961). The beds at Garden Park were deposited between 145 and 155 million years ago and consist of claystones, limestones, and sandstones deposited by meandering rivers on a broad, rich alluvial plain (Colorado Natural Areas Program 2004). *Eriogonum brandegeei* is found mainly in pockets along steep slopes cut by creeks, and within basins of eroded bentonite clay soil (Colorado Natural Heritage Program 2005).

The dominant vegetation at Garden Park is a mosaic of high quality pinyon-juniper woodlands, grasslands, and clay barrens. The clay barrens are sparsely vegetated, but *Oryzopsis hymenoides* (Indian ricegrass), *Frankenia jamesii* (frankenian), and *Atriplex* spp. (saltbush) also grow on them.

Garden Park is an area of considerable scientific and historic significance. It is famous for the numerous type specimens of late Jurassic life that have been discovered there. “The quarries at Garden Park produced the type specimens of *Stegosaurus*, *Camarasaurus*, *Allosaurus*, *Ceratops*, *Diplodocus* and *Haplocanthosaurus*, as well as at least 16 species of freshwater invertebrates. The skeletons of dozens of species of Jurassic mammals, fish, crocodiles and turtles have also been recovered” (Colorado Natural Areas Program 2004). The fossil beds at Garden Park are particularly rich, and they are unique in that fossils can be found throughout the 350-foot-thick formation. An occurrence of *Eriogonum brandegeei* is known from the quarry site of Edward Cope, a paleontologist who excavated many important dinosaur discoveries during the 1870s. Five other quarries, including that of Cope’s rival, Othniel C. Marsh, are also found at Garden Park. The first oil well in the western United States was also drilled at Garden Park in 1862 (Colorado Natural Areas Program 2004). In recognition of its importance in Colorado’s cultural and natural history, 2,668 acres were designated a State Natural Area in 1991 (Colorado Natural Areas Program 2004). The Bureau of Land Management designated 2,728 acres in Garden Park as an Area of Critical Environmental Concern in 1996 (Bureau of Land Management 2004a).

Most occurrences of *Eriogonum brandegeei* at Garden Park are found on moderate to very steep slopes, not in the bottomlands where grazing occurs. It is not known whether grazing is responsible for its absence in valley bottoms. On top of the slopes where the gradient flattens out and the vegetation is dominated by pinyon-juniper woodland, there are no plants (Grant personal communication 2004, Colorado Natural Heritage Program 2005).

## Chaffee County

Most occurrences of *Eriogonum brandegeei* in Chaffee County are found on barren slopes of the Dry Union Formation (O’Kane 1988). This formation was deposited during the Pliocene and Miocene Epochs of the Tertiary Period (23.8 to 1.8 million years ago). It consists of volcanic rocks reworked by flowing water into alluvial deposits and is thus highly heterogeneous. Wallace et al. (1997, p. 8) note that it “consists mainly of interbedded boulder, cobble, and pebble conglomerate, pebbly sandstone, sandstone, sandy siltstone, siltstone, shale, and claystone,” thus running the gamut of particle size. It is typically moderate- to light-gray, yellowish-gray, and greenish-gray in color. This formation consists of material “of a strong local provenance,” including clasts derived from Wall Mountain Tuff and biotite latite (Wallace et al. 1997, p. 8). *Eriogonum brandegeei* is found only in portions of this formation composed of fine particles sometimes described as “tuffaceous” (Colorado Natural Heritage Program 2005). Occurrences in Chaffee County also occur on or near Quaternary gravels and alluvium derived at least in part from the Dry Union Formation.

### Droney Gulch

Droney Gulch consists of sparsely vegetated light-brown hills of lacustrine deposits and alluvium of the Dry Union Formation (Colorado Natural Heritage Program 2005). The soils at this site range from silt-loams to sands. These stark, barren slopes support one of the best-known occurrences of *Eriogonum brandegeei* (Figure 4; EO#5 in Table 2). At the base of the slopes there are sparse stands of *Pinus edulis* (pinyon pine) with *Cercocarpus montanus* (mountain mahogany) and *Oryzopsis hymenoides*. The surrounding uplands are dominated by denser stands of *P. edulis* and *Juniperus osteosperma* (Utah juniper). The toe slopes at the bottom of the valley are dominated by *Bouteloua gracilis* (blue grama), *P. edulis*, *Krascheninnikovia lanata* (winterfat), and *Atriplex canescens* (four-wing saltbush). While Droney Gulch is noteworthy for the large occurrence of *E. brandegeei* that it supports, it is also an example of an intact functioning ecological system that spans several ecological zones (Spackman 2000). Unfortunately, this area is also besieged by human impacts from off-road vehicle use, high impact camping, residential development, and trash dumping.

The BLM established an ACEC at Droney Gulch in 1996 (totaling 705 acres) to protect a portion of the *Eriogonum brandegeei* occurrence at this site (Bureau of Land Management 2004a). 785 acres of Droney

Gulch were later designated a State Natural Area in 1999 (Colorado Natural Areas Program 2004).

### Hecla Junction

The occurrence at Hecla Junction (EO#1 in Table 2) is bisected by Route 285, where *Eriogonum brandegeei* grows in relatively undisturbed habitat and has colonized the road cut. Here *E. brandegeei* is found in open pinyon-juniper woodland and in open sites associated with *Artemisia*. The soils at this location are powdery gray, tuffaceous clays.

### Cleora/ Loggie Gulch

There is less information available on this area than for Garden Park and Droney Gulch, but it may support the largest known occurrence of *Eriogonum brandegeei* (Coles personal communication 2004, Grant personal communication 2004). It is also the most threatened by residential development, largely due to its proximity to Salida. Residential development has already impacted the occurrence of *E. brandegeei* at Cleora (Coles personal communication 2004). A north flowing tributary to the Arkansas River has cut through a fine textured, gray to brown deposit of the Dry Union Formation at Cleora. Vegetation is very sparse (approximately 10 percent cover), and some of the steep and sharply eroded slopes and ridges are devoid of vegetation. This area is also known as “Castle Gardens” after the strange landforms at this location.

### Harrington Gulch

Harrington Gulch supports a robust occurrence of *Eriogonum brandegeei* on slopes of light buff colored, fine, loose soil. The slopes are sparsely vegetated with pinyon, mountain mahogany, Indian ricegrass, and *Astragalus tridactylus* (foothills milkvetch).

### Other potential occurrences

Potential habitat on lands administered by the BLM was thoroughly searched by Spackman and Floyd (1996). Private lands in Chaffee County where outcrops of the Dry Union Formation are present are likely to support additional occurrences. These outcrops are conspicuous and generally easy to see, and Spackman and Floyd (1996) did not note any large outcrops on private land that could be seen en route to search areas on BLM land (Spackman Panjabi personal communication 2004). The probability of finding more large occurrences is low. There may be a few small occurrences on inconspicuous clayey sites on private

land in Chaffee County. **Figure 6** and **Figure 8** provide an overview of the distribution of private land and suitable geology.

### Reproductive biology and autecology

In the Competitive/Stress-Tolerant/Ruderal (CSR) model of Grime (2001), characteristics of *Eriogonum brandegeei* most closely approximate those of stress-tolerant species. Stress-tolerant attributes of *E. brandegeei* include long life span, slow growth, adaptation to xeric conditions, tolerance of difficult edaphic conditions, and low reproductive output. Because it allocates relatively little biomass to the production of its relatively large propagules, the life history pattern of *E. brandegeei* is best classified as *K*-selected (using the classification scheme of MacArthur and Wilson 1967).

While annual *Eriogonum* species tend to be somewhat competitive (and can be aggressive and ruderal), perennial *Eriogonum* species are usually specialists that do well on a particular substrate but do not do well when in competition with more aggressive, invasive species. The adaptations to peculiar substrates allow perennial *Eriogonums* to persist where other more competitive species are excluded (Reveal personal communication 2004). *Eriogonum brandegeei* has limited resources in its barren habitat and grows slowly, as is typical of a stress-tolerator.

Reveal (personal communication 2004) and Coles (personal communication 2004) offered many thoughts on the role of disturbance in the autecology of *Eriogonum brandegeei*. *Eriogonum brandegeei* is well adapted to natural disturbance and is narrowly specialized to tolerate a specific disturbance regime. Consequently, soil movement may not always be deleterious, but this is not to say that erosion would increase population density. It is commonplace to see the woody roots or *E. brandegeei* exposed in rivulets on eroded banks, but this is probably not particularly deleterious to individuals. While natural erosion is probably not a threat to *E. brandegeei*, the mechanical damage associated with disturbance from off-road vehicle use and grazing is probably beyond the physiological tolerances of the species.

Regarding the response to disturbance of *Eriogonum lewisii*, Morefield (1996) wrote the following, which is true for *E. brandegeei* as well:

“At several sites, *Eriogonum lewisii* has been observed to colonize and reproduce on recent,

recovering disturbances such as road banks. I have observed this to be true of many, if not most, rare plant species in the arid west, and this is often interpreted by some to suggest that the species in question is not threatened by habitat disturbance, but instead is able to survive or even thrive with continual disturbance. This is usually a misinterpretation of plant ecologic responses based on short-term observation. Most rare plant species are rare because they are adapted to and depend upon rare habitat types. Many of these habitat types impose harsh growing conditions that exclude most other plant species, thus creating relatively low-competition conditions for the few remaining species that are able to adapt. Disturbance also creates a temporary low competition situation of which rare species, already adapted to such conditions, frequently are able to take short-term, opportunistic advantage. Almost always, though, this is observed only if the disturbance occurs within or immediately adjacent to a source population occupying the rare soil or other habitat type that the species requires for long-term survival, and only when the disturbance is temporary and has begun to stabilize. Almost never has a rare plant species been observed to continue spreading onto disturbances farther outside its rare habitat type, or to persist where disturbance is severe and continuous. If rare species had the biologic and ecologic characteristics of invasive weeds, they would not now be rare. No plant population can withstand severe, uninterrupted disturbance of its habitat, and rare plants are no exception.

Thus, while *Eriogonum lewisii* may be seen thriving for a few generations on disturbed sites, all my observations indicate that its long-term survival depends upon the continued availability of undisturbed or recovering [habitat]. *Eriogonum lewisii* has never been observed spreading off of such sites along disturbance corridors, and permanent loss of plants is evident where disturbance has been continuous and severe, such as on road beds bisecting the habitat.”

The specific responses of *Eriogonum brandegeei* to disturbance are not known, but the habitats in which it is often found suggest that it is tolerant of chronic surface disturbance caused by erosion and shrinking and swelling of its bentonite substrate. At Garden Park, O’Kane and Anderson noted that *E. brandegeei* appears to require a degree of natural disturbance (Colorado

Natural Heritage Program 2005). On some slopes there are few if any plant species associated with *E. brandegeei*, suggesting that it possesses adaptations to this environment that other species do not have. Like *E. lewisii*, *E. brandegeei* is also found on highway road cuts and along the right-of-ways of two-track and gravel roads. While it is capable of colonizing such sites where they pass through its habitat, the overall impacts of roads are most likely negative.

There have been several investigations of the ecophysiology of *Eriogonum* species (e.g., Cole 1967, Mooney et al. 1983, Chapin and Bliss 1987), but no studies have been done on *E. brandegeei* to investigate its adaptations to its habitat. Mooney et al. (1983) observed rapid stomatal closure in response to decreased humidity in *E. latifolium*, which is an effective mechanism for maximizing water use efficiency. The tomentum of *E. brandegeei* is probably also an adaptation to drought stress, forming a vapor barrier that reduces water loss. The tomentum may also reduce excess light to prevent photosaturation. Insolation is probably very high in its open habitat with light colored, reflective soils.

### *Reproduction*

There has been no detailed investigation of the reproductive biology of *Eriogonum brandegeei*. Reveal (personal communication 2002) explained the sequence of maturation and floral biology typical of *Eriogonum* as follows:

The anthers mature a day or two before the stigma is receptive. On the first day, a given flower opens and six stamens dehisce and shed pollen while the style and stigma remain coiled around the achene (fruit) within the flower. At this time the flower is functionally male and cannot self-pollinate. The flower will close that night and open again the next day. On the second day, the remaining three stamens dehisce and shed pollen, and the stigma and style uncoil. At this time the stigma is receptive, and may be pollinated by selfing or outcrossing. If pollination has not occurred by the end of the second day, the flower will self-pollinate when it closes that night, assuring that a seed will be produced either by outcrossing or selfing.

Most perennial members of the genus *Eriogonum* reproduce both vegetatively and sexually. The relative importance of these modes of reproduction varies considerably within the genus. Clonal propagation may be the primary mode of reproduction in *E. ovalifolium*

var. *williamsiae* (U.S. Fish and Wildlife Service 1995) while other species, particularly annuals, rely heavily or entirely on reproduction by seed. Many widespread species of *Eriogonum*, particularly caespitose, low elevation species, are tolerant of fragmentation by the action of the hooves of herbivores. Like *E. brandegeei*, these species have a deep-seated, vertical taproot and an extensive system of lateral caudex branches. The lateral branches may produce adventitious roots, and if the branch is broken away from the main body of the plant under favorable conditions, it will proceed to grow as a clone of the parent plant and produce a new taproot. It is not known if *E. brandegeei* is tolerant of this kind of disturbance or if it can reproduce this way, but Reveal (personal communication 2004) speculates that this kind of disturbance would probably be deleterious to *E. brandegeei*. There are no observations suggesting that clonal propagation is prominent in *E. brandegeei*, but Grant and DePringer-Levin (2005) report that individuals can be difficult to distinguish, and that rosettes within 10 cm of each other are often connected underground. This suggests that *E. brandegeei* may reproduce to some extent by clonal perennation.

Annual variation in reproductive effort was observed at two locations in Garden Park in 2004 and 2005 (Grant and DePringer-Levin 2005). The differences were most pronounced at Garden Park West, where 60 percent of the observed individuals flowered in 2004, but only 50 percent in 2005.

### *Pollination ecology*

Most *Eriogonum* species throughout the Rockies, Sierra Nevada, and Cascades are visited by a broad range of generalist pollinators, with no clear examples of specialization (Reveal personal communication 2002, Tepedino 2002). Plants with very little floral specialization are considered 'promiscuous' 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). *Eriogonum ovalifolium* var. *williamsiae* individuals transplanted to containers at the Nevada Division of Forestry nursery successfully produced seed, suggesting that it does not depend on the pollination services of a highly specific pollinator (U.S. Fish and Wildlife Service 1995). *Eriogonum* species offer a small amount of nectar at the base of the filaments and ovaries and are important nectar sources for many insects. This reward, along with pollen, attracts bees, flies, ants, and other insects (Reveal personal communication 2002).

Preliminary research was done to investigate the pollination biology of *Eriogonum brandegeei* in 2001 (Spackman Panjabi 2004). Several other endemic plant species were also studied in this project (*Mentzelia chrysantha*, *M. densa*, *Oenothera harringtonii*, *Oxybaphus rotundifolius*, *Penstemon degeneri*, and *Oenopsis puebloensis*). Insect visitors to *E. brandegeei* include several species of bees, flies, wasps, ants, and a bug (**Table 3a**). Although ants can act as pollinators, it appears unlikely that they are pollinating *E. brandegeei*; ant pollination is rare and difficult to verify (Hickman 1974, Beattie et al. 1984). Members of the genus *Lasioglossum* are solitary bees that nest in the ground (Borror et al. 1989, Finnermore and Michener 1993). Of some other species observed on *E. brandegeei*, Pineda (2002) noted that the larvae of *Poecilanthrax* are endoparasites of moths in the family Noctuidae (cutworm, owlet moths) (Painter and Hall 1960, Hull 1973). Adults visit flowers in search of nectar and pollen. *Eucerceris superbus* and *E. fulvipes* are parasitic ground nesting wasps (Bohart and Menke 1976). These species visit flowers for both nectar and pollen. As most species of this family have short tongues, they frequent flowers with short corollas such as those common among members of the Asteraceae, Euphorbiaceae, Apiaceae, and Polygonaceae. Flies in the family Bombyliidae were the most frequently documented insect visitors in timed observations of *Eriogonum brandegeei* (**Figure 9**). They were also the most frequently collected taxa (**Table 3b**) in the vicinity of *E. brandegeei* (Spackman Panjabi 2004).

### Phenology

There are differing reports of the flowering and fruiting time of *Eriogonum brandegeei*, with the onset of flowering beginning between late June (Colorado Native Plant Society 1997) to late July (Johnston et al. 1981) or August (Reveal 1969), and continuing through mid-August (Colorado Native Plant Society 1997) or September (Reveal 1969). Specimens housed at the University of Colorado Herbarium (COLO) were collected as early as June 28 and July 11 with flowers, but most flowering plants were collected in late July and early August. Fruits mature in late August or September (Johnston et al. 1981). Because the time of flowering was similar in two consecutive years, Johnston et al. (1981) suggest that flowering is probably controlled by day length.

The foliage turns purple in the winter months, making the plants stand out on their barren substrate when snow is absent (Johnston personal communication 2004). Young plants with poorly developed root systems

are probably more vulnerable to desiccation than mature plants. Thus, successful recruitment is probably episodic, coinciding with periods of one or several wet years during which plants can become established.

Great phenological variation has been observed between Sonoran and Chihuahuan Desert populations of the desert annual *Eriogonum abertianum* (Fox 1990). Significant life history differences between this species and *E. brandegeei* suggest that these observations are not relevant for *E. brandegeei*, but some phenological variation has been observed. At Hecla Junction, plants on the road cut flowered earlier than those in a natural setting (Colorado Natural Heritage Program 2005).

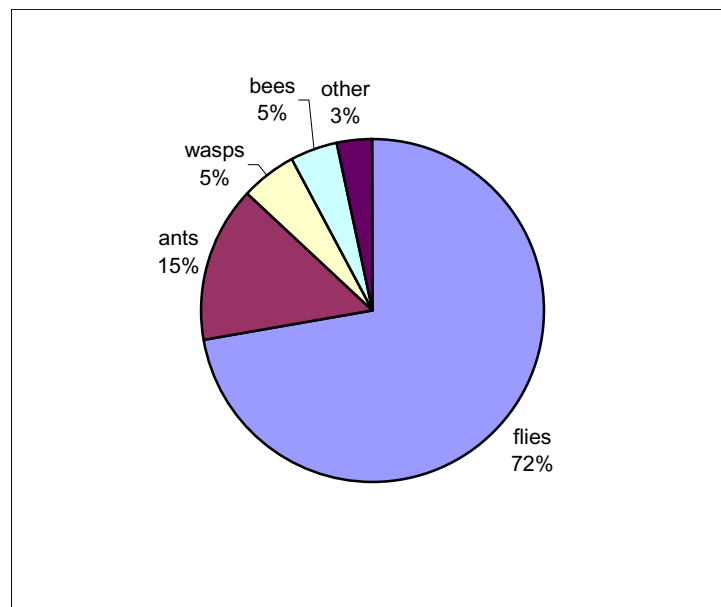
### Fertility, seed viability, and seed dormancy

*Eriogonum* species produce numerous small flowers in umbels. One seed is produced per flower and is borne within an achene that dehisces from the flower when ripe. Seed viability exceeded 60 percent in a study of ten native perennial *Eriogonum* species of Utah (Meyer and Paulsen 2000). However, seed viability of two *Eriogonum* species was shown to be very low. Viability tests of seeds of *E. ovalifolium* var. *williamsiae* yielded less than 1 percent live seed (U.S. Fish and Wildlife Service 1995). Seeds of *E. annuum* recovered from sandhill prairie soil samples in Nebraska also showed less than 1 percent germination (Perez et al. 1998).

The germination requirements of *Eriogonum brandegeei* are not known. In a study of *E. umbellatum*, its seeds germinated without pre-treatment over a wide range of incubation temperatures (Young 1989). The highest germination rates were for seeds exposed to widely fluctuating temperatures, suggesting that they will germinate best near the soil surface. Seeds of an annual *Eriogonum* species (*E. abertianum*) from the Chihuahuan Desert were found to exhibit an annual pattern of conditional dormancy in the winter and non-dormancy in the summer, which is typical of annuals in unpredictable habitats. Temperature and soil moisture control germination in this species (Baskin et al. 1993). In a study of ten species of native perennial *Eriogonum* species of Utah, Meyer and Paulsen (2000) determined that chilling is a primary regulator of dormancy status in the species studied. Seeds of these species have no carryover mechanism to prevent germination in the first year following seed production, but it is possible that light requirements might cause some seeds to persist in the seed bank. Dormancy in *Eriogonum* appears to cause seeds to germinate during the year following seed production, causing late winter germination and early

**Table 3a.** Insect visitors to *Eriogonum brandegeei* observed between July 18 and July 22, 2001 (Spackman Panjabi 2004). Identification determined by Drs. B. Kondratieff and H.E. Evans.

Order	Family	Genus	Species	Common Name	Location
Diptera	Bombyliidae	<i>Chrysanthrax</i>	<i>edititius</i>	Bee Fly	SE of Garden Park
Diptera	Bombyliidae	<i>Geron</i>	sp.	Bee Fly	SE of Garden Park
Diptera	Bombyliidae	<i>Poecilanthrax</i>	<i>willistoni</i>	Bee Fly	SE of Garden Park
Diptera	Bombyliidae	<i>Villa</i>	sp.	Bee Fly	SE of Garden Park
Hemiptera	Phymatidae	<i>Phymata</i>	sp.	True Bug	SE of Garden Park
Hymenoptera	Formicidae	<i>Dorymyrmex</i>	<i>insana</i>	Ant	Droney Gulch
Hymenoptera	Formicidae	<i>Formica</i>	sp. 1	Ant	SE of Garden Park
Hymenoptera	Formicidae	<i>Formica</i>	sp. 2	Ant	SE of Garden Park
Hymenoptera	Halictidae	<i>Halictus</i>	<i>confusus</i>	Halictid Bee	SE of Garden Park
Hymenoptera	Halictidae	<i>Lasioglossum</i>	sp. 1	Halictid Bee	SE of Garden Park
Hymenoptera	Halictidae	<i>Lasioglossum</i>	sp. 3	Halictid Bee	SE of Garden Park
Hymenoptera	Sphecidae	<i>Eucerceris</i>	<i>fulvipes</i>	Sphecid Wasp	SE of Garden Park
Hymenoptera	Sphecidae	<i>Eucerceris</i>	<i>superbus</i>	Sphecid Wasp	SE of Garden Park



**Figure 9.** Proportion of observed insect visits by flies, ants, wasps, bees, and other unidentified insects during 17 30-minute observations of *Eriogonum brandegeei* at two study sites (Droney Gulch and Southeast of Garden Park). From Spackman Panjabi (2004), used with permission.

**Table 3b.** Summary data for insects collected and observed during timed 30-minute observations during visitation to *Eriogonum brandegeei* at the two study sites by Spackman Panjabi (2004).

Order	Number of Collections	Percent of Total Collected
Diptera	24	44
Hemiptera	4	7
Hymenoptera	21	39
Unidentified	5	9
<b>Total</b>	<b>54</b>	<b>100</b>

spring emergence in most species. A few *Eriogonum* species are used as rock garden plants, and they are generally easily germinated in well-drained soils (Reveal 1989a, Hickman 1993, Reveal 2003). Slaby (2001) recommends cultivation of *E. exilifolium* in a sunny site with a poor, sandy soil. It can be propagated by seed in the spring, or with cuttings in late summer.

#### *Dispersal mechanisms*

The seeds of *Eriogonum* species are dispersed by wind, rain, streams, and animals (Stokes 1936). Due to their high oil content, the seeds float and are readily moved by sheet flow during heavy rains. Stokes (1936) also cites birds and vehicles as likely dispersal vectors, particularly for annual species of *Eriogonum*. Wind is an effective dispersal agent for many species of *Eriogonum* (Reveal personal communication 2004). *Eriogonum ovalifolium* var. *williamsiae* is an example of a wind-dispersed species (U.S. Fish and Wildlife Service 1995), as is *E. scabrellum* (Reveal personal communication 2004). In some species of *Eriogonum*, such as *E. brachypodium*, dispersal is thought to be similar to that of tumbleweeds. Spatial studies of *E. fasciculatum* and *E. inflatum* suggest that most seeds fall close to the parents (Miriti et al. 1998).

Of particular interest for the possible dispersal of *E. brandegeei* are ants. Many species of *Eriogonum* actively engage ants in their seed dispersal. *Eriogonum* seeds have abundant, oil-rich endosperm (Reveal personal communication 2002) and are a valuable food source for many animals (Stokes 1936). Some *Eriogonum* species also have specialized structures on the seed called elaiosomes, which store oil and are an attractant to ants. However, these structures have not been documented on the seeds of *E. brandegeei*. Ants will often carry seeds of *Eriogonum* underground where they are provided a safe site for germination (Reveal personal communication 2002). Ants are often observed on *E. brandegeei* and may also play a role as pollinators (Spackman Panjabi personal communication 2004).

While ants may play an important role in dispersal, they may have a negative impact on plant density. Ryti (1992) observed lower densities of *Eriogonum umbellatum* in a montane grassland in Montana where ants (*Formica altipetens*) tend aphids on this species. There has been no documentation of aphid or other insect utilization of *E. brandegeei*.

#### *Phenotypic plasticity*

*Eriogonum* species show varying degrees of phenotypic plasticity. One taxon, *E. densum*, had been considered one of the rarest taxa in New Mexico until it was shown to be an environmentally-induced phase of *E. polycladon* (Spellenberg et al. 1988). *Eriogonum brandegeei* is not particularly morphologically or ecologically variable, and there are no indications that *E. brandegeei* is a phenotypic variant of another species (Reveal personal communication 2004).

Ecophenic variation has been found to occur in several species of coastal and inland California *Eriogonum* (Cole 1967). Two species (*E. fasciculatum* and *E. parviflorum*) that have a prostrate, matted growth form in their native habitat were shown to produce a more erect habit when grown in a greenhouse. Thus the prostrate growth form is a phenotypic response to strong wind and unstable soil in species that live on the coast, and these plants appear morphologically similar to inland species in the absence of these conditions. It is thus plausible to expect an ecophenic response in other low-growing *Eriogonum* species, including *E. brandegeei*.

A morphological response to light intensity has been observed in *Eriogonum apricum*. Differences between an erect variety found in shaded sites and a prostrate variety growing in open sites were attributed to a growth response to light (Myatt and Kaufman 1998). It is likely that *E. brandegeei* would exhibit a similar response by growing less prostrate if it were to grow in a shaded site.

O’Kane (1988) observed variation in the density of the tomentum among specimens of *Eriogonum brandegeei*, but overall it does not appear to be morphologically plastic (see the Hybridization section of this assessment for discussion of this issue).

#### *Mycorrhizae*

Roots of *Eriogonum brandegeei* have not been assayed for the presence of mycorrhizal symbionts, and its role as a mycorrhizal host has not been investigated. Arbuscular mycorrhizal (AM) fungi belong to a group of nondescript 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).

The effects of AM fungi on growth, reproduction, and survival of three plant species, including one species of *Eriogonum* (*E. parvifolium*), were observed at a dune restoration site in California. Little or no colonization by AM fungi was observed in *E. parvifolium*, and inoculated plants showed no responses in growth, reproduction, and survival (Holte 1994). However, plants collected from wild populations were infected with vesicles and arbuscles.

### Hybridization

Several stable hybrids have been documented in the genus *Eriogonum* (Stokes 1936). Welsh (1984) observed evidence of hybridization among members of the *E. brevicaulis* complex (the closest relatives of *E. brandegeei*) with *E. corymbosum*, *E. lonchophyllum*, *E. microthecum*, and possibly others. However, these species are not sympatric with *E. brandegeei*, so hybridization events involving *E. brandegeei* are unlikely.

Apparent hybrids in which *Eriogonum brandegeei* is suspected to be a parent have been documented at Garden Park (by O'Kane in Colorado Natural Heritage Program 2005) and collected at Droney Gulch (Spackman #SS0105B at COLO). Because of the proximity of occurrences of *E. jamesii* to the Droney Gulch occurrence of *E. brandegeei*, Spackman suspected that an unusual plant she collected with a branched flowering stalk similar to that of *E. jamesii* and other intermediate characters was of hybrid origin (Spackman Panjabi personal communication 2004). However, Reveal (personal communication 2004) considers such a hybridization event unlikely since *E. brandegeei* and *E. jamesii* are in different subgenera, and he suggested alternate explanations for this anomalous plant. Branched flowering stalks are characteristic of some members of the genus, and even species such as *E. brandegeei* that have a capitate inflorescence will occasionally produce a branched inflorescence. *Eriogonum spathulatum*, the nearest relative of *E. brandegeei*, is very similar to *E. brandegeei* morphologically except that it has a branched inflorescence. Alternatively, the plant may have been browsed or grazed, or rust might have caused abnormal growth in this

individual. Under these scenarios, the branching is produced by abnormal growth of a meristematic region. Whether such plants are hybrids or merely phenotypic anomalies, they have rarely been seen (Spackman Panjabi personal communication 2004). There is little to suggest that hybridization or introgression occurs widely in *E. brandegeei*.

### Demography

Although there has been much work on the systematics of *Eriogonum* (e.g., Small 1906, Stokes 1936, Reveal 1969, Reveal 1985, Kuyper et al. 1997, and numerous others listed in Reveal 1989b), there have been few studies of population genetics of *Eriogonum* species. Nonetheless, some meaningful inferences regarding the population genetics of *E. brandegeei* can be drawn from previous studies of rare *Eriogonum* species.

Endemic and rare taxa often have low genetic variability (Hamrick and Godt 1989, Karron 1991). They also tend to have greater rates of self-pollination and inbreeding (Inoue and Kawahara 1990, Karron 1991). However, two studies of rare *Eriogonum* species have found surprisingly high levels of genetic diversity. Occurrences of the extremely rare and federally listed *E. ovalifolium* var. *williamsiae* were shown to have high levels of polymorphic loci, with many more alleles per locus and greater heterozygosity than expected for such a narrow endemic (Archibald et al. 2001). The genetic variability of *E. ovalifolium* var. *williamsiae* exceeds that typically seen in a common, widespread taxon. These populations showed no evidence of inbreeding and were likely the result of random mating. Another federally listed endangered taxon, *E. ovalifolium* var. *vineum*, is highly outcrossed, with apparent selective pressure against homozygosity (Neel et al. 2001). The results of these studies indicate that conservation of this species will require the maintenance of large populations to prevent increases in inbreeding and to support pollinator communities that facilitate outcrossing. In subsequent studies, Neel and Cummings (2003) and Neel and Ellstrand (2003) showed that selecting occurrences for conservation effort using several principles of ecological reserve selection (as reviewed by Noss et al. 1997 and Margueles and Pressey 2000) was not better than randomly selecting populations in terms of preservation of genetic diversity of *E. ovalifolium* var. *vineum*. They concluded that incorporating as many populations as possible into preservation efforts is the best means of conserving genetic diversity. These studies underscore the importance of understanding the population genetics for species conservation (as described by Hamrick et



al. 1979, Brown 1989, Hamrick and Godt 1989, and Loveless and Hamrick 1989).

The value of these data for drawing inferences regarding *Eriogonum brandegeei* is unknown. However, levels of genetic diversity tend to be highly correlated between rare and widespread congeners (Gitzendanner and Soltis 2000), suggesting that *E. brandegeei* may also exhibit high genetic diversity. It is likely that the distance between Garden Park and occurrences in Chaffee County is a significant barrier to gene flow, so plants in these locations are likely to harbor important genetic differences. The level of genetic variability in *E. brandegeei* has not been measured, but no readily observable effects of inbreeding depression have been documented in *E. brandegeei*.

The probability of dispersal of seeds and other propagules decreases rapidly with increasing distance from the source (Barbour et al. 1987). Thus, long distance dispersal events are rare. Pollinator-mediated pollen dispersal is largely limited to the flight distances of pollinators (Kearns and Inouye 1993). Due to the physical limitations to dispersal of seeds and pollen between occurrences, there is probably no pollen exchange between the Chaffee County and Garden Park occurrences of *Eriogonum brandegeei*. Areas of unsuitable habitat for *E. brandegeei* separating the two areas act as sinks when seeds are moved to these areas.

No Population Viability Analysis (PVA) has been performed on *Eriogonum brandegeei*, nor has there been a PVA performed on any member of the genus *Eriogonum* from which inferences could be drawn for this assessment.

Occurrences of *Eriogonum brandegeei* appear large enough to avoid the consequences of 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), and it generally becomes a concern in effective populations of fewer than 500 individuals.

Because of its extremely limited range, environmental stochasticity could impact populations of *Eriogonum brandegeei*. Environmental stochasticity includes temporal variation in reproduction and survival as a consequence of environmental conditions

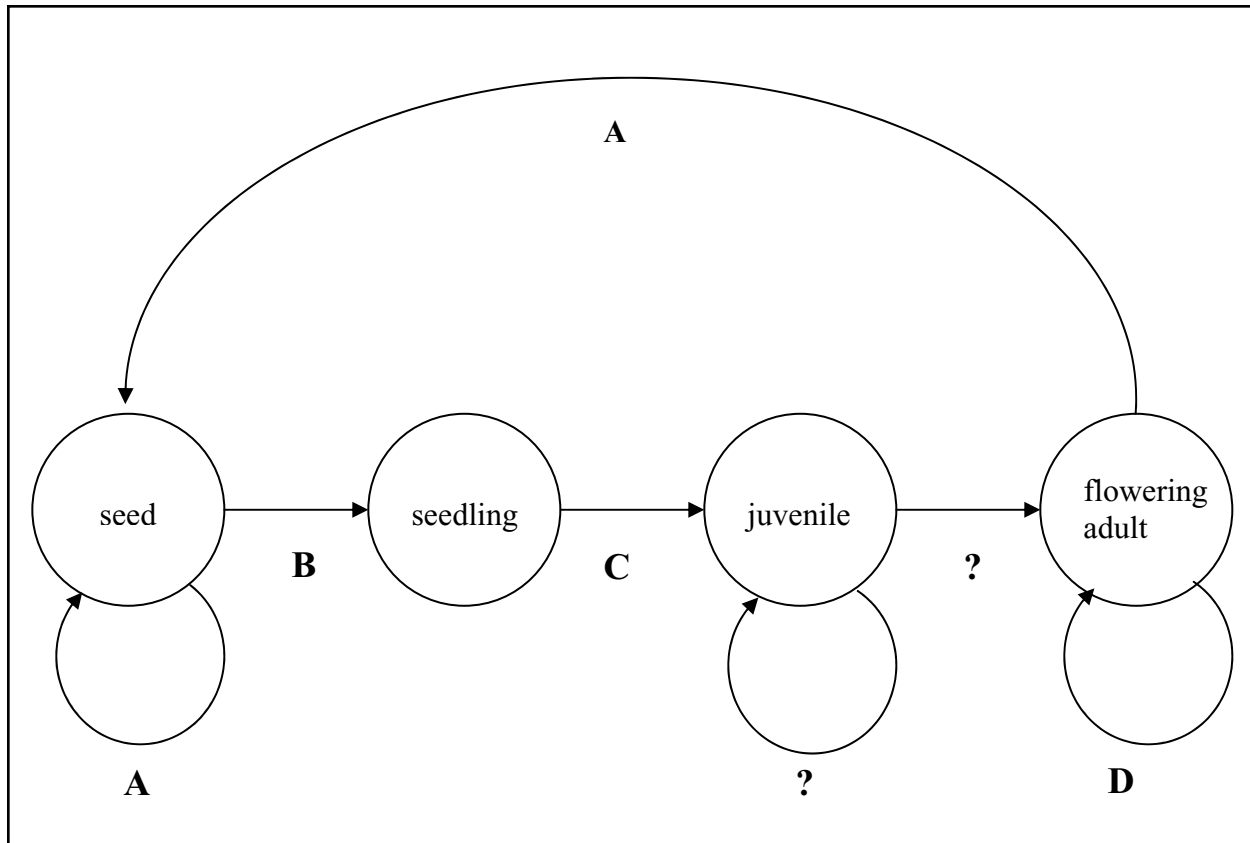
and catastrophic local events, and it could lead to local extinction (Lande 1998, Oostermeijer et al. 2003). Environmental stochasticity can operate at many scales and thus may impact large or small populations. Maintaining the largest populations possible is most likely to reduce potential negative consequences.

Many life history parameters remain unknown in *Eriogonum brandegeei*. Information on seeds and recruitment would be especially valuable. A better understanding of seed production, longevity, dormancy, and the variables controlling these parameters would reveal potential bottlenecks in the life history of *E. brandegeei*. Recruitment rates and longevity are unknown, but they are critical for understanding the population dynamics and extinction potential of this species.

There have been no observations of seedlings or successful recruitment in *Eriogonum brandegeei*, suggesting that recruitment events are rare and episodic and occur only under favorable conditions. No seedlings were observed in 2004 or 2005 in monitoring plots at Garden Park and Cleora (Grant and DePringer-Levin 2005).

A wide range of size classes has been observed at Droney Gulch, ranging from plants 1 inch across with a single stem to mats more than 2 ft. in diameter with dead centers (Spackman Panjabi personal communication 2004, Colorado Natural Heritage Program 2005). Large plants with senescent centers have also been observed at Cleora (Coles personal communication 2004). Dawson (personal communication 2004) noted that most plants she observed seemed old, suggesting that recent recruitment has been limited. Nothing is known about recruitment success of *Eriogonum brandegeei* (see **Figure 10** for a lifecycle graph of this species). The large size of some individuals at Droney Gulch and elsewhere suggests that they may be tens or possibly hundreds of years old. Some shrubby *Eriogonum* species in California were found to be more than 100 years old (Reveal personal communication 2002). Individuals in the genus *Dedekera*, a close relative of *Eriogonum*, have been aged using annual growth rings and exceed 150 years in age (Reveal personal communication 2002). Perennial species of *Eriogonum* may occasionally propagate through fragmentation. Thus, a single product of a sexual reproduction event may persist for a very long period of time (Reveal personal communication 2002).

Mean basal area of plants at two Garden Park study sites and at Cleora was determined in 2004 and



**Figure 10.** Hypothetical lifecycle graph (after Caswell 2001) for *Eriogonum brandegeei*. There has been no investigation of the life history stages of this species. No transition probabilities are known for *E. brandegeei*, although ongoing demographic studies should provide insight. The value of A probably varies from year to year depending on climatic variables, but is likely to be small based on the research of Meyer and Paulsen (2000). No seedlings have been observed, so there are no data from which to infer B and C. The duration of the juvenile stage is not known, but even plants one inch in diameter can produce a flowering stalk; it is not known how old these plants are. Casual observations of *E. brandegeei* and observations of other species cited by Reveal (personal communication 2002) suggest that plants probably survive for decades to more than 100 years as flowering adults (D).

2005 (Grant and DePringer-Levin 2005). In general, larger plants were found at Garden Park West, where the average basal area was 229 cm<sup>2</sup> in 2004 and 150 cm<sup>2</sup> in 2005. A few individuals approaching 20 by 60 cm were observed at this location. The average size was smallest at the Garden Park East site (68 and 65 cm<sup>2</sup> in 2004 and 2005, respectively), and intermediate at Cleora (149 cm<sup>2</sup> in 2004). Grant and DePringer-Levin (2005) speculate that the great variability in mean basal area observed at Garden Park West may be due to errors in measuring a few very large individuals, which would have a large influence on the mean. Most plants at all three sites were approximately 15 by 20 cm.

#### Community ecology

There has been no formal study of the community ecology and interspecific relationships of *Eriogonum*

*brandegeei*. Available information is limited to surveys, herbarium specimens, and observations. Preliminary monitoring of exotic species has been initiated at Droney Gulch and Garden Park (Anderson et al. 2001; see the Interaction of *Eriogonum brandegeei* with exotic species section for an overview of the findings of this study). Associated species that have been documented with *E. brandegeei* are presented in **Table 4**.

#### Vegetation

*Eriogonum brandegeei* is found in pinyon-juniper woodlands (Colorado Division of Wildlife 1998); however, within this matrix community *E. brandegeei* is more often associated with shrublands dominated by *Chrysothamnus nauseosus* (rabbitbrush), *Cercocarpus montanus*, and *Atriplex* spp. *Eriogonum brandegeei* is also documented with *Frankenia jamesii*, a distinctive

**Table 4.** Associated species reported with *Eriogonum brandegeei*.

Associated Species	Rare/Exotic?	Associated Species	Rare/Exotic?
<i>Agropyron</i> sp.		<i>Eriogonum</i> sp.	
<i>Agropyron smithii</i>		<i>Frankenia jamesii</i>	
<i>Allium</i> sp.		<i>Grindelia squarrosa</i>	
<i>Aristida fendleriana</i>		<i>Gutierrezia sarothrae</i>	
<i>Aristida purpurascens</i>		<i>Hymenoxys richardsonii</i>	
<i>Artemisia frigida</i>		<i>Juniperus monosperma</i>	
<i>Artemisia</i> sp.		<i>Juniperus osteosperma</i>	
<i>Astragalus kentrophyta</i>		<i>Kochia scoparia</i>	E
<i>Astragalus lonchocarpus</i>		<i>Melilotus alba</i>	E
<i>Astragalus</i> sp.		<i>Melilotus officinale</i>	E
<i>Astragalus tridactylicus</i>		<i>Mentzelia chrysantha</i>	R
<i>Atriplex canescens</i>		<i>Mirabilis</i> sp.	
<i>Atriplex</i> spp.		<i>Opuntia imbricata</i>	
<i>Atriplex confertifolia</i>		<i>Oryzopsis hymenoides</i>	
<i>Bouteloua curtipendula</i>		<i>Parthenium tetraeuris</i>	
<i>Bouteloua gracilis</i>		<i>Pinus edulis</i>	
<i>Cercocarpus montanus</i>		<i>Pinus ponderosa</i>	
<i>Chaenactis douglasii</i>		<i>Salsola iberica</i>	E
<i>Chrysothamnus nauseosus</i>		<i>Sphaeralcea coccinea</i>	
<i>Chrysothamnus</i> sp.		<i>Stipa</i> sp.	
<i>Cleome serrulata</i>		<i>Tetradymia canescens</i>	
<i>Elymus elymoides</i>		<i>Thermopsis</i> sp.	
<i>Eriogonum effusum</i>		<i>Yucca angustissima</i>	
<i>Eriogonum jamesii</i>		<i>Yucca glauca</i>	

short shrub that is disjunct in the Arkansas Valley. It is also known from shale badlands in Montezuma County, Colorado and in Texas and New Mexico.

Pinyon-juniper woodlands are widely distributed throughout the western United States (West and Young 2000) and comprise approximately 11 percent of the Southern Rocky Mountain Ecoregion (Rondeau 2000). In the pinyon-juniper woodlands of southern Colorado, including the Arkansas Valley, *Pinus edulis* and *Juniperus monosperma* are the dominant overstory species (Chumley 1998, West and Young 2000). This is the northernmost extent of this community, which is more extensive in northern New Mexico and West Texas (Peet 2000). These woodlands are found at elevations slightly higher than saltbush-greasewood shrublands that are also common in the Arkansas Valley (West and Young 2000). In Colorado, pinyon-juniper woodlands are found between 4000 and 9000 ft. in elevation (Rondeau 2000). At approximately 6,500 ft., the relative abundance of pinyon and juniper is approximately equal, but as elevation increases the

relative cover of juniper decreases and pinyon increases (Tueller et al. 1979). Grazing and fire suppression have greatly altered this vegetation type throughout its range (West and Young 2000). While grazing in many areas was much heavier in the early and mid-20<sup>th</sup> century than it is today, the legacy of this overgrazing persists in many areas. Grazing reduces the cover of perennial bunchgrasses in pinyon-juniper woodlands, opening them to invasion by cheatgrass (*Bromus tectorum*) and other exotic species. The loss of native understory results in increased erosion (West and Young 2000).

#### Herbivores

There are no indications that *Eriogonum brandegeei* is browsed regularly by herbivores, but some browsing damage has been observed at Garden Park and Cleora (Grant and DePringer-Levin 2005). Cleora showed the highest incidence of browsing damage, where 48 percent of the individuals sampled showed evidence of browsing; nearly half of this damage (23 percent) was to leaves while 11.7 percent

of the inflorescences were damaged by browsing. Little or no browsing damage to inflorescences was observed at Garden Park East while 8.9 percent of individuals at Garden Park West had browsed inflorescences. Browsing of inflorescences resulted in the removal of all the flowers and potential fruits from the peduncle. However, most of the browsing observed at all sites was of leaves. Deer are likely to be the major species browsing *E. brandegeei* since deer trails traverse occurrences at Droney Gulch (Colorado Natural Heritage Program 2005). No herbarium specimens appeared to be browsed.

Some species of *Eriogonum* are important in the diets of herbivore species. Several studies addressed the use of *Eriogonum* species as forage by bighorn sheep (*Ovis canadensis*). *Eriogonum* species are important winter forage for desert bighorn sheep in Mexico, where they compose up to 8 percent of their fall and winter diet (Tarango et al. 2002). Bighorn sheep grazing resulted in the decline of *E. heracleoides* and *E. niveum* in British Columbia. Grazing pressure also strongly reduced vigor and reproductive potential in these species (Wikeem and Pitt 1991). However, California bighorn sheep foraged based primarily on plant availability, and they did not appear to seek out *E. niveum* and *E. heracleoides* as they did other species (Wikeem and Pitt 1992). *Eriogonum* species in Oregon are among the primary forbs consumed by sage grouse (*Centrocercus urophasianus*). Nutrient content analyses of these species showed that they have high nutritional value for sage grouse (Barnett and Crawford 1994).

The lack of *Eriogonum brandegeei* in the bottomlands at Garden Park may be due to environmental differences but may also be due to grazing pressure and competition from weeds, both of which can be very high in these areas. It is not known if any of the grazed bottomlands were once inhabited by *E. brandegeei*.

### *Competitors*

There is no information on competitors for biotic and abiotic resources with *Eriogonum brandegeei*. As a habitat specialist, *E. brandegeei* may be a poor competitor and may be vulnerable to negative impacts from introduced species. Some species of *Eriogonum* are competitive and respond positively to disturbance (Reveal personal communication 2002). However, stress-tolerant species sensu Grime (2001) do not need to be good competitors since highly competitive species are not capable of withstanding the chronic stress regime to which stress tolerators are adapted. Thus,

they typically do not share the same resource pool with species such as *E. brandegeei*.

### *Parasites and disease*

The occurrence of rust has been documented on several Colorado *Eriogonum* species including *E. brandegeei* (Colorado Natural Heritage Program 2005). *Eriogonum* species are commonly attacked by the rust *Uromyces intricatus* (Savile 1966). This species is broken into six varieties, all of which attack members of the genus *Eriogonum* throughout western North America.

Samples of the rust from *Eriogonum brandegeei* were obtained in 2001 and 2002 from Droney Gulch and Loggie Gulch and identified as a species of *Uromyces*, possibly *U. intricatus* (Dawson personal communication 2004, Grant and DePringer-Levin 2005). Attacks of this rust are cyclical and may be brought on by drought or other stress. More than half of some occurrences of *E. brandegeei* appeared severely affected by the rust, but it is unknown whether rust epidemics have resulted in mortality or lasting impacts on the occurrences. While the impacts of the rust appear dramatic, it does not typically do serious damage to its host. This rust typically causes the leaves to fall off but does not attack the plants systemically (Reveal personal communication 2004). The presence of many very old plants at Droney Gulch and elsewhere suggests that periodic rust attacks do not result in widespread plant mortality. In monitoring plots at Garden Park and Cleora, 1.7 percent of plants were infected with rust in 2004, and none in 2005, and no ill effects of the infections were observed (Grant and DePringer-Levin 2005). However, the combination of drought, increased erosion, and disturbance by off-road vehicle use in its habitat may weaken plants and leave them more susceptible to rust attack. Under these conditions, an attack may have long-term consequences for individuals or occurrences (Spackman Panjabi personal communication 2004).

## CONSERVATION

### *Threats*

Much has changed in the Arkansas Valley in the past 23 years. Johnston et al. (1981) wrote that "Several observers have failed to find any threats" to *Eriogonum brandegeei*. O'Kane (1988) noted that bentonite mining threatened one occurrence at Garden Park, and that development for second homes might threaten occurrences near Salida in the

future. However, the human population explosion in the Arkansas Valley that took place in the 1990s probably exceeded the expectations of these authors. The residential development predicted by O’Kane has encroached on one of the best occurrences of *E. brandegeei*, and abuse of its habitat from off-road vehicle use has become widespread. All known occurrences of this species are now directly threatened by human activities (Spackman 2000).

Numerous reports and observations describe several threats to the persistence of *Eriogonum brandegeei*. In order of decreasing priority, these threats include off-road vehicle use and other recreation, residential and commercial development, timber thinning and extraction, mining, right-of-way management, exotic species invasion, grazing, effects of small population size, rust, fire, global climate change, and pollution. These threats and the hierarchy ascribed to them are somewhat speculative, and more complete information on the biology and ecology of this species may elucidate other threats. Assessment of threats to this species will be an important component of future

inventory and monitoring work. See the following sections for specific treatments of these threats to habitat and individuals.

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

### *Recreation*

Inappropriate recreational use of its habitat is the greatest threat to *Eriogonum brandegeei* (**Figure 11**; The Nature Conservancy 2001, Brekke personal communication 2004). Presently, recreation impacts are intense at Garden Park, Loggie Gulch, Cleora, and Droney Gulch (Brekke personal communication 2004, Coles personal communication 2004, Grant personal communication 2004, Spackman Panjabi personal communication 2004, Colorado Natural Heritage Program 2005, Grant and DePringer-Levin 2005), and the proximity of occurrences to a rapidly growing human population increases this threat. All known occurrences of *E. brandegeei* are threatened by off-road vehicle use, which is increasing throughout the Arkansas Valley



**Figure 11.** Off-road vehicle impacts at a popular destination near Droney Gulch. *Eriogonum brandegeei* (blue-green plants) and *Melilotus officinalis* are found together at this site. Photograph provided by Susan Spackman Panjabi, used with permission.

(Brekke personal communication 2004, Coles personal communication 2004). Due to their challenging slopes and the lack of interference from vegetation, areas occupied by *E. brandegeei* are frequently exploited by users of all-terrain vehicles (ATVs), 4-wheel drive trucks, motorcycles, and mountain bikes for off-road vehicle recreation (Lyon and Denslow 2001). The intensity of off-road vehicle use will certainly increase as human populations increase in the Arkansas Valley, so management attention is needed for all occurrences (Anderson et al. 2001). Land managers have recognized the immediacy of the threat of off-road vehicle activity to *E. brandegeei*; intensive management of off-road vehicle use is a stated goal in problematic areas covered in travel management plans (Bureau of Land Management 2004b). After recognition of a problem, the most difficult part is enforcement, given the large areas involved and limited human resources to enforce road and area closures (Brekke personal communication 2004). Trash dumping and high impact camping have become a problem at Droney Gulch, but road closures were implemented recently to try to curtail these activities (Brekke personal communication 2004). While far less than those of off-road vehicles, impacts from horseback riding have also been documented in *E. brandegeei* occurrences (Colorado Natural Heritage Program 2005).

### *Residential development*

Residential development poses a significant and increasing threat to the quality and availability of habitat for *Eriogonum brandegeei*. Urban growth is occurring rapidly throughout Colorado; growth rates in some areas are among the highest in the United States. The population of Fremont County grew 43 percent between 1990 and 2000, and it continues to be one of the fastest-growing counties in the United States (U.S. Census Bureau 2003). Chaffee County also saw rapid population growth in this time period (see the Evidence of populations in Region 2 at risk section of this assessment). While residential development is cited as the second-most significant threat to *E. brandegeei*, it could become the greatest threat to *E. brandegeei* if it continues to result in permanent habitat loss. Residential development throughout the Arkansas Valley has already resulted in a decline in available habitat for *E. brandegeei*, and at Cleora it has probably resulted in the extirpation of portions of the occurrence. Growth of the city of Salida poses the greatest threat to *E. brandegeei*, given its proximity to occurrences at Cleora and Loggie Gulch, but subdivision and dispersed development threaten other occurrences. Low and medium density development, which is rampant

throughout the Colorado Front Range, fragments large areas of natural habitat (Knight et al. 2002). The proliferation of roads and disturbance from construction are likely to encourage the spread of weeds throughout Fremont and Chaffee counties and increase the threat of exotic species to *E. brandegeei*.

As a consequence of the Healthy Forest Initiative, forest thinning activities may begin in the near future that may include pinyon-juniper stands within and adjacent to occurrences of *Eriogonum brandegeei*. These activities are potentially deleterious to *E. brandegeei* for several reasons. Timber extraction on sites underlain by the Dry Union Formation has the potential to destabilize the outwash cap that protects the erosive slopes on which *E. brandegeei* grows. Direct impacts to plants are also possible, as is the introduction of exotic species such as Russian thistle (*Salsola iberica*).

A timber sale has taken place on National Forest System land above Droney Gulch (Elliott personal communication 2004). While this is unlikely to directly impact occurrences in this area, indirect impacts are possible from heavy equipment operations on the access road to Droney Gulch that will be used by timber crews.

### *Mining*

The Arkansas Valley contains many mineral deposits, some of which are commercially valuable and have been mined (e.g., copper, gold, and tungsten) (Wallace et al. 1997). No mineral extraction is currently taking place in *Eriogonum brandegeei* occurrences or its habitat. Exploration for oil, gas, and minerals has the potential to impact occurrences of *E. brandegeei*. The extremely rough and impassable terrain at some sites such as Cleora and Droney Gulch precludes access by heavy equipment, but as oil and gas development proceeds there are likely to be cases where exploration or extraction affects *E. brandegeei* habitat or occurrences. The magnitude of this threat is currently difficult to assess.

Bentonite mining has been cited as a threat to *Eriogonum brandegeei* at Garden Park (O'Kane 1988, Colorado Natural Heritage Program 2005). However, the bentonite pit at Garden Park has been closed for several years, and the site is closed to off-road vehicle use to prevent further degradation of the site (Brekke personal communication 2004). There are other bentonite pits in the Cañon City vicinity (The Nature Conservancy 2001), but apparently none in *E. brandegeei* habitat are active at this time. There is no bentonite mining taking

place near occurrences in Chaffee County (Brekke personal communication 2004). Threats from bentonite mining are probably greatest to occurrences on private land (Brekke personal communication 2004).

#### *Paleontological excavation*

Paleontological excavations are a potential threat to *Eriogonum brandegeei* at Garden Park. However, excavations have not directly impacted *E. brandegeei* individuals, and there have been no conflicts between this activity and plant conservation. There is currently no authorized fossil excavation occurring at Garden Park. Paleontologists are interested in fossils deposited in the sandstone lenses within the Morrison Formation, which do not support occurrences of *E. brandegeei*. The threat from this activity is low (The Nature Conservancy 2001, Brekke personal communication 2004).

#### *Livestock grazing*

Livestock grazing is an indirect threat to *Eriogonum brandegeei* since the sites where it grows are usually inaccessible to livestock and of low forage value. The effects of livestock grazing on *E. brandegeei* individuals are not known, but its life history strategy and the instability of its substrate suggest that grazing may be deleterious. In fragile soils such as those inhabited by *E. brandegeei*, grazing can enhance erosion. The outwash cap that protects *E. brandegeei* habitat supports not only trees but also forage for livestock. Overgrazing can result in erosion of the outwash cap and destabilization of the slopes where *E. brandegeei* grows. Other impacts from grazing, particularly those cited by West and Young (2000), include the introduction of exotics such as cheatgrass. Horse grazing on small subdivision parcels can also result in habitat degradation and erosion, which can in turn eliminate occurrences on private land. At appropriate stocking rates, livestock will not tend to use the barren areas occupied by *E. brandegeei* since these areas have low forage value.

#### *Road maintenance*

For *Eriogonum brandegeei*, roadside occurrences are a relatively small proportion of the total population. Occurrences within right-of-ways are susceptible to road maintenance activities such as mowing, spraying for weeds, and road widening. Plants within 23 ft. of the pavement (or 15 ft., depending on the size of the mower used) may be mowed repeatedly through the growing season (Powell personal communication 2003). Threats to roadside occurrences will be difficult

to fully mitigate or prevent. While plans have been formulated to mitigate these threats in the Cañon City area (Grunau et al. 2003), they will not be implemented along Route 285 or at other roadside occurrences of *E. brandegeei* because they fall outside the area covered under this plan.

#### *Fire*

Several studies have addressed the response of *Eriogonum* species to fire, including summer burning regimes (Rickard 1989) and post-fire succession (Malanson 1982). Fire is important for maintaining the population viability of *E. longifolium* var. *gnaphalifolium* (Satterthwaite et al. 2002). However, fire probably plays a minor role in the maintenance of barren *E. brandegeei* habitat, and so it is unlikely that it is well-adapted to fire. The barren substrates where *E. brandegeei* grows would probably not carry fire.

Hydromulch containing *Agropyron cristatum* (crested wheatgrass) was sprayed on part of the occurrence at Droney Gulch within the Droney Gulch State Natural Area in an attempt to establish forage for livestock. Apparently the attempt was unsuccessful and did not appear to negatively impact *Eriogonum brandegeei* plants there (Coles personal communication 2004).

#### *Disease*

Numerous observers have cited rust attack as a threat to *Eriogonum brandegeei*. However, it appears that the rust does not usually kill its hosts or cause long-term damage. Epidemics of this rust have probably always periodically occurred in *E. brandegeei* occurrences. The demography of known populations and observations in 2004 and 2005 suggest that rust does not induce widespread mortality in *E. brandegeei*. However, it is possible that plants that are already stressed or disturbed by human impacts such as off-road vehicle use may succumb to rust attacks. In this scenario, rust is part of a suite of threats that could exacerbate the decline of *E. brandegeei*.

#### *Loss of pollinators*

Activities that decrease the size or change the composition of pollinator populations are likely to impact *Eriogonum brandegeei* if they result in a decrease of pollen exchange. Maintenance of genetic diversity has been shown to be important for other species of *Eriogonum*, and this may be true for *E. brandegeei* as well. Surface disturbance or compaction

is a potential threat to ground nesting pollinators, some of which are known to visit flowers of *E. brandegeei*. Further study is needed to determine whether sufficient pollinator resources are available for *E. brandegeei* and if ongoing impacts to *E. brandegeei* occurrences are affecting its pollinator resources.

### *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<sub>2</sub> trends that suggest average temperatures will increase while precipitation will decrease in the West. However, Giorgi et al. (1998) showed that temperature and precipitation increased under simulated doubling of atmospheric CO<sub>2</sub> levels. Either scenario could significantly affect the distribution of suitable habitats for *Eriogonum brandegeei*. Temperature increase, predicted by both models, could cause vegetation zones to climb 350 feet in elevation for every 1 °F of warming (U.S. Environmental Protection Agency 1997). Because the habitat for *E. brandegeei* is already xeric, lower soil moistures during the growing season induced by decreased precipitation could have serious impacts. Garden Park, which supports the lowest elevation occurrences of *E. brandegeei*, may be the most threatened by upward shifts in vegetation zones since there are no higher elevation sites in the area with suitable habitat.

Experimentally-elevated CO<sub>2</sub> levels resulted in increased rate of biomass accumulation and reduced stomatal conductance in *Eriogonum inflatum*, a widespread desert annual or short-lived perennial, but they did not change its seasonal pattern of net photosynthesis. In general, *E. inflatum* retained its important traits for persisting under the conditions present in its desert habitat (Huxman and Smith 2001). However, the consequences in increased CO<sub>2</sub> levels on a perennial *Eriogonum* species, such as *E. brandegeei*, are difficult to predict.

### *Pollution*

Atmospheric nitrogen deposition has become one of the most important agents of vegetation change in densely populated regions (Köchy and Wilson 2001). Nitrogen loading and vegetation change have been observed to be greatest near or downwind of metropolitan areas (Schwartz and Brigham 2003). Thus,

measurable impacts from nitrogen pollution might be expected within the range of *Eriogonum brandegeei*. Nitrogen enrichment experiments show universally that nitrogen is limited (Gross et al. 2000). A change in biologically available soil nitrogen is likely to cause a few species to increase in abundance and many others to decline (Schwartz and Brigham 2003). The degree to which nitrogen pollution has resulted in vegetation change in *E. brandegeei* habitat is unknown. Acid deposition, which has increased markedly in Colorado through the 20<sup>th</sup> century, may have already caused changes to the soil chemistry that affect habitat quality for *E. brandegeei* locally or regionally. High elevation watersheds of the Front Range have already reached an advanced stage of nitrogen saturation (Burns 2002).

### *Interaction of Eriogonum brandegeei with exotic species*

Exotic species have been documented growing in areas where *Eriogonum brandegeei* is found, and they are a threat to occurrences in both natural and human-impacted habitats (**Figure 11**). Two exotic plant species have been documented with *E. brandegeei*: Russian thistle, and yellow sweetclover (*Melilotus officinale*). These are the most pervasive weeds in habitat for *E. brandegeei* at the Garden Park ACEC, and a monitoring program has been initiated to study the behavior of these species and their impacts on *E. brandegeei* and on another rare species, *Mentzelia chrysantha* (golden blazingstar) (Anderson et al. 2001). Other exotic species present in Garden Park but not yet within occurrences of *E. brandegeei* include field bindweed (*Convolvulus arvensis*), cheatgrass, tumble mustard (*Sisymbrium altissimum*), and timothy (*Phleum pratense*).

There have been no observations where non-native species were implicated in negatively impacting *Eriogonum brandegeei*. Several potentially problematic exotic species occur at Droney Gulch (Anderson et al. 2001), most commonly along roadsides in and surrounding the Droney Gulch ACEC. These species include tansy mustard (*Descurainia sophia*), Russian thistle, tumble mustard, leafy spurge (*Euphorbia esula*), yellow sweetclover, common lambsquarters (*Chenopodium album*), and cheatgrass. Exotic species were not found in direct association with *E. brandegeei* at Droney Gulch. Use of herbicides for right-of-way weed management and for range management threatens *E. brandegeei* where it occurs on road cuts or roadsides. Care must be taken with the application of herbicides in habitat for *E. brandegeei*, and use of herbicides within known occurrences should be limited to hand application to the target species.



Sweetclover, a Eurasian genus, has become widely naturalized in North America (Mabberley 1997). Yellow sweetclover has been linked to decreasing density of *Astragalus ripleyi* (Ripley's milkvetch), a rare Colorado and New Mexico endemic (Colorado Natural Heritage Program 2005). 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 *Eriogonum brandegeei*. It appears to thrive where disturbance from off-road vehicle use is taking place in habitat for *E. brandegeei* (**Figure 11**).

Cheatgrass is an aggressive invader of native plant habitat, and its spread throughout the western United States has been 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 eliminated (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 *Eriogonum brandegeei*.

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

Other exotic species of concern for *Eriogonum brandegeei* include halogeton (*Halogeton glomeratus*), Russian knapweed (*Acroptilon repens*), and medusa head rye (*Taeniatherum caput-medusae*). These species have not been documented with *E. brandegeei*, but they are aggressive invaders of large areas of habitat throughout the West. Russian knapweed has spread to the southern Front Range and is extremely difficult to control (Colorado Weed Management Association 2002). Although it can grow in poor soils, Russian knapweed prefers roadside ditches and swales while *E. brandegeei* is found in better-drained settings. The Nature Conservancy (2001) cited weeds, including Russian thistle, clover (*Trifolium* spp.), cheatgrass, and toadflax (*Linaria vulgaris* and *L. dalmatica* ssp. *dalmatica*), as threats to *E. brandegeei*, although

toadflax and clover have not yet been documented in *E. brandegeei* occurrences or habitat.

#### Threats from over-utilization

There are no known commercial uses for *Eriogonum brandegeei*. Many species of *Eriogonum* are sought after for the horticulture trade (Reveal 1989a, Hickman 1993, Reveal 2003). Members of the genus *Eriogonum* are reputed to be good plants for honey production (Lovell 1969, Hickman 1993). Native Americans used the roots of some *Eriogonum* species for medicinal purposes (Kearney and Peebles 1960), including the treatment of colds, tuberculosis, bladder problems, skin cuts, open sores, and itching (Train et al. 1957, Ayer et al. 1989). Plant extracts of *E. brevicaulis* have been shown to have medicinal potential but exhibited some lethality in mice (Abdel-Kader and Stermitz 1996). *Eriogonum brandegeei* is an attractive species and could be of potential horticultural interest. There is potential for over-utilization of *Eriogonum* species if they become popular in the herb trade. Harvest of wild populations of *E. brandegeei* would present a threat if it became a common practice. In collecting plants for scientific purposes, care should be taken by collectors not to remove plants from small populations (Wagner 1991, Pavlovic et al. 1992).

### ***Conservation Status of Eriogonum brandegeei in Region 2***

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

Significant human impacts to the habitat for *Eriogonum brandegeei* probably began in the 1860s when oil drilling and bentonite mining were followed by dinosaur quarrying at Garden Park. The impacts of grazing are speculative but may have reduced the species' distribution and abundance locally where plants were accessible to livestock. While these early impacts may have caused some population decline, widespread impacts to *E. brandegeei* habitat apparently did not begin until the late 20<sup>th</sup> century. The pre-settlement population size and extent of *E. brandegeei* are not known. Therefore, it is difficult to assess the effects of recreation, infrastructure, extractive use, and management regimes on abundance. However, given the dramatic increase in the intensive recreational use of its habitat and the encroachment of residential development, and the autecological attributes of *E. brandegeei*, it is very likely that its distribution and abundance have declined. Inventory and monitoring

work will help to determine the current population trend of this species.

Do habitats vary in their capacity to support this species?

The range of population sizes and densities of documented occurrences suggests that habitats vary in their capacity to support *Eriogonum brandegeei*. As yet, key environmental variables have not been identified, but they probably include soil texture, parent material, slope/aspect, disturbance regime, geochemistry/soil chemistry, pollinator availability, and associated species. The identification of these variables is a high-priority research topic. The basic habitat requirements of *E. brandegeei* have been determined through observations of its natural history, but the physiological ecology and tolerance limits of *E. brandegeei* have not been defined. The presence of bentonite in the substrate is clearly a key habitat factor, probably because *E. brandegeei* is uniquely adapted to it. Any changes to *E. brandegeei*'s habitat that mitigate the harsh edaphic conditions would probably lead to dominance by more competitive species and the exclusion of *E. brandegeei*. Refinements of our understanding of the relationships between *E. brandegeei* and its habitat will only be possible through research.

#### Vulnerability due to life history and ecology

The conflict between *Eriogonum brandegeei*'s narrow endemism and the intensive human use of its limited habitat are the primary sources of its vulnerability and high degree of imperilment. Its narrow tolerance of edaphic conditions appears to limit it to soil types derived from specific geological strata. The proximity of suitable habitats to roads and to a growing human populace, habitat fragility, potential commercial value of the substrate, and attractiveness to off-road vehicle users leave occurrences highly vulnerable to human impacts, and the habitat specificity of *E. brandegeei* makes it susceptible to extirpation.

While some perennial *Eriogonum* species tolerate damage from off-road vehicles and hoofed herbivores, this is probably not the case for *E. brandegeei* (Reveal personal communication 2004). The instability of its

substrate and its slow growth would result in a long recovery time. *Eriogonum brandegeei* probably lacks specific adaptations to mechanical disturbance and herbivore damage because it has not historically been subject to human impacts and grazing pressure.

Assessing the roles that life history and ecology may play in the vulnerability of *Eriogonum brandegeei* is complicated by the paucity of information available. As a long-lived, stress-tolerant perennial, it is buffered from the effects of environmental stochasticity such as drought. Its mechanisms for selfing may buffer it from impacts to its pollinators. Studies of *E. ovalifolium* var. *williamsiae* show that maintaining heterozygosity is important in the fitness of the population. Preventing the buildup of homozygous loci in the population requires outcrossing, which is augmented by the presence of pollinators and sufficiently large populations (Neel et al. 2001).

#### Evidence of populations in Region 2 at risk

There is substantial evidence to suggest that occurrences of *Eriogonum brandegeei* are at risk. Its habitat specificity, high level of endemism, limited occupied area, small number of occurrences, isolated occurrences, and eminent threats all suggest that *E. brandegeei* is imperiled. The two centers of *E. brandegeei* distribution in Chaffee and Fremont counties are probably genetically isolated from each other, which increases the risk of inbreeding. With a known global distribution of 1.27 square miles, any activities that reduce or degrade its habitat put *E. brandegeei* at greater risk.

Fremont and Chaffee counties are growing rapidly; Fremont County has one of the highest human population growth rates in the United States (**Table 5**; U.S. Census Bureau 2003). Thus, the development pressures exerted on *Eriogonum brandegeei* habitat are likely to increase, and occurrences on private land are at risk from future development. Building permits issued in Fremont County between 1991 and 1998 experienced a 339.5 percent increase (The Nature Conservancy 2001). New construction has occurred near Dronery Gulch (Colorado Natural Heritage Program 2005), and a new subdivision at Cleora has probably resulted in the loss

**Table 5.** 1990 and 2000 human census data for Fremont and Chaffee 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
Chaffee	12,684	16,242	3,558	28.1

of *E. brandegeei* plants (Coles personal communication 2004). Development might also negatively impact the pollinator species on which *E. brandegeei* depends by reducing local nectar resources.

The potential value of natural resources in and near *Eriogonum brandegeei* occurrences places it at risk of extirpation when these resources are extracted. Some resource extraction, mostly bentonite mining, has already occurred in *E. brandegeei* habitat. The potential indirect impacts of timber harvest are significant, as are the potential impacts of oil and gas exploration and extraction. The risk of losing *E. brandegeei* occurrences to these activities is correlated with economics and the market value of these resources, which could change suddenly and with little notice.

The autecology of *Eriogonum brandegeei* is poorly understood, which is a liability because well-intended conservation actions are not as effective when basic information is not available.

The known occurrences of *Eriogonum brandegeei* are large enough that they are probably not at immediate risk of genetic bottlenecks. However, given the population genetics of *E. ovalifolium* var. *williamsiae* (Archibald et al. 2001) and *E. ovalifolium* var. *vineum* (Neel et al. 2001), large populations may be important in preventing inbreeding depression. Thus, *E. brandegeei* may be at risk from any impacts that result in the obstruction of gene flow among populations that would lead to smaller effective population sizes and increase the risk of inbreeding depression. Fragmentation may reduce the movement of pollinators, which would create barriers to gene flow.

Portions of some occurrences of *Eriogonum brandegeei* are known from sites that have been created or maintained by an anthropogenic disturbance regime (e.g., road cuts). Since these sites are not managed to protect *E. brandegeei*, they are at risk from routine road maintenance practices such as mowing, grading, and herbicide use. They are also threatened by road widening projects, as are plants in adjacent natural habitat.

There remains a good chance that the collection of *Eriogonum brandegeei* from Raspberry Gulch represents another occurrence that has not yet been well documented. If this record represents an occurrence that is still extant, it cannot benefit from conservation actions until it is relocated and better geographic data are available.

## ***Management of Eriogonum brandegeei in Region 2***

Implications and potential conservation elements

The best data available suggest that *Eriogonum brandegeei* is a narrowly endemic species imperiled due to a limited global range, small number of occurrences, limited habitat availability, and threats to its habitat. Conservation elements for *E. brandegeei* include the need for barren sites, correlated with poor soils and bentonite geology; a suitable disturbance regime, the exact nature of which is unknown; availability of pollinators; and a lack of competitors.

The loss of all or part of an occurrence is significant and could result in reduction of the species' genetic diversity. Protection of known occurrences, designation of ACECs, acquisition of habitat by federal agencies through land exchange, conservation easements to protect habitat on private lands, public education, and development of effective management strategies and protective regulations offer the best chance for the conservation of *Eriogonum brandegeei*. Given its rarity, threats to its habitat, demonstrable impacts, and declining available habitat, management policies must take steps to ensure that this species persists. Without strong proactive conservation efforts, *E. brandegeei* and other narrow endemics of the Arkansas Valley may warrant future listing under the federal Endangered Species Act. Restoration policies must address restoration of native plant communities, grazing management, human and natural disturbance, and pollinator resources. Further research on the ecology and distribution of *E. brandegeei* will help to develop effective approaches to its management and conservation.

Desired environmental conditions for *Eriogonum brandegeei* include sufficiently large areas where the natural ecosystem processes upon which it depends can occur, unimpeded by human activities and their secondary effects, such as weeds. This includes a degree of ecological connectivity between occurrences to provide corridors and other nectar resources for pollinators. Although there has been significant change within and near its habitat, this remains a feasible goal for *E. brandegeei* if steps are taken before more occurrences and habitat are lost. Steps towards its conservation have already been taken, and laudable efforts have been made by agencies and individuals. It

is possible that most or all of the ecosystem processes upon which *E. brandegeei* depends are functioning properly at many or most of the occurrences of this species. Given its very limited global distribution, conserving all known occurrences is a realistic goal.

## Tools and practices

### *Species and habitat inventory*

Compared with some rare plant taxa in the Arkansas Valley, inventory efforts for *Eriogonum brandegeei* have been relatively thorough and there is a good understanding of its distribution. Past surveys were conducted by experienced botanists, and it is unlikely that large occurrences remain to be discovered. A recent significant survey was that of Spackman and Floyd (1996), which focused on BLM land and generated accurate maps of several occurrences. Surveys focusing on private land are likely to find at least a few occurrences. However, the habitat for *E. brandegeei* is conspicuous and can usually be seen from a distance, and Spackman and Floyd (1996) noted that there did not appear to be large areas of suitable habitat on private land. They reported few outcrops of the Dry Union Formation or other clay barrens that would be suitable for *E. brandegeei* on unsurveyed private lands. If other occurrences remain undocumented, they are probably small since very little unsurveyed habitat remains for this species (Spackman and Floyd 1996, Coles personal communication 2004).

Areas with the highest likelihood of new occurrences are those with the appropriate bentonite substrate in the immediate area of the known occurrences. As noted by Coles (personal communication 2004), land ownership boundaries in the species' range are complicated, and there are numerous fences that complicate searches. When willing landowners are identified, the opportunity should be taken to search for the species on their property.

Further effort is needed to determine the location of *Eriogonum brandegeei* in Raspberry Gulch and to determine if it falls within the San Isabel National Forest (Johnston personal communication 2004). It remains uncertain whether suitable habitat exists at this location. Additional searches near Jefferson in Park County (where it was reportedly collected by Kelly) and at Colorado Springs are not worthwhile because there is little appropriate habitat in those areas.

*Eriogonum brandegeei* could benefit from inventory and mapping using Global Positioning

System technology to increase the precision of occurrence boundaries. This would provide land managers with data to support land use planning and permitting decisions. The value of such a project would be enhanced by the collection of systematic population estimates and ecological data. The best time to conduct surveys for *E. brandegeei* is from July to mid-August when it is flowering most profusely, but it could also be sought in winter when snow is absent since its purple color is very conspicuous at that time (Johnston personal communication 2004).

Systematic population counts or estimates, as have been conducted for several rare *Eriogonum* species including *E. codium* and *E. gypsophila* (Reveal personal communication 2004), are needed to obtain a better determination of the population size. The cost and human resources required to count plants depend on occurrence size and the methods used. For some species, such as *E. ovalifolium* var. *williamsiae*, a census is difficult because they proliferate actively via fragmentation; hence defining individuals is nearly impossible (Archibald et al. 2001, Reveal personal communication 2004). Preliminary information on *E. brandegeei* suggests that similar difficulties may occur with this species (Grant and DePringer-Levin 2005). The use of quantitative sampling techniques, as described by Bullock (1996), would help to develop a better understanding of the conservation status of this species.

Aerial photography, topographic maps, soil maps, and geology maps can be used effectively to refine surveys of large areas for *Eriogonum brandegeei*. These tools are most effective for species about which we have basic knowledge of substrate and habitat specificity, and from which distribution patterns and potential search areas can be deduced.

Searches for *Eriogonum brandegeei* could be aided by predictive distribution modeling using deductive and inductive techniques. The availability of fine-scale Geographic Information System data with high predictive value for *E. brandegeei* (e.g., Colorado Division of Wildlife 2003) suggests that these techniques would generate useful models for guiding and focusing future surveys. Species distribution modeling is an effective means of determining the extent of suitable habitat on National Forest System lands. Techniques for predicting distributions of species are reviewed extensively by Scott et al. (2002). Habitat modeling has been done for other sensitive plant species in Colorado (Decker et al. 2005), and these methods would apply to *E. brandegeei* as well. In the case of *E. brandegeei*,

the value of modeling as a heuristic tool for hypothesis generation for the autecology of *E. brandegeei* may outweigh the potential benefit from predicting species distributions in most of its range. However, model outputs may be valuable in any possible efforts to verify the report of *E. brandegeei* from Raspberry Gulch.

### *Population monitoring*

Population monitoring has been recommended for *Eriogonum brandegeei* to detect population trends (Johnston et al. 1981). Demographic monitoring is ongoing at two sites at Garden Park (Garden Park West and Garden Park East) and at Cleora (Grant and DePringer-Levin 2005). The goals of this study are to quantify demographic variables for *E. brandegeei* (including reproduction, recruitment, and longevity) and to assess the impacts of fungal rust and off-road vehicle disturbance on population viability. Scoping for suitable permanent plot sites occurred in 2001, 2003, and 2004 (Dawson personal communication 2004, Grant personal communication 2004, Grant and DePringer-Levin 2005), and population monitoring was conducted in 2004 and 2005. Grant and DePringer-Levin (2005) include an appendix in which the setup and protocols for monitoring this species are described; these are summarized briefly here.

At each of three sites, a 20 x 30 meter macroplot was established with the long side running perpendicular to the slope to minimize trampling and erosion impacts to the site. Each macroplot contains five randomly placed belt transects (0.5 m wide), which also run perpendicular to the slope. However, power analyses revealed that more transects are needed. Within each belt transect, all rosettes are counted and marked sequentially. The species' apparent tendency to produce clonal rosettes and its clumped distribution makes it difficult to be certain that rosettes represent individual plants. Grant and DePringer-Levin (2005) developed methods of dealing with this problem.

During annual visits, data are gathered for each marked plant, which will be used to determine vital rates and population viability. Grant and DePringer-Levin include a measure of basal area, determined by two perpendicular measurements taken across the basal portion of the plant and using the formula for an ellipse used as a measure of size; life history stage (i.e., seedling, vegetative, reproductive); fecundity, the number of inflorescences per plant; and evidence of rust or browsing. Recruitment within each belt transect can be quantified by counting seedlings.

Other stratified-random sampling designs (discussed in Elzinga et al. 1998) are also suitable for monitoring populations of *Eriogonum brandegeei*. A new monitoring program that addresses recruitment, seed production, seed and plant longevity, population variability, and pollinators would generate additional data useful to managers and the scientific community.

The most sensitive measure of population change will be gleaned from recruitment success, which may not be difficult to determine for *Eriogonum brandegeei* since it is found in barren sites with few other species. Suitable methods for monitoring pollinators are discussed in Kearns and Inouye (1993) and have been employed by Spackman Panjabi (2004). 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).

To document important demographic parameters (mainly seedlings and fruit set), two visits per growing season may be required, one in early spring and one in late August or early September. A monitoring program for *Eriogonum brandegeei* targeting robust populations in both natural and anthropogenic settings could incorporate an investigation of human impacts such as recreation and grazing. Monitoring sites under a variety of land use scenarios will help to identify appropriate management practices for *E. brandegeei* and will help to understand its population dynamics and structure.

Resampling of monitoring plots annually will be necessary at first to understand the population dynamics of *Eriogonum brandegeei*. Since *E. brandegeei* is a slow growing, long-lived perennial, it may be determined later that monitoring every two years or more is sufficient. However, this may result in missing a major recruitment event if a particularly favorable year is skipped.

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. Data from several years of such monitoring could provide insight into the rate of change among the life history stages of seeds, seedlings, juveniles, and reproductive individuals and would provide data from which transition probabilities could be determined. Such data would also yield insight into the longevity, fecundity, seed bank dynamics, annual growth rate, and recruitment rate of *E. brandegeei* and

permit the use of modeling to determine critical life history stages, minimum viable population size, and probability of extinction.

Several methods of monumentation are recommended in Elzinga et al. (1998) depending on the site physiography and frequency of human visitation to the site. This is an important consideration that will reap long-term benefits if done properly at the outset of the monitoring program. Monumentation will be somewhat challenging given the steep, unstable substrates where most occurrences of *Eriogonum brandegeei* are found. Large galvanized nails are being used to mark individuals in monitoring plots at Garden Park and Cleora, but demographic monitoring efforts were aborted at Cleora in 2005 due to trouble with monumentation and concern for the impacts of monitoring activities (Grant and DePringer-Levin 2005).

Estimating cover and/or abundance of associated species within the plots described above would help to describe the interspecific relationships through ordination or other statistical techniques. In very sparsely vegetated plots, this can be done using appropriate cover classes or subdivided quadrat frames. Understanding environmental constraints on *Eriogonum brandegeei* would facilitate the development of beneficial management practices for this species. Gathering data on slope, aspect, and soil characteristics (particularly moisture and texture) from the permanent plots described above would permit the 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, as recommended by Elzinga et al. (1998), could facilitate the tracking of individuals and add valuable qualitative information. A handbook on photo point monitoring (Hall 2002) provides guidance 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.

### *Habitat monitoring*

Habitat monitoring in the absence of *Eriogonum brandegeei* individuals could be conducted on sites within the known distribution with suitable geologic substrate and vegetation. For *E. brandegeei* occurrences, habitat monitoring should be conducted concurrently with population monitoring. Documenting habitat attributes, disturbance regime, and associated

species during all monitoring visits will improve our understanding of its habitat requirements and management needs. This could be incorporated into the field forms used for the population sampling regimen described above. Habitat monitoring of known occurrences will alert managers of new threats, such as weed infestations and damage from motorized vehicle use or grazing. Changes in environmental variables might not cause observable demographic repercussions for several years, so resampling the chosen variables may help to identify underlying causes of population trends. Evidence of current land use practices are 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 changes in existing impacts. For estimating weed infestation sizes, using broad abundance classes helps to reduce the effects of observer bias. 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*

Due to the erodible soils, the barren nature of its habitat, and its proximity to large human populations, *Eriogonum brandegeei* is vulnerable to recreational uses. Any management actions that limit recreational impacts will confer benefits to this species. The BLM has taken several significant steps towards this end, but as noted previously in this assessment, the enforcement of off-road vehicle regulations and road closures is challenging (Brekke personal communication 2004). An ongoing commitment to fix and maintain gates and fences is needed (The Nature Conservancy 2001). Assessment of other problematic areas will likely identify additional occurrences that will benefit from road closures, gates, and fences. The Nature Conservancy (2001) cited the conservation needs of *E. brandegeei* as a reason to locate recreational infrastructure so as to ensure that it does not impact rare plants.

The development of public appreciation and support for the conservation of *Eriogonum brandegeei*, particularly among local residents (as recommended for the recovery of *E. gypsophilum* by Limerick 1984) would help to alleviate some of the misuse of the clay barrens. The Bureau of Land Management has taken steps toward this end at Garden Park (**Figure 12**).

The establishment of protected areas managed for the conservation of *Eriogonum brandegeei* is an



**Figure 12.** Educational sign about *Eriogonum brandegeei* at Garden Park, Fremont County, Colorado, installed by the Bureau of Land Management. Photograph provided by Susan Spackman Panjabi, used with permission.

important conservation tool for this species. Two areas, Garden Park and Droney Gulch, already benefit from their status as Areas of Critical Environmental Concern (ACEC) and State Natural Areas. Droney Gulch was designated specifically for the conservation of *E. brandegeei*, a consideration that has been given to relatively few rare plant species. Because the area occupied by *E. brandegeei* is so small, these areas do not need to be particularly large. However, including some surrounding areas within designated protected areas to buffer potential impacts to habitats for *E. brandegeei* may be needed. At Droney Gulch, additional areas outside the known extent of *E. brandegeei* were included within the ACEC to ensure the protection of the outwash cap. All other occurrences, particularly those at Cleora and Loggie Gulch, are in need of land protection to ensure their long-term viability.

There are several approaches that are likely to be effective in conserving occurrences, particularly if all the available options are utilized. Designation of an ACEC for the Cleora and Loggie Gulch areas is warranted given the ongoing impacts to these sites. ACEC designation for populations was among the recommendations for the recovery of *Eriogonum gypsophilum* (Limerick 1984). Bringing sites on private land into public

ownership through land exchange or purchase could also protect occurrences from residential development. Similarly, consideration of land exchanges involving sites that are currently on public land would not be beneficial to *E. brandegeei*. Conservation easements and other land trust activities would be a useful tool for protecting occurrences on private land. Purchasing conservation easements on small properties may confer significant benefits to the conservation of *E. brandegeei* since its occurrences and habitat are naturally insular and limited in size. Purchase of land or conservation easements by County Open Space Programs, such as Fremont County is developing, would also be a useful conservation tool. The conservation of *E. brandegeei* would be an appropriate goal to include in county and city planning efforts. Management plans are needed for Garden Park (The Nature Conservancy 2001) and Droney Gulch ACECs/State Natural Areas that address the conservation needs of *E. brandegeei*.

Given the potential threats to *Eriogonum brandegeei* and its habitat from exotic species, aggressive management of weeds in and near *E. brandegeei* occurrences is a high priority for its conservation. Any management strategies that work to prevent weed infestation of occurrences of *E.*

*brandegeei* are likely to confer the greatest benefits. Although mowing and weed control have the potential to negatively impact some occurrences of *E. brandegeei*, right-of-way management practices can be modified to mitigate these impacts. Hand pulling weeds where possible and appropriate probably has the least impact on *E. brandegeei*. Limiting the use of herbicides within occurrences of *E. brandegeei* to direct application to target species will mitigate the loss of plants due to overspray and indiscriminate application. Avoiding right-of-way mowing in *E. brandegeei* occurrences from June until late August or September (after fruits have dried and seeds are released) is also likely to be beneficial. Colorado Natural Heritage Program data on the distribution of this species in right-of-ways are provided to the Colorado Department of Transportation to assist with avoiding impacts to occurrences. Surveys of areas in question by someone who is familiar with *E. brandegeei* will help to prevent impacts to occurrences during road projects such as utility line installation and road widening.

Managing for pollinators is likely to benefit *Eriogonum brandegeei* as residential development decreases the amount of natural habitat available. Appropriate management of natural vegetation near occurrences of *E. brandegeei* is likely to benefit pollinators and may improve the likelihood of persistence for currently undocumented occurrences. Incorporating native plantings and native bee nesting boxes into landscape designs as recommended in Buchmann and Nabhan (1996) will help to ensure that pollinator services are available to *E. brandegeei*. There have been no active population or habitat management efforts on behalf of *E. brandegeei*.

Although direct impacts to *Eriogonum brandegeei* from livestock are probably limited, management practices that reduce the impacts from grazing are likely to contribute greatly to the achievement of conservation goals for this species. Research is needed to identify grazing regimes that are compatible with *E. brandegeei*. The best approach to determining the impacts from grazing is to incorporate grazed and ungrazed areas into a monitoring protocol, as recommended among the recovery steps for the federally listed species *E. gypsophilum* (Limerick 1984). The use of exclosures to prevent access by livestock to portions of occurrences susceptible to erosion would probably have little effect on available forage in a given grazing allotment since the barren sites where *E. brandegeei* is typically found have very low forage value. Maintaining livestock stocking rates at suitable levels will most likely prevent impacts to *E. brandegeei* from grazing. Because of

the poor forage value that is typical of *E. brandegeei* occurrences, livestock are unlikely to venture into significant portions of occurrences unless stocking rates become so high as to force animals onto this less productive range. Monitoring grazing impacts to pinyon-juniper woodlands near *E. brandegeei* occurrences will be important to ensure that erosion does not increase and result in degradation of adjacent slopes that support *E. brandegeei*.

Although as much as 80 percent of the known habitat in the Arkansas Valley has been searched (Colorado Natural Heritage Program 2005), additional areas (cited in the Tools and practices section of this assessment) have not been thoroughly searched. Because occurrences of *Eriogonum brandegeei* may remain to be documented, conducting surveys within project areas will help to ensure that impacts to this species resulting from human activities are minimized.

The establishment of a monitoring program (as recommended for the recovery of *Eriogonum gypsophilum* by Limerick 1984) would benefit *E. brandegeei* by providing information on its population biology and threats that would help to develop better management protocols and conservation priorities. Studying its population genetics and autecology would have similar benefits from a management perspective and provide valuable scientific data. Continuing the work, started in 2000 by Anderson et al. (2001), to monitor occurrences at Droney Gulch and Garden Park would provide information on the invasiveness of specific weed species and determine the impacts of these species on *E. brandegeei* and its habitat.

#### *Seed banking*

No seeds or genetic material are currently in storage for *Eriogonum brandegeei* at the National Center for Genetic Resource Preservation (Miller personal communication 2004). It is not among the National Collection of Endangered Plants maintained by the Center for Plant Conservation (Center for Plant Conservation 2003). Collection of seeds for long-term storage will be useful if restoration work is ever necessary.

### ***Information Needs***

Life cycle, habitat, and population trend

Specific research on *Eriogonum brandegeei* is needed to understand its population ecology. Although some inferences can be made from other taxa, they do



not take the place of basic research on *E. brandegeei*. Information on vital rates and other variables (e.g., safe sites, seed viability, seed germinability on different substrates including non-calcareous soils) would help to establish basic life history parameters that would be useful in restoration efforts and in developing population models.

Although basic descriptive information is available for the habitat of *Eriogonum brandegeei*, more detailed information is needed. Information on the ecological amplitude of *E. brandegeei* with respect to soil texture, soil moisture, nutrient concentrations, and disturbance would be useful to scientists and land managers, and it is needed to more fully understand the species-environment relationships for *E. brandegeei*. Investigating possible spatial autocorrelation with other species may help to determine underlying ecosystem processes. Autecological research is needed to help refine our definition of appropriate habitat and to facilitate effective habitat monitoring and conservation stewardship of this species.

The population trend of *Eriogonum brandegeei* is not known and may be difficult to quantify given its long life and episodic recruitment. Lack of access to many occurrences on private land will further complicate this research. However, understanding the population biology of *E. brandegeei* is important for appropriate stewardship and management of this species.

#### Response to change

Preliminary work on the reproductive biology of *Eriogonum brandegeei* has set the stage for a more rigorous study. Although the research of Spackman Panjabi (2004) revealed basic information about the insect visitors of *E. brandegeei*, research is needed to determine which species are most effective as pollinators, and the various roles other insect visitors play in the floral biology of *E. brandegeei*. Changes in the levels of residential development and infrastructure in the habitat of *E. brandegeei* may decrease the availability and diversity of pollinators, and pollinators capable of residing 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 *E. brandegeei*.

The impact of exotic species on *Eriogonum brandegeei* is not known. At least two exotic species are found in *E. brandegeei* occurrences, but their invasiveness of clay barrens is not known and it is not known if they are negatively impacting *E. brandegeei*.

Determining these factors will help managers to assign appropriate priority levels to weed management efforts on behalf of *E. brandegeei*.

Understanding the specific responses of *Eriogonum brandegeei* to disturbance is important for determining compatible land management practices, but its resilience to natural and human disturbance (particularly recreation and grazing) has not been studied. Because *E. brandegeei* is a long-lived perennial, population level responses to environmental impacts may be somewhat slow (see the Reproductive biology and ecology section of this document for further discussion of disturbance).

#### Research priorities for Region 2

A rigorous determination of the abundance of *Eriogonum brandegeei* in Region 2 using quantitative methods is needed; available data are somewhat incongruous and speculative. Limited species inventory work is also needed (see the Species and habitat inventory section under Tools and practices in this assessment for details).

Understanding the influence of human activities, including grazing, on individuals and habitat of *Eriogonum brandegeei* will confer substantial practical benefits for land managers and planners. Identifying life history and phenological stages when *E. brandegeei* is less sensitive to grazing impacts would greatly help managers to mitigate threats by developing grazing practices that are compatible with *E. brandegeei*. Exploring the effects of different stocking rates, timing of grazing, and resting pastures is likely to yield valuable information. Documenting the impacts of herbivory by cattle, deer, and other herbivores (possibly mice and sheep) on *E. brandegeei* is needed to monitor the status of the species. Grant and DePringer-Levin (2005) may investigate the impacts of off-road vehicle use at Cleora as a part of their demographic monitoring efforts; this could provide valuable information to support management decisions regarding off-road vehicle use. Monitoring the impact of non-native species on *E. brandegeei* will help to assess the importance of weed management for the conservation for this species. Continuing the monitoring established by Anderson et al. (2001) at Garden Park and Droney Gulch and conducting similar monitoring elsewhere will help managers to mitigate impacts from exotic species by identifying problem species and infestations.

Studies of the habitat requirements and autecology of *Eriogonum brandegeei* are needed. Information

gleaned from studies of the physiological and community ecology of *E. brandegeei* will be valuable in the event that a population needs to be restored. Such information will also help to determine biotic and abiotic factors that contribute to this species' survival. Understanding the plant-environment relationship for *E. brandegeei* will be insightful in understanding the coping strategies employed by this species, modeling its potential distribution, and understanding the causes of its rarity. Examination of hypotheses regarding the causes of endemism and rarity in *E. brandegeei* will help to gain an understanding of management practices, locations for further searching, and potential reintroduction sites. The role of disturbance in the autecology of *E. brandegeei* remains poorly understood. An understanding of the specific tolerances of *E. brandegeei* to different human and natural disturbance regimes will assist with developing conservation strategies and management plans by determining the levels of disturbance most likely to negatively impact it.

Demographic studies are needed for *Eriogonum brandegeei*. The continuation of demographic monitoring initiated in 2004 (Grant and DePringer-Levin 2005) is a high priority for the conservation of *E. brandegeei*. 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 *E. brandegeei* will allow managers to focus their efforts on implementing management protocols that benefit those stages. Determining the effective population size and vital rates of *E. brandegeei* will have considerable practical value and will help to determine its conservation status. In 2006, Grant and DePringer-Levin plan to analyze soils for the presence of *E. brandegeei* seeds to investigate the possible existence of a seed bank, and to continue demographic monitoring (Grant and DePringer-Levin 2005).

An investigation of the population genetics of *Eriogonum brandegeei* would be a valuable tool for its conservation. The determination of its genetic diversity and whether there are genetic differences among occurrences is an important question to answer for *E. brandegeei*. Although preliminary research has been conducted by Spackman Panjabi (2004), further study of the role of pollinators in the population biology of *E. brandegeei* is needed to understand the relative importance of floral visitors in pollen transfer.

#### Additional research and data resources

A forthcoming volume of the Flora of North America will include a treatment of *Eriogonum* by James Reveal that was not available for inclusion in this assessment.

## DEFINITIONS

**Allopolyploid** – a polyploid formed from the union of genetically distinct chromosome sets, usually two different species (Allaby 1998).

**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 Presumed Extinct: Not located despite intensive searches and virtually no likelihood of rediscovery.
- GH Possibly Extinct: Missing; known only from historical occurrences but still some hope of rediscovery.
- G1 Critically Imperiled: At high risk of extinction due to extreme rarity (often 5 or fewer occurrences), very steep declines, or other factors.
- G2 Imperiled: At high risk of extinction due to very restricted range, very few populations (often 20 or fewer), steep declines, or other factors.
- G3 Vulnerable: 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 Apparently Secure: Uncommon but not rare; some cause for long-term concern due to declines or other factors.
- G5 Secure: Common; widespread and abundant.

**Competitive/Stress-tolerant/Ruderal (CSR) model** – a model developed by J.P. Grime in 1977 in which plants are characterized as Competitive, Stress-tolerant, or Ruderal, based on their allocation of resources. Competitive species allocate resources primarily to growth; stress-tolerant species allocate resources primarily to maintenance; and ruderal species allocate resources primarily to reproduction. A suite of other adaptive patterns also characterizes species under this model. Some species show characteristics of more than one strategy (Barbour et al. 1987).

**Ecophene** – the morphological response of a phenotypically plastic species to environmental variation (after Cole 1967).

**Ecotype** – the morphological expression of a unique genotype that is adapted to particular habitat attributes (after Allaby 1998).

**Ocrea** – a sheath around the stem formed from the stipules that is common throughout most of the Polygonaceae, but absent in *Eriogonum* (Harris and Harris 1999).

**Potential Conservation Area (PCA)** – 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 2000). They are ranked as follows based on their biodiversity significance:

- B1 Outstanding Significance: Only location known for an element or an excellent occurrence of a G1 species.
- B2 Very High Significance: One of the best examples of a community type, good occurrence of a G1 species, or excellent occurrence of a G2 or G3 species.
- B3 High Significance: Excellent example of any community type, good occurrence of a G3 species, fair occurrence of a G2 species, or a large concentration of good occurrences of state-rare species.
- B4 Moderate or Regional Significance: Good example of a community type, fair occurrences of a G3 species, excellent or good occurrence of state-rare species.
- B5 General or State-wide Biodiversity Significance: Good or marginal occurrence of a community type, S1, or S2.

**Stomata (plural for Stomate)** – a pore or aperture, surrounded by two guard cells that allows gaseous exchange (Harris and Harris 1999).

**Tomentum** – a covering of short, soft, matted, wooly hairs (Harris and Harris 1999).

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