Boechera crandallii (B.L. Robinson) W.A. Weber (Crandall's rockcress): A Technical Conservation Assessment

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

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COVER PHOTO CREDIT

Boechera crandallii (Crandall's rockcress). Photograph by Barry C. Johnston, USDA Forest Service.

SUMMARY OF KEY COMPONENTS FOR CONSERVATION OF *BOECHERA CRANDALLII*

Status

Boechera crandallii (Crandall's rockcress) is a regional endemic of west-central Colorado and southwestern Wyoming. The NatureServe Global rank for this species is imperiled (G2). It is designated imperiled (S2) by the Colorado Natural Heritage Program and critically imperiled (S1) by the Wyoming National Diversity Database. The Bureau of Land Management Colorado State office lists it as sensitive. In the evaluation of species for the 2003 Region 2 Regional Forester's Sensitive Species list, it was determined that there was insufficient information to recommend *B. crandallii* for sensitive species status.

Primary Threats

Habitat loss is a substantial threat to this species. Extrinsic factors such as resource extraction, activities associated with recreation, road development, and grazing are the primary range-wide threats to *Boechera crandallii*. Invasion of habitat by non-native species is also a source of concern. The species is likely only moderately competitive and may be out-competed by non-native plant species. Occurrences on land managed by the USDA Forest Service Region 2 are likely to be most vulnerable to invasive weeds encroaching their habitat, activities associated with recreation, campground and road improvement, and livestock grazing. Details of imminent threats to specific occurrences are unavailable. Long-term population sustainability may be vulnerable to declines in pollinator populations. Actions that substantially reduce the numbers of individuals within a population may exacerbate the potential for inbreeding depression that would reduce population viability.

Primary Conservation Elements, Management Implications and Considerations

Boechera crandallii is a species endemic to west-central Colorado and southwestern Wyoming. Although it is a rare species on a regional scale, it can be locally abundant within suitable habitat. The possibility that *B. pallidifolia* has been misidentified as *B. crandallii* raises concerns that *B. crandallii* is less common than currently estimated. No management plans currently exist that directly address *B. crandallii*. *Boechera crandallii* is susceptible to *Puccinia* (fungus) infection that can potentially reduce vigor and fecundity. At historical, or even evolutionary, levels this infection is unlikely to be of concern. However, additional stresses to a plant, for example grazing pressure or disturbance from off-road vehicles, may exacerbate its susceptibility and cause significant harm to a population. The consequences of inbreeding depression may become a significant threat if populations experience significant declines in size or range. Because there appears to be little genetic diversity within populations, loss of isolated populations will reduce the genetic diversity within the species.

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INTRODUCTION

This assessment is one of many being produced to support the Species Conservation Project for the Rocky Mountain Region (Region 2), USDA Forest Service (USFS). *Boechera crandallii* is the focus of an assessment because it is a regional endemic species of west-central Colorado and southwestern Wyoming (Spackman et al. 1997). It is not designated a sensitive species for Region 2 or for any other region within the National Forest System, but its rarity and narrow geographic range suggest that its status and vulnerability need to be evaluated. According to Forest Service Manual 2670.5(19), 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. A sensitive species may require special management, so knowledge of its biology and ecology is critical. In the evaluation of species for the 2003 Region 2 Regional Forester Sensitive species list it was determined that there was insufficient information to recommend *B. crandallii* for sensitive species status (Fertig 2002). This species is listed as sensitive by the Bureau of Land Management (BLM) Colorado State Director (USDI Bureau of Land Management Colorado 2000).

Members of the genus *Boechera* have been long considered members of the genus *Arabis* (see Systematics and synonymy section for more detail). Most North American species of *Arabis* have recently been transferred to *Boechera* (Al-Shehbaz 2003). Therefore, much of the literature relevant to *B. crandallii* refers to the *Arabis* genus. In the Systematics and synonymy section of this document, the genus used in the original publication is the one to which this document refers. Otherwise, for consistency, *Boechera* rather than *Arabis* has been used in almost all cases throughout this assessment, whatever the name in the original document.

Goal

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 scientific knowledge accumulated prior to initiating the assessment. 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, it cites management recommendations proposed elsewhere and examines the success of those recommendations that have been implemented.

Scope

This *Boechera crandallii* assessment examines the species' biology, ecology, conservation, and management with specific reference to the geographic and ecological characteristics of the USFS Rocky Mountain Region. Although some of the relevant literature may originate from field investigations outside the region, this document places that literature in the ecological and social context of the central and southern Rocky Mountains and surrounding lands. Similarly, this assessment is concerned with reproductive behavior, population dynamics, and other characteristics of *B. crandallii* in the context of the current environment rather than under historical conditions. The evolutionary environment of the species is considered in conducting this synthesis, but placed in a current context.

In producing the assessment, the refereed (peer-reviewed) literature, non-refereed (not peer-reviewed) publications, research reports, and data accumulated by resource management agencies were reviewed. Not all publications on *Boechera crandallii* may have been referenced in the assessment, but an effort was made to consider all relevant documents. The assessment emphasizes the refereed literature because this is the accepted standard in science. Some non-refereed literature was used in the assessment because information was unavailable elsewhere. In some cases, non-refereed publications and reports may be regarded with greater skepticism. However, many reports or non-refereed publications on rare plants are often 'works-in-progress' or isolated observations on phenology or reproductive biology and are important sources of information. For example, demographic data may have been obtained during only one year when monitoring plots were first established. Insufficient funding or manpower may have prevented work in subsequent years. One year of data is generally considered inadequate for publication in a refereed journal but still provides a valuable contribution to the knowledge base of a rare plant species. Unpublished data (e.g., Natural Heritage Program and herbarium records) were important in estimating the geographic distribution and occurrence sizes for this species. These data required special attention because of the diversity of persons and methods used in their collection. Records that were associated with locations at which herbarium specimens had been collected at some point in time were weighted higher than observations only.

Treatment of Uncertainty

Science represents a rigorous, systematic approach to obtaining knowledge. Competing ideas regarding how the world works are measured against observations. However, because our descriptions of the world are always incomplete and our observations are limited, science focuses on approaches for dealing with uncertainty. A commonly accepted approach to science is based on a progression of critical experiments to develop strong inference (Platt 1964). However, strong inference, as described by Platt, suggests that experiments will produce clean results (Hillborn and Mangel 1997), as may be observed in certain physical sciences. The geologist, T.C. Chamberlain (1897), suggested an alternative approach to science where multiple competing hypotheses are confronted with observation and data. Sorting among alternatives may be accomplished using a variety of scientific tools (e.g., experiments, modeling, logical inference). Ecological science is, in some ways, more similar to geology than physics because of the difficulty in conducting critical experiments and the reliance on observation, inference, good thinking, and models to guide understanding of the world (Hillborn and Mangel 1997).

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. While well-executed experiments represent a strong approach to developing knowledge, alternative approaches such as modeling, critical assessment of observations, and inference are accepted approaches to understanding.

There are two related elements of uncertainty for *Boechera crandallii*. The first is that there is the suggestion that *B. crandallii* should be placed in synonymy with *B.* (*Arabis*) *pallidifolia* (Johnston personal communication 2004). *Boechera pallidifolia* is sympatric with *B. crandallii*, and some of the characteristics that distinguish *B. crandallii* from *B. pallidifolia* are variable or difficult to determine on herbarium specimens (Johnston personal communication 2004). Genetic variation in some morphological characteristics can be confounded by environmental influences on phenotype (Hamrick 1989). Although alone they may not provide a definitive answer, studies at the biochemical and molecular level might be needed to help resolve the issue. This sympatric occurrence of a morphologically similar species, *B. pallidifolia*, can lead to misidentification in the field, which can result in inaccurate estimates of abundance and habitat requirements of both taxa. While every effort is made to avoid such inaccuracies, the possibility that some data actually refer to *B. pallidifolia* should be recognized. Where appropriate, the potential for inaccurate information has been noted in this assessment.

Publication of Assessment on the World Wide Web

To facilitate use of species assessments in the Species Conservation Project, they are being published on the Region 2 World Wide Web site. Placing the documents on the Web makes them available to agency biologists and the public more rapidly than publishing them as reports. More important, it facilitates their revision, which will be accomplished based on guidelines established by Region 2.

Peer Review

Assessments developed for the Species Conservation Project have been peer reviewed prior to release on the Web. This report was reviewed through a process administered by the Society for Conservation Biology, employing at least 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

Boechera crandallii is a regional endemic of west-central Colorado and southwestern Wyoming. The NatureServe (2003) Global[1] rank for this species is imperiled (G2). It is designated imperiled (S2) by the Colorado Natural Heritage Program and critically imperiled (S1) by the Wyoming National Diversity

[1]For definitions of "G" and "S" ranking see "Rank" in the "Definitions" section at the end of this document.

Database (NatureServe 2003). It is listed as sensitive by the BLM Colorado State Director (USDI Bureau of Land Management Colorado 2000) but not by the BLM Wyoming State Director (USDI Bureau of Land Management Wyoming 2002). Marriott (2003) recommended that *B. crandallii* be added to the BLM Wyoming State Director's Sensitive Species list because of the high conservation priority status, G2S1, awarded it by the NatureServe Network and also because one of its few occurrences in Wyoming is at risk from mining activity.

Existing Regulatory Mechanisms, Management Plans, and Conservation Strategies

In Colorado, *Boechera crandallii* occurs on private lands as well as on land managed by the BLM, the National Park Service (Black Canyon of the Gunnison National Monument), and the USFS (Pike-San Isabel and Gunnison national forests). *Boechera pallidifolia* is known to occur on the White River National Forest, and because this species can be mistaken for *B. crandallii*, it is prudent to consider that *B. crandallii* might occur on that national forest as well. *Boechera crandallii* is not listed as a sensitive species for USFS Region 2 (USDA Forest Service Region 2 2003). In the evaluation of species for the 2003 Region 2 Regional Forester Sensitive species list it was determined that there was insufficient information to recommend *B. crandallii* for sensitive species status (Fertig 2002). There are no plans that specifically address the management of *B. crandallii*, but it is included by name in a document outlining general management strategy for selected sensitive plant species on the Grand Mesa, Uncompahgre, Gunnison, San Juan, Rio Grande, Pike and San Isabel national forests (USDA Forest Service GMUG, SJ-RG and PISCC 1999). *Boechera crandallii* (as *Arabis crandallii*) is listed on the Colorado BLM State Director's Sensitive Species list (USDI Bureau of Land Management Colorado 2000).

Some occurrences of *Boechera crandallii* in Colorado are relatively secure because they occur in areas that are afforded protection by land use designation, for example in the Buffalo Peaks Wilderness Area (**Table 1**; Orthner 1999). Wilderness is defined in the law as "an area of undeveloped Federal land retaining its primeval character and influence, without permanent improvements or human habitation, which is protected and managed so as to preserve its natural conditions" (Environmental Media Services 2001). Although Congress has granted exemptions, in general, commercial activities, motorized access, roads, bicycles, structures, and facilities are prohibited in Wilderness areas. In addition, the size of visitor groups may be limited in some circumstances.

In Wyoming, all known occurrences of *Boechera crandallii* are located within the boundaries of public lands managed for multiple use or in the intervening sections of private land (Fertig et al. 1998). It occurs within the Wyoming portion of the Flaming Gorge National Recreation Area, which is under the management of the Ashley National Forest (USDA Forest Service - Region 4). *Boechera crandallii* is not on the USDA Forest Service - Region 4 Sensitive Plant Species list, but it is currently being considered for inclusion on a revised list (Goodrich personal communication 2003). Management plans have not been designed to specifically address its management on National Forest System land (Houston personal communication 2003), but several formal surveys that have targeted rare or endemic species, including *B. crandallii*, have been conducted (Fertig et al. 1998, Elliott and Hartman 2000).

Biology and Ecology

Classification and description

Systematics and synonymy

Arabis is a genus of the Brassicaceae, commonly known as the mustard family. Löve and Löve (1975) proposed the genus *Boechera* to differentiate *Arabis* species with a chromosome base number of 7 from those with a base number of 8. Weber (1982) further emphasized this distinction by defining morphological characters that described *Boechera* to include short clustered caudices, small or absent and almost always entire leaves on the flowering stem, and often very dense forked or star-shaped (stellate) hairs covering the herbage.

The taxonomic position of *Arabis* and *Boechera* has recently been resolved. Al-Shehbaz (2003) transferred all but approximately 10 North American *Arabis* species to *Boechera*. Unpublished DNA sequence data show that about 40 taxa from within *Arabis* form a monophyletic *Boechera* clade (Mitchell-Olds personal communication 2003). This work, which is a collaborative project between Ihsan Al-Shehbaz, Marcus Koch, and Thomas Mitchell-Olds, is to be published within the next few years and is likely to provide more support to the separation of *Boechera* from *Arabis*.

Table 1. Occurrence data for *Boechera crandallii* in Colorado.

Arbitrary number	County	Dates observed	Management	Site	Source of information[1]
1	Gunnison	April 1898, pre-1941, June 1983	Bureau of Land Management (BLM) or private	East of Sapinero and on hill extending above town and east of town	*Wheeler 596* 1898 COLO, *Rollins 2111* Harvard in Rollins (1941), *Rollins 8374* 1983 CSU & COLO
2	Gunnison	May 1952, June 1953	BLM or private (may now be in Blue Mesa Reservoir)	Gunnison River Canyon, west of Sapinero	*Weber 7461* 1952 COLO, *Penland 4377* 1953 COLO
3	Gunnison	July 1992, May 1997	National Park Service, BLM, and private	Sapinero	USDA Forest Service (2003 transect data)
4	Gunnison	May and June 1997	BLM, private, and National Park Service	Sapinero, Carpenter Ridge area	USDA Forest Service (2003 transect data)
5	Gunnison	August 1994	BLM	Carpenter Ridge - East	USDA Forest Service (2003 transect data)
6	Gunnison	June 1985	BLM or private	Approximately 4 miles north-northwest of junction between Gunnison River and Indian Creek	*Baker 8564* CSU
7	Gunnison	June 1978, May 1981	BLM or private	South Beaver Creek southwest of Gunnison	*Ratzloff s.n.* 1978 COLO, *Johnston 2392* 1981 COLO
8	Saguache	July 1998	BLM	Razor Creek Dome	USDA Forest Service (2003 transect data)
9	Chaffee	June 1995	San Isabel National Forest	Mosquito Range - slope leading to Marmot Peak	*Hogan 2589 with Yeatts* COLO
10	Park	June 1998	Buffalo Peaks Wilderness Area, Pike National Forest	Mosquito Range - near Weston Pass Campground	*Orthner 483* COLO, Orthner (1999)
11	Delta	May 1997	BLM	Young's Peak area near Crawford	*Hartman 56688 with Taylor* COLO
12	Gunnison	June 1997	BLM or State	Northern Gunnison Basin: West of Gunnison	*Taylor 929* COLO
13	Gunnison	pre-1941, May 1979	Unknown (possibly Gunnison National Forest, private, BLM, or State)	East of Gunnison	*Rollins 7952 with K. Rollins* 1979 COLO. Specimen at Harvard Herbaria (GH) in Rollins (1941)
14	Gunnison	pre-1941	Unknown	South of Iola	Specimen at Harvard Herbaria in Rollins (1941)
15	Gunnison	May 1979	Unknown (possibly BLM, private, or State)	Off Gunnison River Canyon, 17 to 18 miles west of Gunnison	*Rollins 7969 with K. Rollins* COLO
16	Montrose	May 1997	BLM (may extend into private)	Northern Gunnison Basin, Cimarron Point area	*Hartman 56208 with Taylor* COLO
17	Montrose	May 1898, 1901	Unknown	1898: Cimarron 1901: "Cimarrons"	*Baker 21* 1901 NY (Isotype) Specimen at Harvard Herbaria in Rollins (1941)
18	Grand (Eagle)	pre-1941	Unknown	Gore Canyon	Specimen at NY, RM in Rollins (1941)
19	Rio Blanco	May 1976	Unknown	South of Meeker	*Cronquist 11455* MO

Table 1 (cont.).

Arbitrary number	County	Dates observed	Management	Site	Source of information[1]
21	Chaffee	June 1998	Unknown	Wet Mountains, Wet Mountain Valley, Sangre de Cristo Range and vicinity, south of Poncha Springs	Specimen at RM in Elliott and Hartman (2000)
22	Gunnison	May 1998	Gunnison National Forest	Almont - Taylor River Canyon between Almont and Taylor Park Reservoir	*Taylor 5475* May 1998 CS. Colorado Natural Heritage Program (2002)
23	Gunnison	June 1993	Gunnison National Forest	Almont - Flat Top	USDA Forest Service (2003 transect data)
24	Gunnison	June 1996	Gunnison National Forest	Almont, Taylor River Canyon, below Gunnison Mountain Park Campground	*Lederer 96-TR-22* and *Lederer 96-TR-23, with Jennings, Marotti, & Murphy* COLO, Colorado Natural Heritage Program (2002)
26	Gunnison	June 1996	Gunnison National Forest	Near Taylor Reservoir	*Lederer 96-TR-6 with Jennings, Marotti, & Murphy* COLO. Colorado Natural Heritage Program (2002)
27	Saguache	pre-1941	Gunnison National Forest	Below Sargents	Specimen at Harvard Herbaria in Rollins (1941)
28	Saquache	July 1992	Gunnison National Forest	Sargents	USDA Forest Service (2003 transect data)
29	Gunnison	pre-1941	Unknown	North of Sargents	Specimen at Harvard Herbaria in Rollins (1941)
30	Gunnison	June-August 1997	Gunnison National Forest	Pitkin - south	USDA Forest Service (2003 transect data)
31	Gunnison	August 1994	Gunnison National Forest	Pitkin - north	USDA Forest Service (2003 transect data)
32	Gunnison	June 1992, August 1995	BLM	McIntosh Mountain	USDA Forest Service (2003 transect data)
33	Saguache	September 1992	Gunnison National Forest	Doyleville	USDA Forest Service (2003 transect data)
34	Saguache	July 1992, July 1995	Gunnison National Forest	West Baldy	USDA Forest Service (2003 transect data)
36	Gunnison	August 1993	BLM	Powderhorn Lakes	USDA Forest Service (2003 transect data)
37	Gunnison	July 1994, May-August 1995	BLM	Signal Peak	USDA Forest Service (2003 transect data)
38	Gunnison	June 1995	BLM	Gunnison	USDA Forest Service (2003 transect data)
39	Gunnison	August 1993	BLM	Powderhorn	USDA Forest Service (2003 transect data)
40	Gunnison	June 1994	Gunnison National Forest	West Elk Peak (SW)	USDA Forest Service (2003 transect data)
41	Gunnison	May 1998	BLM	East of Gunnison and south of Signal Peak	*Taylor 5253* COLO

Table 1 (concluded).

Arbitrary number	County	Dates observed	Management	Site	Source of information[1]
42	Chaffee	June 2000	Gunnison National Forest	Along Cottonwood Creek, near Rainbow Lake	*Manier s.n.* CS
43	Gunnison	May-August 1995	BLM	Parlin	USDA Forest Service (2003 transect data)
44	Gunnison	July 1995	Gunnison National Forest	Parlin	USDA Forest Service (2003 transect data)
45	Saquache	June 1995	BLM	Houston Gulch	USDA Forest Service (2003 transect data)
46	Gunnison	June 1995	BLM	Iris	USDA Forest Service (2003 transect data)
47	Saquache	July 1992, July 1995	Gunnison National Forest	West Baldy	USDA Forest Service (2003 transect data)
48	Gunnison	August 1995	BLM	Rudolph Hill	USDA Forest Service (2003 transect data)

[1]Abbreviations as to the source of information:

COLO – herbarium at University of Colorado, Boulder.

CS – herbarium at Colorado State University.

GH – Gray Herbarium; one of the herbaria at Harvard University.

MO – herbarium at Missouri Botanical Garden.

RM – Rocky Mountain Herbarium, University of Wyoming, Laramie, Wyoming.

USDA Forest Service. 2003. Transect data from data collected in the Northern Gunnison Basin Vegetation Classification Project. Unpublished data provided by Johnston personal communication 2003.

Rollins (1941) remarked that many *Arabis* species are extremely similar and difficult to distinguish, especially by the inexperienced. However, he noted that there are a number of clearly discrete species that can function as "guideposts … that afford a general basis for interpreting species of a less clearly defined nature." He went on to conclude that *A. crandallii* is one such "guidepost" species.

Cladistic analyses can use morphological, and more recently, biochemical, or molecular methods to determine which members of a genus are most closely related. These analyses generate clades that are often hypotheses of relationship, and as hypotheses, they may be confirmed or disproved. It is important to appreciate that change to established relationships is neither a defect of cladistics, nor an inevitable consequence of the use of molecular data. Molecular data frequently serve to confirm existing relationships. This is true for *Arabis crandallii*, which has been accepted as part of the *A. holboellii* complex for several decades (Rollins 1941, Roy 1995).

Unpublished work by Roy, Koch, and Mitchell-Olds indicates that *Arabis crandallii* has a chloroplast (cp) genome closely related to that of *A. platysperma*, but the variation in nucleotide sequence in the internal transcribed spacer (ITS) regions of nuclear ribosomal DNA places it closer to *A. demissa* (Roy personal communication 2003). This lack of concordance between nuclear and cp DNA strongly suggests hybridization in the past and chloroplast capture (Roy personal communication 2003). *Arabis crandallii* shows a close relationship to *A. fernaldiana* and *A. fecunda* in some molecular cladistic analyses (Roy personal communication 2003). This is in agreement with Rollins' (1941) analysis based on morphology that placed *A. crandallii* most closely related to *A. fernaldiana*. Some information on specific gene sequences in *A. crandallii* is published by the National Center for Biotechnology Information (2001; see also Benson et al. 2000, Wheeler et al. 2000).

Rollins (1993) described *Arabis pallidifolia*, which he determined to be a close relative of *A. crandallii*. *Arabis pallidifolia* is morphologically very similar to *A. crandallii*, but its status as a unique taxon has been questioned (Johnston personal communication 2003). The morphological differences between the two species are listed in **Table 2**. In addition, Rollins (1993) reported that the two species occupied different habitat niches within the same range (see Habitat section).

Synonyms for *Boechera crandallii* (B. L. Robinson) W. A. Weber are *Arabis crandallii* B. L. Robinson, and *A. stenoloba* E. L. Greene.

History of species

The genus *Boechera* is named in honor of Tyge W. Böcher, an arctic botanist who studied members of the Brassicaceae for many years (Löve and Löve 1975). *Boechera crandallii* was first collected at the end of the nineteenth century in Colorado. In 1899, Robinson originally described *B. crandallii* as the unique taxon *Arabis crandallii*. The specific epithet, *crandallii*, was in honor of Charles Spencer Crandall, a notable botanist and horticulturist at Colorado Agricultural College between 1889 and 1899 and one of the early collectors of this species (Ewan and Ewan 1981). In 1901, Greene described *A. stenoloba* (Greene 1901). Rollins (1941) determined that the two species were exactly the same and hypothesized that Greene must not have seen the original description by Robinson, which had been published only two years earlier. *Boechera crandallii* was discovered relatively recently (1968) in Wyoming, where it remains very rare (Fertig et al. 1998, Ward 1998).

Non-technical description

Boechera crandallii is an herbaceous perennial that grows from a branched caudex (**Figure 1** and **Figure 2**). It has numerous slender stems that are covered by soft hairs (pubescence). The stems are usually erect or

Table 2. Morphological differences between *Boechera crandallii* and *B. pallidifolia* (after Rollins 1993).

Species	Siliques	Petals	Cauline leaves	Growth form	Caudex
crandallii	very narrow, torulose, erect, straight	white or nearly white	mostly non-auriculate	Densely caespitose	much branched below the ground
pallidifolia	broader, nearly plane, divaricately ascending, slightly curved to nearly straight	purplish	always auriculate	caudex is above ground surface on a woody foot	branching or simple above ground

Figure 1. Illustration of *Boechera crandallii*. Copied from Rollins (1941; p 435) and used with permission. The figure is approximately one-half the natural size.

Figure 2. Picture of *Boechera crandallii* and habitat by Barry C. Johnston, USDA Forest Service.

sometimes slightly lie down at the base. The basal leaves are erect and covered by dense hairs that are generally branched into three aerial parts. The leaves are 1.5 to 3 cm long (0.6 to 1.2 inches), less than 4 mm (0.2 inches) wide, and oblong to lance-shaped. The leaf margins are entire or, less commonly, obscurely toothed. The stem leaves are sessile, entire, densely pubescent, and 8 to 15 mm (0.3 to 0.6 inches) long. Usually the stem leaves are auriculate (eared) although the auricles or ears may be nearly obsolete. The flowers have four white to very pale pinkish petals 5 to 7 mm (0.27 inches) long and 2 to 3 mm (0.08 to 0.11 inches) wide. The fruits are slender siliques (pod-like fruits), 3 to 6 cm (1 to 2 inches) long, and borne on erect to slightly spreading pubescent stalks that are 5 to 10 mm (0.2 to 0.4 inches) long. The seeds are wingless or narrowly winged (Rollins 1941, Rollins 1993, Fertig 2000).

Boechera crandallii is sympatric with *B. pallidifolia*, *B. fendleri*, and *B. pulchra* var. *pallens* (see Systematics and synonymy section). It is also sympatric with *B. gunnisoniana* and sometimes with *B. oxylobula* (Johnston personal communication 2004). The erect position of the siliques distinguishes *B. crandallii* from *B. fendleri*, *B. pulchra* var. *pallens*, *B. gunnisoniana*, and *B. oxylobula*, which have pendulous (downward hanging) or spreading (with a downward tendency) siliques (Rollins 1993, Weber and Wittmann 2001).

References to technical descriptions, photographs, and line drawings

A detailed technical description and a line drawing of *Boechera crandallii* can be found in Rollins (1941). Other comprehensive technical descriptions are published in Rollins (1993), Dorn (2001), Weber and Wittmann (2001), and on the Wyoming Natural Diversity Database Web site (2003). A photograph of an isotype herbarium specimen (identified as *Arabis stenoloba*) collected by C. F. Baker (21) on 6 June 1901 from "Cimarrons, Region of the Gunnison Watershed" Colorado is on the New York Botanical

Garden Herbarium web site (2003). The photograph and collection details of the *B. pallidifolia* (as *A. pallidifolia*) type specimen are also on the New York Botanical Garden Herbarium web site (2003). The type specimen, as *A. crandallii*, collected by C.S. Crandall (*6*) in the Cimarron area in Montrose County, Colorado on May 18, 1898 is deposited in the Gray herbarium (GH) at Harvard University, but only the label information is available on the internet. Similarly, only the label information is available on the internet for the isotype specimen (identified as *B. crandallii Crandall 6*) deposited at the University of Colorado Herbarium (COLO). See References section for internet site addresses.

Distribution and abundance

Boechera crandallii is regionally endemic to west-central Colorado and southwestern Wyoming (**Figure 3**). Only four occurrences have been reported in Wyoming: one from Carbon County and three from Sweetwater County (**Table 3**; Fertig et al. 1998, Ward 1998). The plant is more widely distributed in Colorado but is still concentrated in the Upper Gunnison Basin in Gunnison County. It has also been reported in Chaffee, Delta, Montrose, Park, Rio Blanco, and Saguache counties. Specimens were reportedly collected from Gore Creek in Grand County (Rollins 1941). Looking at a recent Colorado map this occurrence actually appears to be in what is currently Eagle County.

All of the element occurrence data that are unaccompanied by herbarium specimens need to be regarded with some skepticism, particularly those that are reported when plants have no flowers and fruit, which are diagnostic characteristics of this species. There is a possibility that *Boechera pallidifolia* and *B. crandallii* have been mistaken for each other (see Systematics and synonymy section). Therefore, although the occurrence data that are listed in this report are the most accurate available at the current time, it may need to be revised when it is clearer as to the abundance and range of *B. pallidifolia*. As a result, the existing occurrence data may not be an accurate estimate of the true abundance of *B. crandallii*.

In Colorado, approximately 48 documented occurrences have been reported since 1891 (**Table 1**), and 32 of these have been observed within the last decade. At least 15 or 16 of the known occurrences are located on National Forest System lands while the others are located on private land and land managed by BLM and the National Park Service.

One occurrence of *Boechera crandallii* often consists of several sub-occurrences. One definition of population, and one that can be equated with occurrence in this assessment, is that it is "a group of individuals of the same species that occurs in a given area" (Guralnik 1982). A more restrictive definition is that a population is "a group of individuals of the same species living in the same area at the same time and sharing a common gene pool or a group of potentially interbreeding organisms in a geographic area" (National Oceanic and Atmospheric Administration 2004). Knowing the number and structure of populations delineated by this more restrictive definition is most useful for conservation planning purposes, but its application to *B. crandallii* will be subject to error until more information about the biology and ecology of the species is available.

In this report, occurrences include plants in patches, or sub-occurrences, in large areas of land where there are contiguous stretches of apparently suitable, or potential, habitat. Given the available information, interaction through pollination or seed dispersal is likely to occur between sub-occurrences. However, without knowing the seed dispersal range and pollination biology it is not possible to delineate what comprises a single interbreeding population. For example, the occurrence near Almont on the Gunnison National Forest (occurrence 21 in **Table 1**) is considered to be composed of several sub-populations extending over three sections. There is currently insufficient information to know if any of these sub-occurrences are actually genetically isolated. Similarly, five occurrences (occurrences 1 through 5 in **Table 1**) have been placed in the Sapinero region, but it may be that all of these plants belong to a single extensive metapopulation. Alternatively, there could be several more than five genetically isolated populations. In some cases, especially amongst older reports where location descriptions are minimal or vague, an occurrence listed in **Table 1** may be more accurately described as a sub-occurrence, but there is insufficient information associated with the report to make an accurate delineation. In other cases, a site may have been revisited and designated a new occurrence due to imprecise location information in earlier reports.

Occurrence data have been compiled from the Colorado Natural Heritage Program, the Wyoming Natural Diversity Database, the Northern Gunnison Basin vegetation classification project (Johnston et al. 2001, Johnston personal communication 2003), specimens at the University of Colorado Herbarium (COLO), the Colorado State University Herbarium

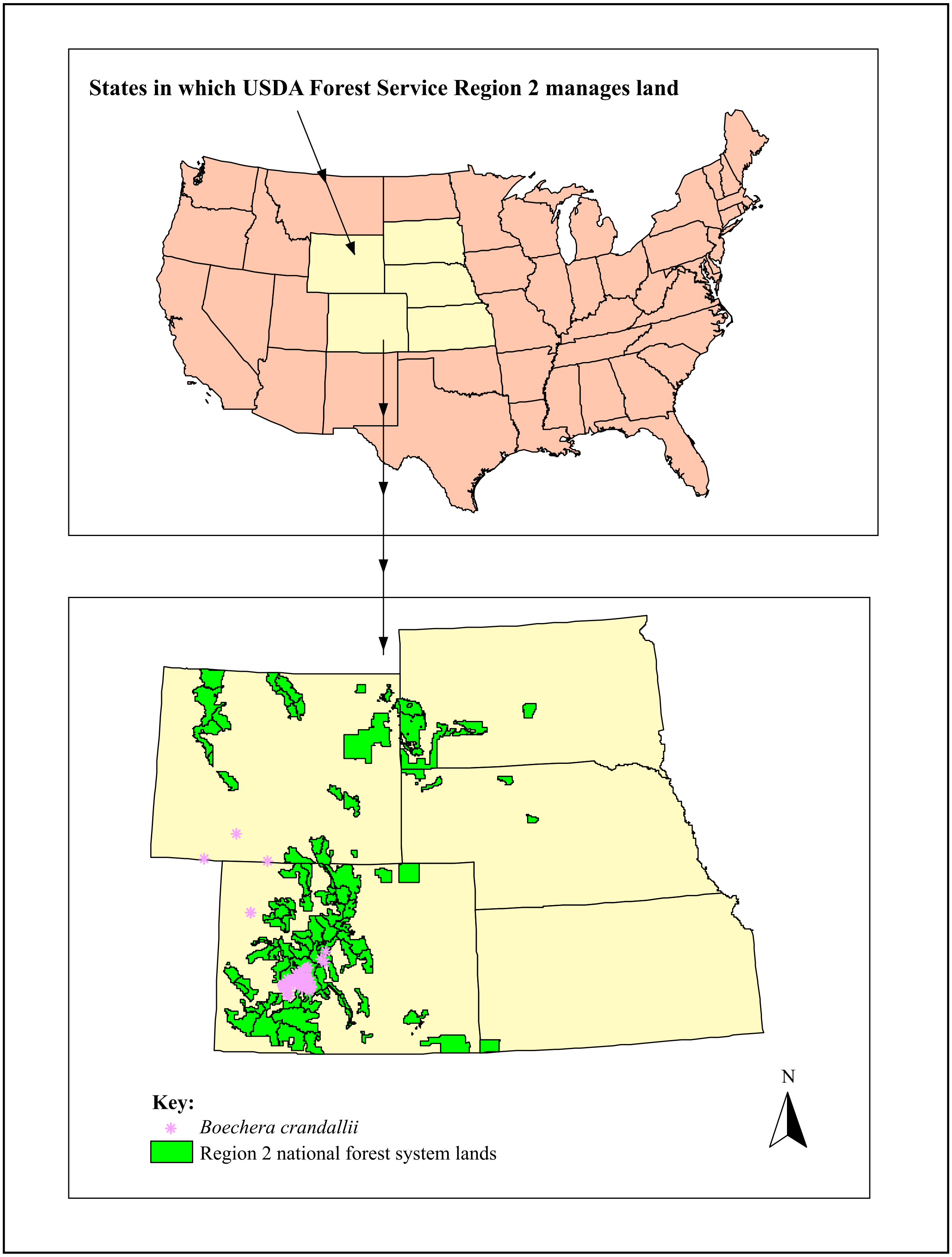

Figure 3. Range of *Boechera crandallii*.

Table 3. Occurrence data for *Boechera crandallii* in Wyoming.

Arbitrary number	County	Date last observed	Management	Site	Source of information[1]
1	Carbon	June 1968	Bureau of Land Management (or possibly private, with all minerals owned by the federal government)	Washakie Basin, Poison Buttes area	*Gibbens, R 68-36* 1968. RM. Wyoming Natural Diversity Database (2002); Fertig et al. (1998)
2	Sweetwater	June 1998	BLM	Green River Basin, east of Flaming Gorge Reservoir and just north of the Utah state line	*Fertig, W. 18232* 1998. RM. Wyoming Natural Diversity Database (2002); Fertig et al. (1998)
3	Sweetwater	June 1995	Flaming Gorge National Recreation Area, Ashley National Forest, Region 4	Rock Springs Uplift, northwest of Dutch John, Utah within the National Forest boundary on east side of Flaming Gorge Reservoir	*Refsdal, C. 3763, 3764* 1995. RM. USDA Forest Service, Wyoming Natural Diversity Database (2002); Fertig et al. (1998)
4	Sweetwater	June 1978	Patented lands (Strip mine)	Great Divide Basin at the "South Haystack Coal site" north of Black Buttes on the Union Pacific Railroad	*Moore, J.A., L.M. Mayer, and D.G. Reardon 539* 1978. RM. Wyoming Natural Diversity Database (2002); Fertig et al. (1998)

[1]Abbreviation as to the source of information:

RM – Rocky Mountain Herbarium, University of Wyoming, Laramie, Wyoming.

(CS), the Kathryn Kalmbach Herbarium at Denver Botanic Gardens (KHD), Missouri Botanical Garden (MOBOT), the Gray Herbarium at Harvard University (GH), the New York Botanical Garden Herbarium (NY), and from the literature (Rollins 1941, Ward 1998, Orthner 1999, Elliott and Hartman 2000).

The Northern Gunnison Basin vegetation classification project incidentally provided habitat descriptions and information on the distribution and abundance for this endemic species (Johnston et al. 2001, Johnston personal communication 2003). "Incidentally" reflects that the goal of this particular project was to gather information for vegetation classification rather than to provide detailed data on *Boechera crandallii*. The vegetation transect data have been included in the estimate of the number of occurrences of this species (**Table 1**). Transect lines only included homogeneous vegetation, soils, and landforms, and they were typically 30 m (98 ft.) long (Johnston et al. 2001). However, if the homogenous patch to be sampled was not large enough to allow a 30 m (98 ft.)-long line, the transect length was reduced accordingly to a minimum length of 15 m (49 ft.) (Johnston et al. 2001). Vegetation canopy cover was measured in ten 0.1-m^2 (20 x 50 cm) (approximately 8 x 20 inches) microplots centered on equidistant points along the tape, avoiding the beginning and end points (Johnston et al. 2001). Between 1992 through 1998 in the Northern Gunnison Basin, *B. crandallii* was recorded on 86 of a total of 1,663 vegetation classification transects and was found in the vicinity of an additional 10 transect lines (Johnston et al. 2001, Johnston personal communication 2003). Its canopy cover ranged from 0.1 to 4.8 percent, averaging approximately 0.5 percent, on the transect lines (Johnston personal communication 2003). Many of the transect lines on which it was found were clustered within a central area of Gunnison County near Sapinero. This area includes portions of the Sapinero and Carpenter Ridge areas that extend into the Curecanti National Recreation Area.

Across all available occurrence records, there are a variable number of plants per occurrence. Observations ranged from "only a few plants" being counted at an occurrence site to, in two cases, several thousand individuals being estimated within an occurrence. Individuals tend to be scattered singly or in patches, so accurately determining the number without making a comprehensive survey of the whole area may be misleading. Such a patchy distribution of widely varying densities can lead to either over- or underestimates of abundance, depending upon whether the sparser or denser patches are sampled. **Figure 4** shows the variation in abundance across the Gunnison

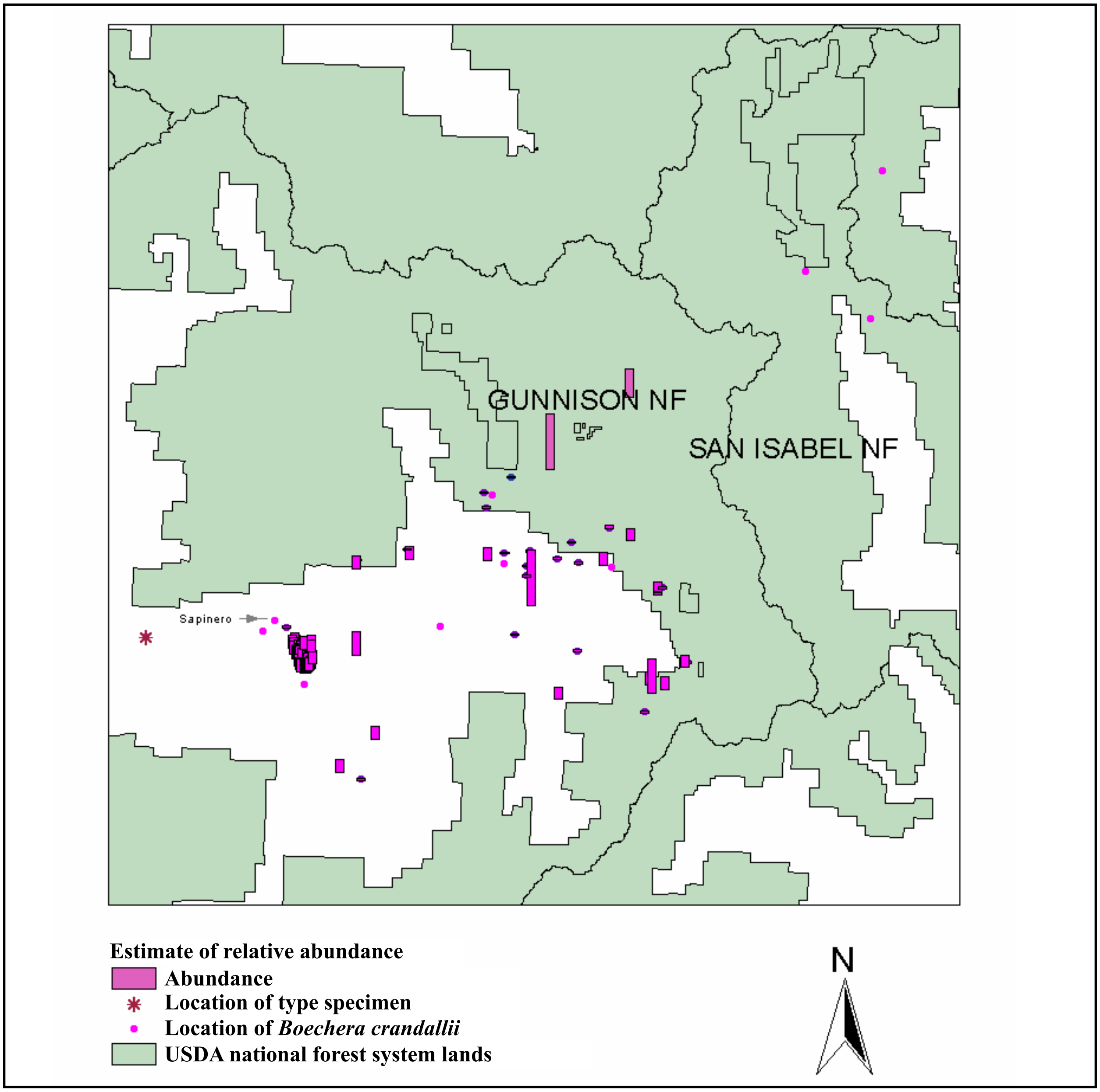

Figure 4. Estimate of the relative abundance of *Boechera crandallii* in the Northern Gunnison Basin and in the Gunnison and Pike-San Isabel national forests. The columns represent relative abundance (tall columns most abundant) and the filled circles represent occurrences when abundance was not noted. The tallest column represents an occurrence where "several thousand" were estimated. The shortest column, looking much like a hyphen (-), represents "only a few plants" or a cover of less than 0.1 percent.

Basin. The columns represent relative abundance (tall columns most abundant), and the filled circles represent occurrences where abundance was not noted. The tallest column represents an occurrence where "several thousand" were estimated. The shortest column, looking much like a hyphen (-), represents "only a few plants" or a cover of less than 0.1 percent. The brown star indicates the approximate location where the type specimen was collected in 1898.

Population trend

There are insufficient data in the literature, associated with herbarium specimens, or at the Natural Heritage Programs to determine accurately the long-term population trends for *Boechera crandallii*. Although plants in Colorado have been reported to be locally common, very few sites have been revisited. Where areas have been revisited, specific populations were not clearly defined during the first observation, and therefore plants are only known to persist in the same general areas. Plants apparently have persisted at sites in the Sapinero, Sargents, and Almont areas for many decades (**Table 1**). It is unknown whether additional recent reports indicate an increase in the range or abundance of the species or whether local extirpations and colonizations have occurred that result in no net gain.

In 1941, Rollins described *Boechera crandallii* as very abundant on "rocky hillsides and open sagebrush slopes in the Gunnison Basin". There has been no quantitative monitoring, and as mentioned earlier, few sites have been revisited. From observations made within the last decade, this species still appears to be relatively abundant in the Gunnison Basin. It appears to occur naturally in variably-sized populations: from isolated plants to thousands. Using data from the vegetation classification project, Johnston (personal communication 2003) estimates that *B. crandallii* occurs at an average cover of 0.1 percent in ecological types covering about 3,000 acres in the Gunnison Basin, approximately 35 percent of which are on National Forest System lands (see Distribution and abundance section).

There is no specific evidence to suggest that *Boechera crandallii* is either more or less common at the present time than in the past. All four occurrences in Wyoming have been discovered since 1968; the most recent was in 1998 (Wyoming Natural Diversity Database 2002). It is unclear if this represents an extension of range or whether plants have only recently been noticed and collected from these regions. The latter case is very likely because relatively few botanical surveys have been made in Wyoming or northwestern Colorado, and the casual observer easily overlooks *Boechera* species.

It is likely that *Boechera crandallii* has experienced a decline in potential habitat in the last century. Considerable loss and fragmentation of habitat has occurred due to highway expansion, resource extraction activities, and recreational use (Colorado Natural Heritage Program 2002, Wyoming Natural Diversity Database 2002). For example, a population found in 1978 in Wyoming may have been lost during the expansion of a nearby coal mine (occurrence number 47 in **Table 1**; Wyoming Natural Diversity Database 2002). This population was at the northernmost end of its known range. Two sub-occurrences were destroyed by a road construction and recreational campground development on the Gunnison National Forest (occurrence number 23 in **Table 1**; Austin personal communication 2003). When Blue Mesa Reservoir was constructed between 1961 and 1968 near Sapinero, Colorado (Walker and Santi 2004), at least two *B. crandallii* sub-occurrences (occurrence 2 in **Table 1**) were likely destroyed.

Habitat

According to Rollins (1993), *Boechera crandallii* and *B. pallidifolia* grow in the same area but colonize different habitats; *B. crandallii* grows in more open, sometimes windswept places whereas *B. pallidifolia* grows in relatively protected places frequently associated with sagebrush. There is little additional information on *B. pallidifolia*, and it appears that most of the information that pertains to *B. crandallii* was collected without considering *B. pallidifolia*. Therefore, this description of habitat is a synthesis of what has been reported for *B. crandallii*, but it needs to be understood that some features of habitat might more appropriately apply to *B. pallidifolia*. As mentioned in a previous section, *B. crandallii* was observed on 86 transects that were designed to classify and describe vegetation communities throughout the Northern Gunnison Basin (see Distribution and abundance section). The frequency with which *B. pallidifolia* was encountered was not reported. The information available from this project has been incorporated into this habitat description. Transects were placed to include only homogeneous vegetation, soils, and landforms. They were generally 30 m (98 ft.) in length but were shortened to a minimum length of 15 m (49 ft.) to avoid heterogeneous vegetation types (Johnston et al. 2001). There were not the same number of transects in each vegetation type.

Boechera crandallii grows at elevations between 1,900 and 3,250 m (6,200 and 10,700 ft.). The majority of occurrences are at sites between 2,300 and 2,600 m (7,500 and 8,550 ft.) in Colorado (**Figure 5**). In Wyoming, all occurrences are between 1,920 and 2,170 m (6,300 and 7,100 ft.). The lower elevations colonized in Wyoming may reflect the difference in latitude (Merriam 1894).

Although soil type and the parent material from which it is derived are variable, *Boechera crandallii* always appears to be associated with rocky or gravelly areas, including the extreme of cases of cliffs and talus slopes (herbarium specimen records, Rollins 1941). Soils have been variously described as alluvial, sandy loam, cobbly sandy loam, and, especially in Wyoming, having a high shale or clay component (Colorado Natural Heritage Program 2002, Wyoming

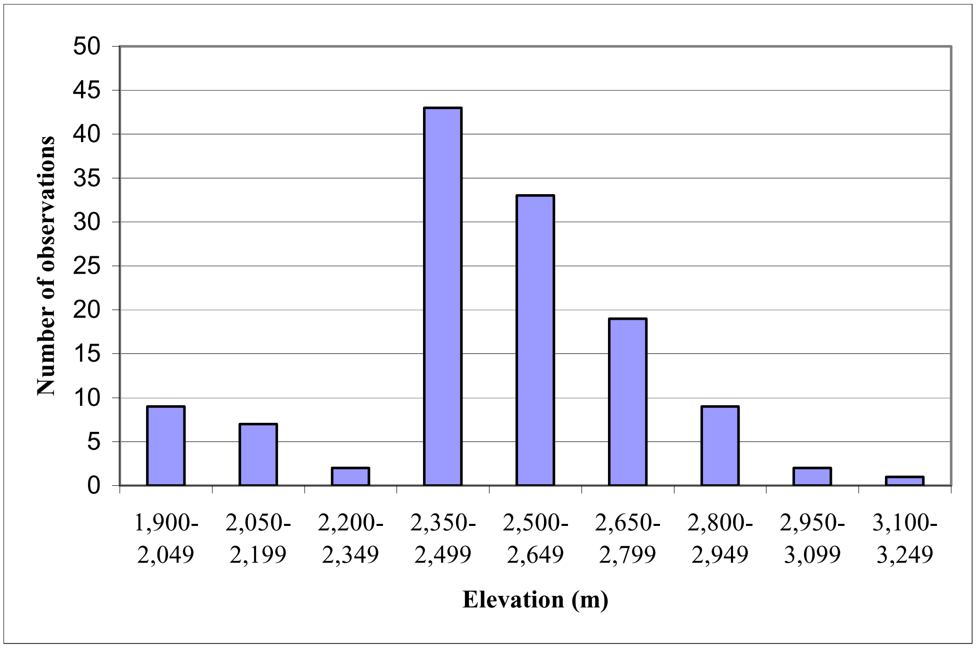

Figure 5. Chart demonstrating the range of elevations at which *Boechera crandallii* has been observed.

Natural Diversity Database 2002, herbarium specimen records). The most commonly reported parent material is granite, specifically Precambrian granodiorite to quartz monzonite, but limestone (limestone chip-rock) and sandstone have also been described. The specific edaphic requirements of *B. crandallii* have not been defined. See Definitions section at the end of the report for definition of talus and other geological terms.

Boechera crandallii grows in a range of habitat types. It grows in full sunlight to partial shade and has been found on both level sites and steeply inclined slopes. It also appears to grow on sites facing any aspect. Some habitats have been described as very dry whereas others may be periodically quite moist, for example, on boulders near water or on a floodplain.

On a broad scale, this species grows within grassland, sagebrush, sagebrush-grassland, piñon-juniper woodland, and ponderosa pine forest communities. It occurs in spruce-fir, ponderosa pine, and lodgepole pine cover-types on the Pike-San Isabel National Forest and in lodgepole pine, grassland (undefined) and other sagebrush (*Artemisia* sp.) cover on the Gunnison National Forest (USDA Forest Service Rocky Mountain Region 2003). In the Gunnison Basin, it was found in at least 18 different ecological types (**Table 4**; for more details on ecological types see Johnston et al. 2001). It is noteworthy that the ecological types include both protected and open, windswept sites. Rollins (1993) reported that *Boechera crandallii* grows in the more open, sometimes windswept places, and *B. pallidifolia* grows in the protected places frequently associated with sagebrush. Therefore, there is the possibility that *B. pallidifolia*, rather than *B. crandallii*, was observed at some of the sites.

Some quantitative reports of associated ground cover exist for specific occurrences (Colorado Natural Heritage Program 2002). Tree cover ranged from 0 to 20 percent, shrub cover from 5 to 70 percent, forb cover from 5 to 30 percent, graminoid cover from 1 to 100 percent, and bare ground from 20 to 80 percent. In occurrences reported from cliffs and talus slopes, the bare ground cover is likely higher than 80 percent, and the cover by the other life forms may be considerably lower. Although averages from the North Gunnison Basin vegetation transect line studies fall mid-way between these ranges (**Table 5**), data from this study estimated tree cover up to 65 percent and forb cover up to 51 percent at some sites. The vegetation classification data also recorded the total number of live plant species per transect line (see Distribution and abundance section). Approximately 27 different species were found along transect lines with *Boechera crandallii*. Some of the individual plant species that are reported to be associated with *B. crandallii* are listed in **Table 6**.

Reproductive biology and autecology

Boechera crandallii is a perennial species (Rollins 1941). It reproduces primarily by seed although the plant

Table 4. Ecological types in which *Boechera crandallii* has been reported (from unpublished data provided by Johnston, Gunnison National Forest 2003). See Johnston et al. (2001) for further description of ecological types.

Ecological type (Additional notable feature in parentheses)	Code	Number of transects[1]	Average *B. crandallii* cover (percent) per transect
Douglas-fir/Wax currant - Arizona fescue-coarse thin-dark soils-steep slopes	FD06	9	0.40
Douglas-fir/Serviceberry - Steep northerly facing slopes (Saskatoon serviceberry or Rocky Mountain maple present.)	FD08	1	0.05
Douglas-fir/Bitterbrush (Bitterbrush >5% and/or big sagebrush >10% cover) - Gentle slopes	FD10*	2	0.25
Aspen-cottonwood-deep alluvial soils-floodplains	FR2	1	0.50
Indian ricegrass/Needle-and-thread - aridic soils - windswept ridge shoulders (Arizona fescue usually absent, rarely <0.05% cover. Indian ricegrass, 0 to 40% cover)	GA01**	2	0.29
Utah serviceberry/Sedge-dark clay soils-leeward (Mountain-mahogany usually absent, sometimes <10% cover)	SA1*	5	0.29
Utah serviceberry-Mountain-mahogany/Sedge-dark clay soils – Protected (Elk sedge absent)	SA2	2	0.89
Serviceberry - Oak - dark clay soils – Protected (Mountain-mahogany absent or occasionally <10% cover)	SA3	5	0.50
Saskatoon serviceberry/Elk sedge – Deep dark soils–lees (Oak usually absent, rarely <10% cover)	SA5**	2	0.55
Wyoming sagebrush/Indian ricegrass – aridic soils (Black sagebrush >15% cover)	SB1	10	0.98
Black sagebrush/Muttongrass - Coarse heavy - clay soils - windward (Arizona fescue absent)	SB2	13	0.50
Black sagebrush/Arizona fescue - Coarse heavy clay soils - windward	SB3	6	4.85
Sagebrush/Muttongrass - Dark clay soils (Arizona fescue and Parry oatgrass both absent or at least <1% cover)	SS1	1	0.50
Bitterbrush - sagebrush/Needlegrass - Dark coarse soils (Arizona fescue and Parry oatgrass both absent or at least <1% cover)	SS2*	11	0.46
Big Sagebrush/Arizona fescue – dark soils (Parry oatgrass always absent)	SS4**	2	0.03
Bitterbrush - sagebrush/Oatgrass - Arizona fescue - Light-colored soils - northerly aspect (Parry oatgrass present)	SS5**	3	0.75
Bitterbrush - sagebrush/Arizona fescue - Dark soils	SS6**	8	0.49
Mountain sagebrush/Thurber - Arizona fescues - Deep cold clay soils - Deeper (average 85 cm [33 in.]), coarser (average 32%), loamier soils	SU1**	1	0.08

[1] The number of transects that were included in the calculation of average cover.

* *Boechera crandallii* found "near" (distance not reported) transects within these ecological types on the Gunnison National Forest.

** *Boechera crandallii* found on transects within these ecological types on the Gunnison National Forest.

Table 5. Average cover of transects on which *Boechera crandallii* was found. Observations from 86 transect lines contributed to tree, shrub, grass, and forb cover and from 37 transects to bare ground (Unpublished data provided by Johnston, Gunnison National Forest 2003).

	Tree cover	Shrub cover	Graminoid cover	Forb cover	Bare ground
Mean (average)	8.90%	36.22%	27.50%	8.99%	13.46%
Mode (most frequently occurring)	0.50%	33.00%	19.00%	5.25%	11.54%

Table 6. Plant species reported to be associated with *Boechera crandallii*. This is not an exhaustive list and represents only the observations that were made on herbarium sheets, in the literature (see text), in Colorado Natural Heritage Program (2002), and in Wyoming Natural Diversity Database (2002).

Species	State reported
Boechera[1] *fendleri*	Colorado
Boechera[1] *pulchra* var. *pallens*	Wyoming
Artemisia[1] *vaseyana*	Colorado
Balsamorhiza sp.	Colorado
Carex rossii	Wyoming
Castilleja chromosa	Colorado
Cercocarpus montanus	Wyoming
Erigeron eatonii	Colorado
Juniperus[1] *osteosperma*	Colorado & Wyoming
Juniperus[1] *scopulorum*	Colorado
Penstemon caespitosus	Colorado
Penstemon teucrioides	Colorado
Pinus edulis (reported as piñon pine)	Colorado
Pinus ponderosa	Colorado
Poa cusickii	Wyoming
Poa secunda	Wyoming
Pseudotsuga menziesii	Colorado
Purshia tridentata	Colorado
Quercus gambelii	Colorado
Ribes cereum	Colorado
Ribes leptanthum	Colorado
Senecio multilobatus	Wyoming
Stenotus acaulis[1]	Wyoming

[1]Synonyms: The reference in parenthesis refers to a Flora in Region 2 in which the synonym is used:

Artemisia vaseyana	*Artemisia tridentata* ssp. *vaseyana* (Dorn 2001)
Artemisia tridentata ssp. *vaseyana*	*Seriphidium vaseyanum* (Weber and Wittmann 2001)
Boechera fendleri	*Arabis fendleri*
Boechera[1] *pulchra* var. *pallens*	*Arabis pulchra* var. *pallens*
Juniperus osteosperma	*Sabina osteosperma* (Weber and Wittmann 2001)
Juniperus scopulorum	*Sabina scopulorum* (Weber and Wittmann 2001)
Stenotus acaulis reported by synonym	*Haplopappus acaulis*

may spread to a limited extent by vegetative growth from its subterranean branching caudex (Rollins 1941). It flowers from late April to mid-June. The earliest date on which flowers have been documented is April 20, and the latest is June 17 (herbarium specimens). Fruits at different stages of maturity have been documented from April 20 to June 30.

Several species within the *Boechera holboellii* complex are agamospermous (Grant 1981, Sharbel et al. 2004). Agamospermous plants can produce seeds exclusively through asexual (apomictic) processes, or they may additionally produce seeds through sexual processes (Grant 1981). Unlike many of the Colorado species of *Boechera*, which are exclusively or predominately apomictic, *B. crandallii* reproduces sexually (Roy 1995). Plants that reproduce sexually may be self-pollinated or cross-pollinated. Evidence from field observation and isozyme studies suggests that *B. crandallii* is predominantly autogamous (self-fertilized). Field observations suggest that *B. crandallii* is self-pollinated as the bud opens (Roy 1995).

The isozyme studies used 19 putative loci and were made on individual plants in a Colorado population in the Almont area of the Gunnison National Forest. The results indicated that there were few heterozygotes in the population and none in natural progeny arrays (Roy 1995). Only 5 percent of the loci in the population were polymorphic. These results suggested that genetic diversity was low. Using methods common for genetic analysis, the number of expected heterozygotes was calculated as being low, and the calculated number closely matched the number observed. This led to a low inbreeding coefficient ($f = 0.11$) for the *Boechera crandallii* population, suggesting little inbreeding (Roy 1995). A low inbreeding coefficient, which can range between 0 (random mating) and 1 (inbred), indicates that outcrossing occurs (Allard 1960). However, the low number of polymorphic loci suggests that fixation of alleles has taken place due to repeated self-pollination (Roy 1995).

Reports of hybridization between *Boechera crandallii* and *B. holboellii* indicate that some cross-pollination occurs. Rollins (1966) reported on the chromosome number ($2n = 21$) of a *B. crandallii* x *B. holboellii* var. *retrofracta* specimen that he had collected from Gunnison County and had deposited at the Gray Herbarium (*Rollins 5194*). Apparently the generalized flower structure of *Boechera* attracts a large number of relatively non-specific insect pollinators (Conservation Management Institute 1996). Studies on a purple-flowered *Boechera* species indicated that potential pollinators include Syrphid flies, solitary bees, and bumblebees (Conservation Management Institute 1996). Flies and bees also visit white-flowered plants, but it is likely that the assemblage of species will be different between the two flower colors (Grant 1981).

There are no details on the quantity or viability of seed produced by *Boechera crandallii*. Seed germination requirements also cannot be accurately predicted. Several *Boechera* species produce seeds that exhibit a physiological dormancy and require cold stratification before germination (Baskin and Baskin 2001). In contrast, seeds of *B. fecunda* germinated readily at room temperature without a stratification requirement (Lesica and Shelley 1995). Interestingly, seeds from different populations of *B. fecunda* behaved differently after cold treatment. Seeds collected from a population at a significantly higher elevation became dormant whereas those from lower elevation habitats had no such reaction (Lesica and Shelley 1995).

Seed dispersal mechanisms are not known. Some of the seeds are narrowly winged, suggesting that wind contributes to dispersal. In general, wind-dispersed seeds move only short distances (Silvertown 1987). Other dispersal mechanisms may include sheet-water action in times of intense downpours, and gathering/caching activities by rodents and ants. The seeds and fruits do not have any characteristics (e.g., barbs that attach them to animal fur) that suggest that they are prone to dispersal over long distances.

Demography

Interspecific hybridization among *Boechera* species is quite common (Rollins 1966, Rollins 1993, Roy 2001). A triploid *B. crandallii* x *B. holboellii* var. *retrofracta* specimen was reported from Gunnison County (see Reproductive biology and autecology section). *Boechera holboellii* appears to have some disposition for apomictic reproduction (Sharbel and Mitchell-Olds 2001). Therefore, this triploid hybrid may be able to reproduce. The presence of such hybrids may add confusion when distinguishing *B. crandallii* in the field. Notwithstanding the potential for cross-pollination, genetic isolation of many populations may be maintained if the species is predominantly self-pollinating.

In light of the limited studies on *Boechera crandallii*, some discussion of studies on another related species is appropriate. A clade derived from molecular analyses placed *B. fecunda* as a close relative of *B. crandallii* (Roy personal communication

2003). *Boechera fecunda* is endemic to southwestern Montana at elevations between 1,430 and 2,440 m (4,700 to 8,000 ft.). It is a perennial species that is both morphologically and ecologically quite similar to *B. crandallii*, having erect siliques and growing in rocky calcareous soils amongst sagebrush (Rollins 1993). *Boechera fecunda* flowers from April to June, and fruits mature from May through July (Lesica and Shelley 1995). *Boechera fecunda* has a mixed-mating system with selfing predominating over outcrossing (Hamilton and Mitchell-Olds 1994). During a study of the relative performance of selfed and outcrossed progeny of *B. fecunda*, evidence suggested that inbreeding depression occurred after selfing (Hamilton and Mitchell-Olds 1994). The inbreeding depression was expressed relatively late in life, by a lower plant dry weight of the adult plant. This characteristic may influence the competitive ability, over-wintering ability, and reproductive output of *B. fecunda* in situations where selfing predominates (Hamilton and Mitchell-Olds 1994). Although this variation in pollination strategy and potential for inbreeding depression was observed in *A. fecunda*, it may be useful to consider when planning further research on *B. crandallii*.

Although most records suggest the majority of plants were either flowering or with fruit, both vegetative and reproductive *Boechera crandallii* plants occur within one population. In contrast, seedlings have not been reported. It is not clear whether their absence is due to the seedlings being small and inconspicuous or actually due to rarity.

The longevity of mature plants is unknown. The current understanding appears to be that the plants are iteroparous (Rollins 1993). It is also not known whether flowering plants can revert to vegetative plants or whether the caudex (woody stem) serves as the organ of dormancy for one or more years during times of environmental stress.

No demographic studies have been undertaken on *Boechera crandallii*. However, demographic studies have been made on *B. fecunda* (Lesica and Shelly 1995), and these studies are useful to consider as they may relate to *B. crandallii*. Three populations of *B. fecunda* were studied over five years. Each population grew in a different habitat type at a different elevation although in all cases the soils were highly calcareous sandy loams. There was a high level of variation in demographic traits among the three populations studied. Stage-structured transition models were developed over the five years at each of the three sites. The density of *B. fecunda* and population size varied considerably between the populations and within populations over years. At one site the equilibrium growth rate was consistently low but stable. At another population, there was exceptional growth one year, followed by little or no growth in subsequent years. Elasticity analysis of the matrix projection models suggested that life strategies, recruitment, and survivorship also varied amongst populations and over time. At the site that had the most stable population size, adult survivorship contributed most to population growth whereas annual fecundity and recruitment were more important at the other two sites, one of which had a particularly variable population size over the years. Annual fecundity and recruitment were therefore negatively correlated with survivorship. These differences may be a reflection of the genetic diversity between populations. Therefore, it is important to consider that differences might exist between populations when making generalizations from observations of *B. crandallii* plants in only one part of its range. These results also emphasize the need for studies that compare populations within various habitats.

Much of the variation observed among the three populations of *Boechera fecunda* is due to a high level of axillary as well as terminal flowering. Largely because of this plasticity, *B. fecunda* exhibits a range of life history strategies, including semelparity and iteroparity, within a single population that maximize its fitness to changing environments (Lesica and Shelly 1995). This is an important reproductive feature that has not been documented for *B. crandallii*.

Characteristics that are known about the life cycle and habitat of *Boechera crandallii* suggest that it is an r-selected, or stress tolerant, species as outlined by MacArthur and Wilson (1967) and Grime et al. (1988). A simple lifecycle model is given in **Figure 6**. Although *B. crandallii* may sometimes be a monocarpic (semelparous) perennial, it is currently understood to be an iteroparous perennial species. Heavy arrows indicate phases in the life cycle that are known, and lighter weight arrows indicate the phases that need clarification. The steps that particularly need to be clarified are noted by "?" at the appropriate arrow.

Population viability analyses have not been made for *Boechera crandallii*. Population size appears to be naturally variable although large numbers of plants are frequently observed in a survey area. Lande (1988) suggested that demographic factors are likely more important than genetics in determining population viability. This may be a good generalization in some circumstances. For example, if habitat is destroyed, then the amount of genetic variation within a population

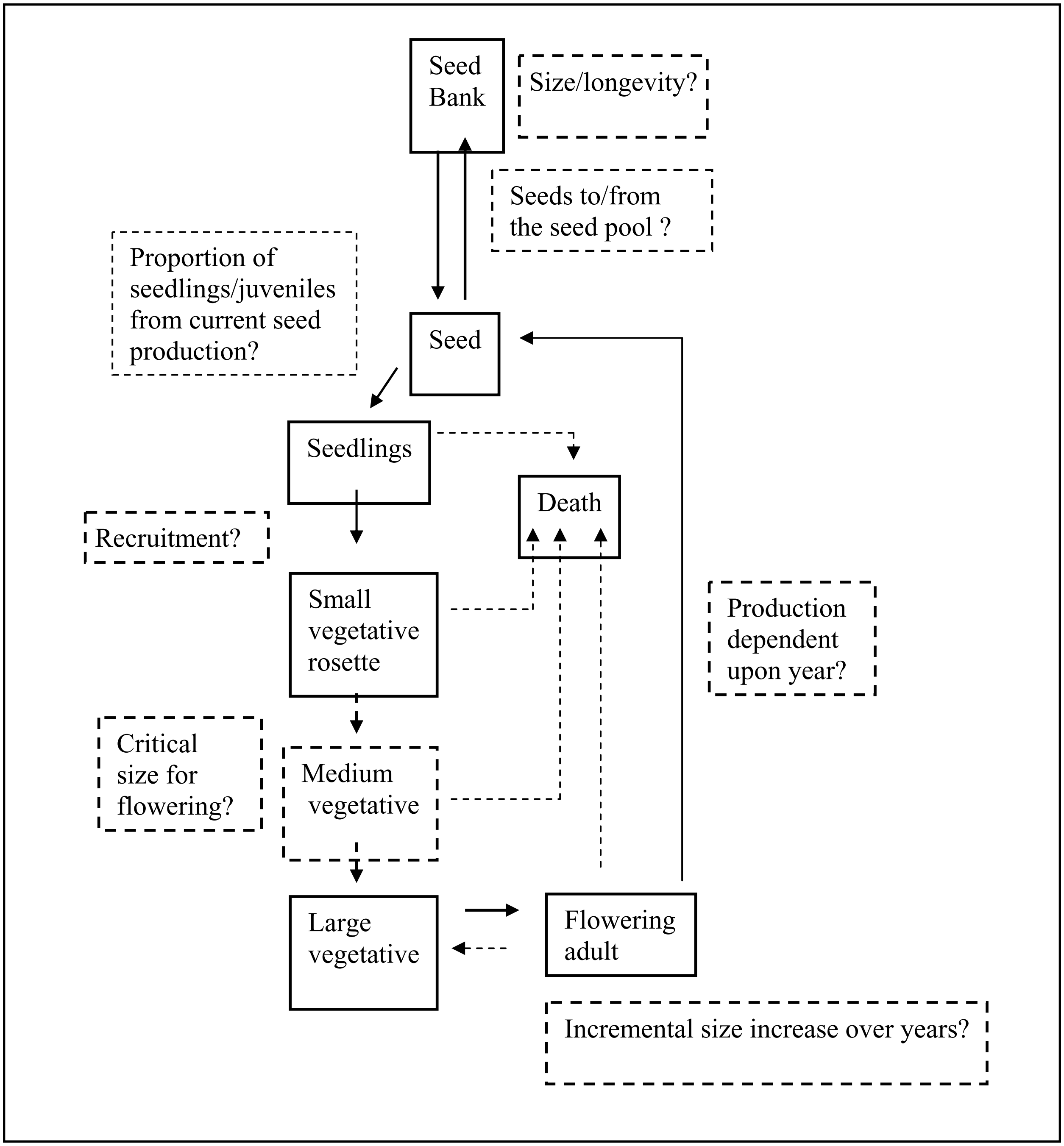

Figure 6. Life cycle diagram for *Boechera crandallii*.

is irrelevant. On the other hand, population size as a reflection of genetic variation may be of utmost importance if inbreeding depression occurs within some populations of *B. crandallii* (see Reproductive biology and autecology section).

Inbreeding is understood to maintain deleterious or lethal recessive alleles at very low frequencies by exposing them to selection in homozygotes (Lande and Schemcke 1985). Therefore, inbred (exclusively self-pollinated) populations may have reduced potential for inbreeding depression because the lethal and severely deleterious alleles have been selected against. Conversely, many plant species that normally reproduce by sib-mating or self-fertilization exhibit considerable heterosis upon outcrossing, which indicates that appreciable inbreeding depression exists within the inbred population (Lande 1988). Research on *Boechera fecunda* indicated that there was a strong maternal influence on progeny performance, which suggested that inbreeding depression was subject to the genetic load, or the number of recessive deleterious alleles, a given maternal genotype possessed (Hamilton and Mitchell-Olds 1994). An alternative explanation may be that the inbreeding depression observed in *B. fecunda* might be maintained by high rates of mildly deleterious mutation that would not be influenced by prior selection on genetic load (Hamilton and Mitchell-Olds 1994). If mutation rates vary among (maternal) parents, the theory of high rates of polygenic mutation is consistent with the evidence that maternal genetic load causes inbreeding depression. The conclusion to these observations is that populations with large numbers of individuals are likely necessary in order to maintain sustainable populations. Severely reduced numbers of individuals within a population would be likely to increase the deleterious impacts of inbreeding depression.

Considering the long-term viability of a population, Franklin (1980) and Lande and Barrowclough (1987) concluded that an effective population size of approximately 500 was sufficient to maintain evolutionary potential in quantitative characters under a balance between mutation and random genetic drift. Lande (1995) cited experiments, which indicated that "the rate of production of quasineutral, potentially adaptive genetic variance in quantitative characters is an order of magnitude smaller than the total variance" added through mutation, and suggested that the effective population size should be an order of magnitude higher, of approximately 5,000. Franklin and Franklin (1998) questioned this number on the basis that many estimates of the required mutational variance already partially accounted for deleterious mutations and heritabilities are often lower than the 50 percent value used by Lande (1995). After taking account of both these points the effective population size reverted to nearer 500 (Franklin and Franklin 1998). However, it is likely that the minimum viable population size will vary significantly from 500 and may approach 5,000 according to the differences in inherent variability among species, demographic constraints, and the evolutionary history of a population's structure (Frankham 1999).

Limits to population growth are not well-defined. Appropriate soils and local microhabitat conditions are likely to influence the establishment of individuals. It is unknown whether there is a balance of frequent local extirpations and colonizations within an area or whether, once established, microsites are occupied for long periods of time. Considering the research on *Boechera fecunda*, these factors may depend upon the population and the habitat conditions.

The inherent instability of the rocky and talus slopes of one of its habitat types suggests that the species grows in areas that experience some natural disturbance. In addition to the occasional rock displacements, there is a constant slide associated with talus slopes. In one study in Colorado, the mean displacement of talus (downslope slide) over a 25-year period was 14.7 m (48.2 ft.) or 0.59 m (1.9 ft.) per year. However, this "average rate" is highly variable as it was five times the rate measured at the same site in 1967. This is likely due to the fact that the 25-year period was marked by several high-intensity storms, including a 100-year precipitation event (52 mm [2 inches] in 8 hr). In addition, the dispersion patterns and travel distance were found to be highly variable within and between sections of the same talus deposits (Davinroy 1993). The shape of talus affected movement. As one would expect, displacement distance increases as particle shape approximated a sphere. Therefore, the shape of the rocks and gravels and their propensity for movement may contribute to the patchy nature of the distribution of *Boechera crandallii*, and *B. crandallii* may well grow in microsites that are relatively stable in an otherwise unstable environment.

There is no evidence to suggest the presence of a large or persistent seed bank, but a persistent seed bank is consistent with the model of a species whose habitats are subjected to temporary and unpredictable disturbance (Grime et al. 1988). Seed longevity has been proposed as a viable life-strategy alternative to long-distance seed dispersal (Harper and White 1974; see Reproductive biology and autecology section).

Community ecology

Systemic rust diseases (*Puccinia*) frequently infect *Boechera* and *Arabis* species. These fungal infections can cause severe reduction in survival and reproduction (Roy 1993, Roy and Bierzychudek 1993). *Puccinia monoica* was one of the first fungi species associated with *Boechera* to be identified (Roy 1993). In Colorado, *B. crandallii* was found infected with a related species, *P. consimilis*. The fungal infection causes a distinct change in morphology. Most noticeably a rosette of leaves, which becomes encrusted with yellow fungal spores, forms on a *Boechera* stem making it look like the plant has a yellow flower. The stems are typically shorter than a normal flowering stalk. These spore-encrusted leaves are termed pseudoflowers (Roy 1993). Interestingly, these structures are truly floral mimics. Not only do they morphologically resemble flowers, but they also produce fragrances that are attractive to bees and flies (Raguso and Roy 1998). The arthropods provide an important "pollination service" by transporting spores during the sexual cycle of these fungi. Pseudoflower fragrance is chemically distinct from the vegetative and floral volatiles produced by the host *Boechera* plants (Raguso and Roy 1998). One aromatic ester, benzyl acetate, was only detected when *B. crandallii* was the host, and sometimes in relatively large quantities. It was not detected when *P. consimilis* used *B. demissa* as host or among any of the other associations, namely *P. monoica* and *P. thlaspeos* on *B. holboellii* and *P. thlaspeos* on *B. gunnisoniana* (Raguso and Roy 1998). The ecological and biological significance of this unique scent is unknown. This association between rust fungus and *Boechera* species is very widespread, at least within New Mexico, Utah, and Colorado (author's personal observation). There is no information on the possible benefit of the fungal association to *B. crandallii*. One could speculate that it functions in processes of genetic selection, and by infecting perhaps weaker genotypes it may indirectly benefit the population by increasing fitness within a population.

Palatability to herbivores is not well-documented. The flowers and seeds of *Boechera* species are borne on a tall stem that makes them vulnerable to browsing and grazing animals. In some circumstances, both sheep and cattle readily eat *Boechera* species, especially when there is an absence of grasses (USDA Forest Service 1988). An observation was made that isopropyl isothiocyanate, a glucosinolate derivative characteristic of other crucifers, was isolated from the vegetative headspace of *B. crandallii* (Raguso and Roy 1998). Although this volatile compound can be quite pungent and unappealing to humans, it is unlikely to deter and might even attract some herbivores. In fact, *Pieris* species of butterflies choose only plants that contain glucosinolates as egg-laying sites for subsequent larval food (Chew 1975). *Boechera* species are also host plants for caterpillars of other members of the "Whites" or Pierinae subfamily, including *Euchloe* and *Anthocharis* spp. (Scott 1997). No information is available specifically on *B. crandallii*'s vulnerability to insect predation. Within the geographic range of *B. crandallii*, both *P. napi macdunnoughii* and *P. occidentalis* have been reported to oviposite on *B. drummondii* (Chew 1975, Chew 1977). *Boechera drummondii* was of an intermediate value as a food plant for the caterpillars as judged by the percent of eggs that hatched and reached maturity and by the speed with which development was completed (Chew 1975, Chew 1977). It is likely that these butterfly species would also use *B. crandallii* as a host plant. No observations have been made on the pollinators of the flowers, rather than the pseudoflowers, of *B. crandallii*. Although it appears to be predominantly self-pollinated, some cross-pollination activity may occur and be important to gene flow (see Reproductive biology and autecology section).

Results from a study by Lesica and Shelly (1992) indicated that microbiotic (cryptogamic) soil crusts benefited populations of *Boechera fecunda*. Apparently older plants had increased survival in microbiotic soils. No increase in the recruitment of *B. fecunda* was observed, although microbiotic crusts have been shown to benefit the seed germination and seedling establishment of other vascular plants (St. Clair et al. 1984). Another species, *B. falcifructa*, also appears to depend on the intact soil-surface moss cover for successful reproduction and/or survival at one or more stages of its life cycle (Morefield 1997). Associations between *B. crandallii* and non-vascular plants have not been reported. Although the rocky habitat of *B. crandallii* may not have microbiotic soils comparable to those associated with *B. fecunda* or *B. falcifructa*, there may be significant cover by certain species of lichen and moss. While the non-vascular component of the community has not been documented, it may be significant to the ecology of *B. crandallii* and merits further investigation.

An envirogram is a graphic representation of the components that influence the condition of a species and reflects its chance for reproduction and survival. Envirograms have been used especially to describe the conditions of animals (Andrewartha and Birch 1984) but may also be applied to describe the condition of plant species. Those components that directly impact *Boechera crandallii* make up the centrum, and the indirectly acting components constitute the web (**Figure 7**). Much of the information needed to make a comprehensive envirogram for *B. crandallii* is unavailable. The envirogram in **Figure 7** is constructed to outline some of the resource components that may directly impact the species. The factors are rather speculative but can be tested in the field by observation or by management manipulation. There is a lack of direct studies on this species that leads to the stretching the significance of observations and forming opinions from inference rather than fact. Inferences are subject to errors when used in predicting responses to management decisions.

In summary, resources in **Figure 7** include rocky soils that provide a suitable edaphic environment. The conditions required for seed germination and seedling establishment are not documented. The non-vascular members of the community may be important to population vigor. Pollinators for cross-pollination may

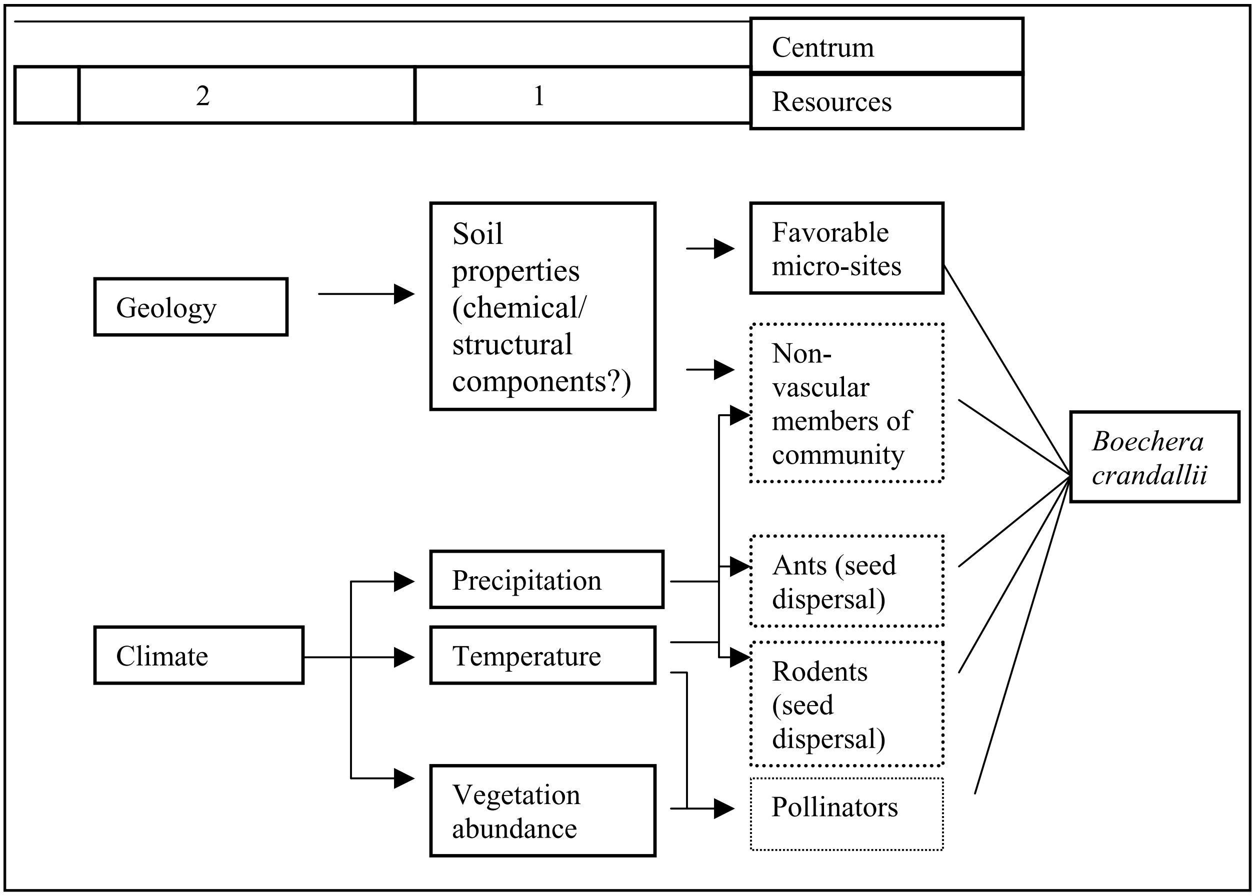

Figure 7. Envirogram of resources of *Boechera crandallii*. Dotted boxes indicate speculative factors.

be important to some populations. Ants, water, and wind may be agents of seed dispersal. All components of climate, most easily separated into temperature and precipitation, influence the population size of both plants and pollinators.

CONSERVATION

Threats

Threats and potential threats that have been identified are related to habitat loss caused by resource development activities and human recreation, herbivory, interspecific plant species competition, unusually high fungal infection rates, and global climate change. Some of these factors were alluded to in the Community ecology section. Although there is little on a local level that can be done to avoid the consequences of global warming, control of pressures that contribute to population stress may to some extent mitigate the impacts in the short term. Each threat or potential threat and its relevance to populations on land managed by the USFS Region 2 is discussed briefly in the following paragraphs.

Habitat loss appears to be a substantial concern. *Boechera crandallii* has already experienced loss of habitat in both Colorado and Wyoming (see Population trend section). As human population increases, this threat will become more significant. Development projects related to recreation, resource extraction, and urbanization are unlikely to stop. In particular, the slopes on which *B. crandallii* grows appear susceptible to any activity that increases soil erosion.

Development projects relating to recreation and road expansion appear to be the most significant threat on National Forest System land. Human activities, associated with the recreation site, impact the area more than the development of the site itself. *Boechera crandallii* grows near campgrounds on the Gunnison National Forest, for example near Taylor Reservoir and the Almont area. These populations are likely to be subject to high levels of disturbance from both hiking and off-road vehicle (ORV) recreation, the latter of which has become increasing popular and includes all-terrain vehicles (ATVs), dirt bikes, and four-wheel drive vehicles. Snowmobiles are also used within the range of *B. crandallii*. All forms of motorized vehicle recreation can severely disturb vegetation, cause accelerated soil erosion, increase soil compaction and add to pollution (Ryerson et al. 1977, Keddy et al. 1979, Aasheim 1980, Fahey and Wardle 1998, Belnap 2002, Misak et al. 2002, Gelbard and Harrison 2003, Durbin et al. 2004). The potential for snow compaction due to recreational activities, especially snowmobiling, is another cause for concern. Snow compaction can cause considerable below-surface vegetation damage (Neumann and Merriam 1972). Significant reductions in soil temperatures, which retard soil microbial activity and seed germination, may also result from snow compaction (Keddy et al. 1979, Aasheim 1980).

When Colorado began a program to register off-highway vehicles (OHVs) in the early 1990s, there were about 11,700 OHVs in the state (Purdy 2001). State records showed that in 2001 there were an estimated 62,000 OHVs (Purdy 2001). Although many routes are advertised for off-road vehicles in the Gunnison Basin (4-Wheel Drive/Offroading Undated), these are unlikely to threaten established *Boechera crandallii* occurrences. Threats are from the, often illegal, travel away from managed trails. In response to the considerable environmental damage caused by ORVs, the Grand Mesa, Uncompahgre, and Gunnison national forests proposed a new plan to better supervise motorized travel (Storch 2001). The decision was to restrict motorized and mechanized vehicle use to existing routes and to eliminate cross-country and off-route travel. The routes proposed for recreational vehicle travel in the National Forest were again revised in 2003 (USDA Forest Service Grand Mesa-Uncompahgre-Gunnison National Forest 2003). A similar amendment to restrict motorized vehicles to within 300 ft. (91 m) of managed trails and roads was proposed for the 1989 BLM Uncompahgre Basin Resource Management Plan (USDI Bureau of Land Management Colorado 2001).

The impacts of grazing by wildlife and livestock are not documented, but elk, deer, and livestock are all likely to use *Boechera crandallii* to some extent. The flowers and seeds of *Boechera* species are borne on a tall stem that make them vulnerable to browsing and grazing animals, and it is common to see "decapitated" *Boechera* species in the field, particularly in active grazing allotments (author's personal observation). The specific palatability of *B. crandallii* is not known, but *B. drummondii* and some other related species generally have low forage value (USDA Forest Service 1988). Although growing conditions and growth stage can influence palatability, its poor forage-value status appears to be due to its low abundance with respect to the presence of alternative forage. When *Boechera* species are more abundant, they attain a higher forage value (USDA Forest Service 1988). This is especially true on over-grazed range, where *Boechera* species have often increased while perennial grasses have been lost to heavy grazing pressure (USDA Forest Service 1988). Many areas where *B. crandallii* currently occurs, such as the bench above South Beaver Creek (occurrence 7 in **Table 1**), have been intensely used by elk, deer, and/or livestock for the last 120 years (Johnston personal communication 2003). Because of the continued presence of this species in these areas and based on the behavior of other *Boechera* species, Johnston (personal communication 2004) suggested that moderate grazing pressure might have led to a greater abundance of *B. crandallii*. There are insufficient records of historical abundance to evaluate this hypothesis, and while it appears that the species can persist under grazing pressures, it cannot be concluded that grazing has resulted in increased abundance without further study (i.e., monitoring plan). Length of time spent at a site, the extent of disturbance by hoof action, and the time of year the animals visit the site, as well as actual use of the plants, are all factors that need to be considered when evaluating the effects of grazing. Indirect affects to soil ecology may also be a factor to consider since livestock grazing negatively impacts microbiotic crusts (Anderson et al. 1982, Anderson et al. 1983, Jeffries and Klopatek 1987, Beymer and Klopatek 1992). Grazing during flowering and seed maturation would be expected to have a greater effect on potential reproductive effort than after seed dispersal in the fall. The impact of early season grazing on fecundity may be reduced if a high level of axillary as well as terminal flowering occurs amongst *B. crandallii* (see Demography section). Mid- to late season herbivory is likely to reduce seed production. The effect of grazing on the long-term survival of a particular plant species is also likely to depend upon the combination of animal species (Mack and Thomson 1982). Different species of animals with complementary plant species preferences at any given site will have far less impact than those with additive preferences.

The impacts from activities such as grazing, hiking, and horse-back riding are expected to be approximately proportional to the extent of use and the amount of disturbance. Considering fundamental ecological principles, two scenarios can be envisaged. Low numbers of people, cattle, and horses may create open habitat and a level of disturbance that would have little impact or possibly even reduce competition from other plant species for this apparently mid-successional species. However, large numbers of people, horses, and cattle cause direct destruction of vegetation and promote soil compaction and soil erosion, which are likely to interfere with the seed bank, plant reproduction, seedling establishment, and sustainability of adult plants. The relationship between the number of motor vehicles and their negative impact is apparently even more sensitive. Several passes by one or more motor vehicles will have greater negative impacts than just one pass of a vehicle (Payne et al. 1983). However even a single vehicle pass can destroy or disrupt microbiotic crusts and damage many types of plants and soils (Payne et al. 1983, Webb 1983, Wilshire 1983). In addition, just a single pass of one snowmobile causes significant snow compaction, which adversely affects snow permeability, soil properties beneath the snow, and snow melt properties (Keddy et al. 1979, Fahey and Wardle 1998).

The effects of fire on *Boechera crandallii* are also unknown. Some plants grow in areas with relatively high grass cover, which suggests that they have evolved in habitats that have the potential for sufficient litter accumulation to carry a fire. On the other hand, the species generally grows in rocky habitats that are typically unlikely to experience frequent or high intensity fires. Recovery after fire depends upon the size of the seed bank, longevity of the seed, or seed dispersal efficiency from adults in unburned areas.

Habitat loss from resource extraction activities is a threat in some regions, particularly on land managed by the BLM. Loss of habitat may be occurring in areas being actively mined for coal, such as in areas east of Rock Springs in Wyoming (Fertig et al. 1998). One population in Wyoming may have already been lost during the expansion of a coal mine (see Population trend section). Coal bed methane is starting to be developed in the Gunnison Basin, especially in Delta County (Colorado State University 2002, Gunnison Energy Corporation 2002-2004). However, the impact of this activity on *Boechera crandallii* habitat, especially on National Forest System lands, is not clear at the current time. *Boechera crandallii* habitat on National Forest System lands in Region 2 appears to be at the edge of potential resource extraction developments (Reese 1976, Gunnison Energy Corporation 2002-2004).

Boechera crandallii may be vulnerable to declines in pollinator populations. Although this species is primarily self-pollinated, a certain level of cross-pollination may be important (see Reproductive biology and autecology section). Arthropods are sensitive to pesticides, changes in plant community composition, livestock grazing practices (Sugden 1985), and habitat fragmentation (Bond 1995).

Weeds (non-native invasive plant species) may be a substantial threat to *Boechera crandallii*. The very low stature of the leaf canopy is likely to make this plant subject to dominance by taller species. Some *Boechera* species will increase on over-grazed range, presumably in response to a decrease in competition from grasses; this suggests that it might be relatively non-competitive with aggressive or invasive species. However, although it often grows in low-competition communities, it also grows with a relatively high number of species and has been reported in areas with high grass, forb, and shrub cover (see Habitat section). Therefore, its ability to persist, if not flourish, in such situations may be fairly good. More information on the position of individual plants within their community is necessary before the competitive ability of the species can be stated with certainty. In addition, many non-native invasive species secrete allelopathic chemicals into the soil, which contributes to habitat loss (Sheley and Petroff 1999). Vehicles, including ORVs, dirt bikes, and those associated with development projects such as earthmovers, will contribute to the spread of invasive weeds.

Natural catastrophes and environmental stochasticity appear to represent less imminent threats to *Boechera crandallii*. It is unclear how global climate change may affect this species. In the last century, the average temperature in Fort Collins, Colorado, has increased 4.1 °F (2.3 °C), and precipitation has decreased by approximately 5 percent in parts of the state where *B. crandallii* occurs (U.S. Environmental Protection Agency 1997). The Intergovernmental Panel on Climate Change and results from United Kingdom Hadley Centre's climate model (HadCM2) have projected that by 2100 temperatures in Colorado could increase by 3 to 4 °F (1.6 to 2.3 °C) in spring and fall, with a range of 1 to 8 °F (0.5 to 4.4 °C), and 5 to 6 °F (2.7 to 3.3 °C) in summer and winter with a range of 2 to 12 °F (1.1 to 6.7 °C) (US Environmental Protection Agency 1997). In Wyoming, precipitation has decreased by approximately 10 percent in parts of the state where *B. crandallii* occurs (U.S. Environmental Protection Agency 1998). Using the same HadCM2 model, by 2100, temperatures in Wyoming could increase by 4 °F (2.3 °C) in the spring and fall (with a range of 2 to 7 °F [1.1 to 3.9 °C]), 5 °F (2.7 °C) in summer (with a range of 2 to 8 °F [1.1 to 4.4 °C]) and 6 °F (3.3 °C) in winter with a range of 3 to 11 °F (1.6 to 6.1 °C). These changes may not have a profound affect on *B. crandallii* because it is apparently adapted to xeric conditions. However, global change may also encourage colonization by non-native plant species that might reduce available habitat.

As well as extrinsic factors that comprise elements of environmental stochasticity and natural catastrophes, intrinsic or biological uncertainties contribute to the species' vulnerability. These intrinsic uncertainties, which are typically addressed in population viability analysis, include elements of demographic stochasticity and genetic stochasticity (Shaffer 1981). Demographic stochasticity relates to the random variation in survival and fecundity of individuals within a fixed population. Genetic stochasticities are associated with random changes, such as inbreeding and founder effects, in the genetic structure of populations (see Reproductive biology and autecology section and Demography section). The potential threat from loss of genetic integrity by hybridization cannot be estimated without more information on the frequency of hybridization or pollination system. Several mechanisms (e.g., pollinator specificity, temporal differences in pollinator activity, or dominance of self-pollination) exist that keep sympatric taxa genetically isolated from each other and from the resulting hybrids (Grant 1981).

Few comments can be made on the influence of demographic stochasticity on individual populations because there is no information on the survival probability of individuals at any given life-stage or age. Studies on a related species suggest that demographic parameters may differ between populations; survival of the adult was most important in some populations while fecundity and recruitment were most important in others (see Demography section). Where survival of the adult is most important, disturbances such as those caused by ORV traffic may be particularly detrimental. Where occurrences are small, perhaps less than 50 individuals, demographic stochasticity may be significant (Pollard 1966, Keiding 1975). That is, chance events independent of the environment may affect the reproductive success and survival of individuals that, in very small populations, have an important influence on the survival of the whole population. Several *Boechera crandallii* occurrences appear to be very small, and therefore the fate of an individual can be relatively important to those populations (Kendall and Fox 2003).

Threats, or malentities, tend to be inter-related. It was difficult to include the relationship between most of the extrinsic threats and the enhanced susceptibility to fungal infection in the envirogram (**Figure 8**; see Community ecology section). **Figure 8** illustrates that extrinsic factors such as mining, recreation, weed infestations, road improvements, and grazing are apparently the primary range-wide threats to *Boechera crandallii*. All contribute to habitat loss. Consequences of inbreeding depression may become a significant threat if populations experience significant declines in size and number (see Demography section). Populations on National Forest System land are likely to be most vulnerable to invasive weeds encroaching their habitat, activities associated with recreation, and livestock grazing. Herbicides are generally applied to control the spread of weeds, but many will directly impact *Boechera* species as well as the target plant. Pesticide applications for management of tree pathogens may have a negative effect on the pollinator assemblage and abundance. Details of imminent threats specific to known occurrences are unavailable.

Conservation Status of the Species in Region 2

Boechera crandallii is not listed by Region 2 as a sensitive species (USDA Forest Service Region 2 2003). Surveys targeting this taxon have not been conducted. There is no evidence to support or refute the hypothesis that the distribution or abundance of this species is significantly changing. Some populations on National Forest System lands appear to have persisted over several decades (see Distribution and abundance section).

Anthropogenic activities have led to a loss of habitat, but the cumulative impact on the abundance and distribution of *Boechera crandallii* cannot be accurately estimated. Activities associated with recreation appear to be the greatest threats within its range on lands managed by Region 2. Disturbance and other impacts caused by ORV recreation are likely to be less than in the past, but the consequences of the recently implemented ORV restrictions on *B. crandallii* occurrences have not been documented (see Threats section). To quantitatively determine the results of changes in management, monitoring studies would need to be established. For example, because there are no precise records of its historical abundance, the consequences of restricting ORV cannot be quantitatively assessed. On National Forest System lands, the current level of threats does not appear to be substantially impacting the sustainability of this taxon. However, the emphasis is on current levels. Even if the intensity of a threat remains the same, an increase in its area of impact can have negative consequences on a species.

Boechera crandallii appears to be currently abundant within its limited range (Johnston personal communication 2003). Some occurrences were lost to developments (see Population trend section), but approximately 10 occurrences have been located on National Forest System lands within the last decade

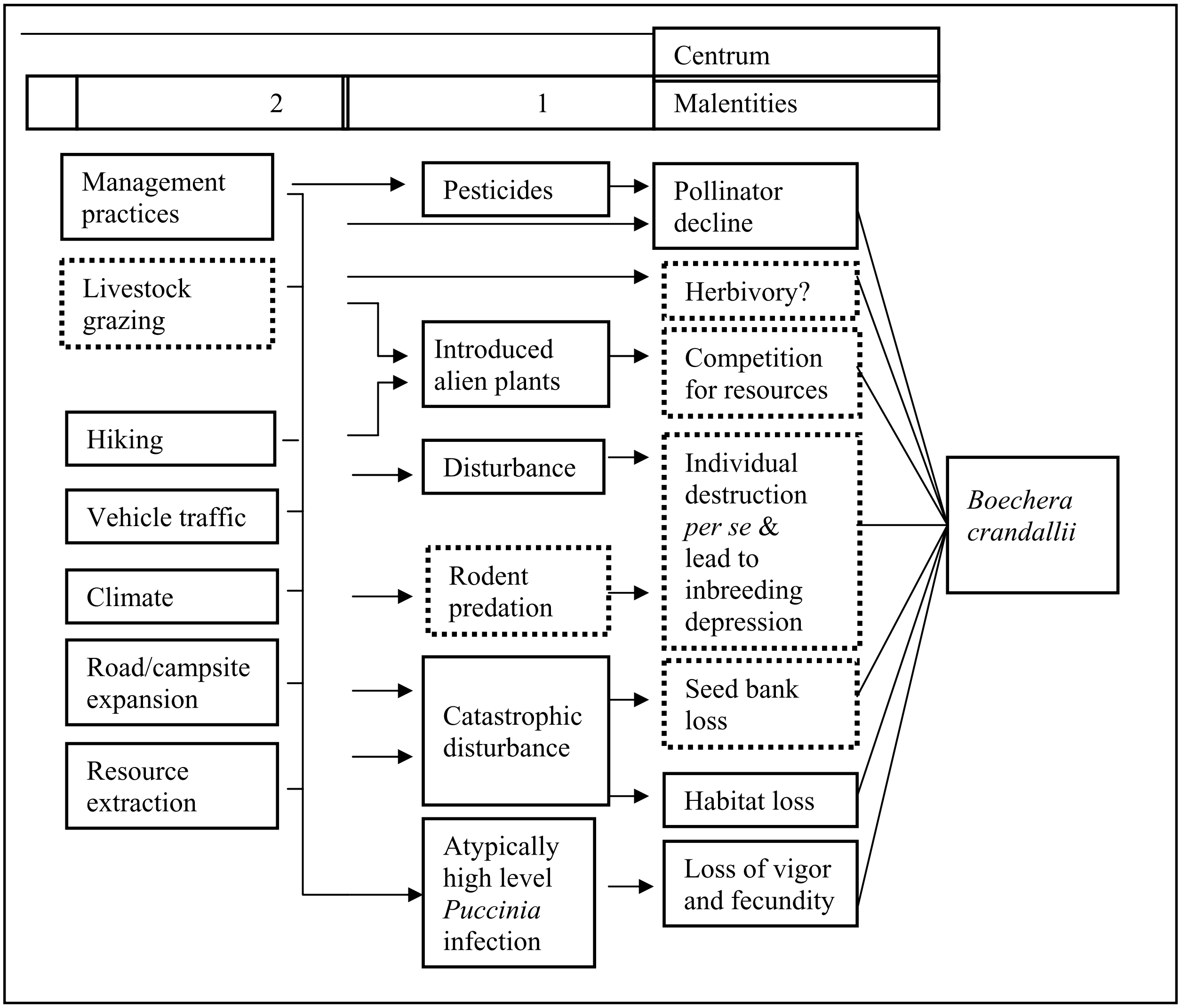

Figure 8. Envirogram outlining the malentities to *Boechera crandallii*. Dotted boxes indicate that the impact of the factor is uncertain.

(**Table 1**). A certain degree of caution needs to be recognized when evaluating apparent abundance because there is a significant chance that *B. pallidifolia* has been mistaken for *B. crandallii*. In addition, occurrences tend to be clustered suggesting that they would be equally vulnerable to many of the same stochasticities.

Management of the Species in Region 2

Implications and potential conservation elements

There are at least five main conservation elements:

- ❖ the sympatry of the morphologically similar taxon *Boechera pallidifolia*;
- ❖ the genetic variability among populations;
- ❖ the potential for inbreeding depression and pollinator dependency;
- ❖ the interactions between the components of the life cycle and management practices;
- ❖ the susceptibility to rust disease.

Each is briefly considered in the following paragraphs.

Although the uniqueness of *Boechera pallidifolia* has been questioned, it has been described as a unique taxon by Rollins (1993), who is a perceptive expert on the Brassicaceae (see Systematics and synonymy section). Therefore, the range and abundance of *B. pallidifolia* need to be determined in order to understand better the rarity of *B. crandallii*. It is clear that *B. crandallii* is a regional endemic, but if it has been mistaken for *B. pallidifolia*, then its rarity may have been underestimated.

Plants that self-fertilize may exhibit significant differences in genetic variation between populations because different alleles are fixed during inbreeding (Crawford 1983, Barrett and Shore 1989). Small populations of *Boechera crandallii* may be genetically depauperate (Roy 1995). This may be a result of changes in gene frequencies due to inbreeding or founder effects (Menges 1991). However, it is important not to underestimate the value of small populations. Alleles that are absent in larger populations may only be found in small populations (Karron et al. 1988). Therefore, in order to conserve genetic variability, in the absence of genetic (DNA) data, it is likely most important to conserve as many populations as possible in as large a geographic area as possible.

The potential for inbreeding depression (see Demography section) may be exacerbated by a reduction in population size. This is a serious consideration when evaluating the tolerance of the species to activities that would decrease the number of individuals within a population or reduce the available habitat around an existing population. A decline in abundance and/or a change in the assemblage of arthropod pollinators may also impose inbreeding.

When considering population management, it may be useful to consider the results of studies on *Boechera fecunda* that have demonstrated substantial differences as to life strategy among different populations (see Demography section). In some populations, the survival of adults was more important than seed production. In such cases, disturbance of the adult plants by ORVs or hikers may be more detrimental to population stability than in those populations where fecundity was most important (see Threats section). In addition, seed collected from a population at a significantly higher elevation became dormant after cold treatment whereas those from lower elevation habitats had no such reaction (Lesica and Shelley 1995; see Reproductive biology and autecology section). These observations suggest that populations are locally adapted, not only to environmental conditions, but also to the degree of natural disturbance they experience. If *B. crandallii* is used in vegetation restoration projects, it may be important to pay particular attention to the seed source.

Boechera crandallii is susceptible to *Puccinia* infection that can potentially reduce vigor and fecundity (see Community ecology section). Additional stresses to a plant (e.g., grazing pressure or disturbance from ORVs) may exacerbate the susceptibility and cause significant harm to a population. Maintaining an abundant, healthy, and appropriate assemblage of pollinators may also be important to population sustainability because *B. crandallii* may suffer from inbreeding depression (see Reproductive biology and autecology section and Demography section).

Tools and practices

Documented inventory and monitoring activities are needed to clarify the status and vulnerability of this species. Most of the occurrence information is derived from herbarium specimens or relatively casual observations by botanists and does not provide quantitative information on the abundance or spatial extent of the populations.

Species inventory

Inventory activities are important for this species. There is a possibility that *Boechera crandallii* can be mistaken in the field for *B. pallidifolia* (**Table 2**; Systematics and synonymy section), and this should be considered in inventory work. The current field survey forms for endangered, threatened, or sensitive plant species used by the Gunnison National Forest and the Colorado Natural Heritage Program (see Colorado Natural Heritage Program internet site) both request the collection of data that are appropriate for inventory purposes. The number of individuals, the area they occupy, and the apparent potential habitat are important data for occurrence comparison. The easiest way to describe populations over a large area may be to count patches, making note of their extent, and estimate or count the numbers of individuals within patches. Collecting information on size distributions and reproductive status (flowering plants versus rosettes versus seedlings) is also valuable in assessing the vigor of a population. The frequency with which plants are infected with *Puccinia* also needs to be noted. A good photograph of an infected *Boechera* plant is published in Roy (1993). It is important to record this feature of a population because the infection may impact future population vigor and fecundity and thus sustainability. Observations on habitat also need to be recorded, especially considering the habitat requirement of *B. pallidifolia* (see Habitat section).

Habitat inventory

The details of information on habitat supplied with descriptions of occurrences is generally insufficient to make accurate analyses. These descriptions suggest that, within the restrictions of geology and the eco-climate zones in which it exists, *Boechera crandallii* grows in a variety of rocky and gravel habitats. There is an insufficient understanding of all the features that constitute "potential" habitat to be able to make a rigorous inventory of areas that are likely to be colonized. In this case, potential habitat may only be defined as habitat that, from casual observation, appears suitable for the species, but that is not occupied by it. There are also no studies that relate the abundance or vigor of populations to habitat conditions.

Population monitoring

No monitoring or demographic studies have been reported. Permanent transects may be the most accurate way to study long-term trends. Lesica (1987) has discussed a technique for monitoring non-rhizomatous, perennial plant species using permanent belt transects. A method applying permanent belt transects was applied to a *Boechera* species that is morphologically comparable to *B. crandallii* (Lesica and Shelley 1995). Elzinga et al. (1998) and Goldsmith (1991) have discussed using a rectangular quadrant frame along transect lines to monitor effectively the "clumped-gradient nature" of populations that would apply to some populations. It is important to monitor the areas between sub-populations because the population dynamics are not known and shifts in stands within a population need to be noted. If it is a relatively short-lived perennial, a series of colonizations and localized extirpations would be expected. Information on size, or size class, rather than an attempt to describe the age of the individuals, could be included in the monitoring scheme (Gross 1981).

Specific monitoring plots with photo-points are very useful, not only in areas with recreational or resource extraction activities, but also in more pristine areas where the consequences of natural disturbances (e.g., erosion, landslides, local soil disturbance) can be evaluated. The monitoring scheme needs to address the patchy and possibly dynamic nature of some of these occurrences. Problems associated with spatial auto-correlation can occur when using permanent plots to monitor a dynamic population. If the size of the plot is too small or the establishment of new plots is not part of the original scheme, then when plants die and no replacement occurs, it is impossible to know the significance of the change without studying a very large number of similar plots.

Habitat monitoring

The relative lack of information on habitat requirements makes it premature to consider that habitat monitoring in the absence of plants can effectively occur. Habitat monitoring in the presence of plant occurrences needs to be associated with population monitoring protocols. Descriptions of habitat need to be recorded during population monitoring activities in order to link environmental conditions with abundance over the long term. Conditions several years prior to the onset of a decrease or increase in population size may be more important than conditions existing during the year the change is observed. Current land use designation and evidence of land use activities (e.g., hiking, biking, livestock grazing) is important to include with the monitoring data.

Population or habitat management approaches

There have been no systematic monitoring programs for this species and no documented attempts of active management. Some management practices to limit disturbance, such as restricting recreational vehicle traffic and routing hikers to designated trails, have been implemented in many areas within the Gunnison National Forest (Austin personal communication 2003). Monitoring populations in areas before and after such management practices have been implemented would be an ideal way to determine the consequences of the changes. However, such monitoring programs would need to be long-term because responses to such changes are sometimes not observed in either vegetation structure or individual plant behavior for several years or even decades, especially in semi-arid and arid environments (Vasek et al. 1975a, Vasek et al. 1975b, Kaye 2002, Guo 2004).

Information Needs

It is very important to acknowledge and, if there is doubt, to confirm the uniqueness of *Boechera pallidifolia*. Its range and abundance also need to be clarified. This would involve examination of herbarium specimens, as well as conducting field studies. Rollins (1993) reported that *B. crandallii* grows in the more open, sometimes windswept places and *B. pallidifolia* grows in the protected places frequently associated with sagebrush. During the study to distinguish between the two taxa, the possibility that different ecotypes of *B.*

crandallii exist also needs to be explored. Dissimilar environmental conditions can contribute to differences in gene expression that result in individuals with significantly different phenotypes.

There is little information on population structure and persistence of either *Boechera crandallii* individuals or populations. Monitoring pre-existing sites is essential in order to understand the implications of existing and new management practices. Where management practices are likely to change, inventory that collects baseline data can be compared to the results gathered during periodic monitoring conducted after the new policy is implemented. Creating a comprehensive inventory of this species will aid in evaluating the vulnerability of the species to local extirpations. Inventory surveys made in Daggett County, Utah and Moffat County, Colorado may be productive in locating occurrences between the two, somewhat disjunct, regions in which *B. crandallii* is currently known (Johnston personal communication 2004).

The factors that limit population size and abundance and that contribute to the variable occurrence sizes are not known. Habitat requirements, including any association with non-vascular species, need to be more rigorously defined, especially in light of the presence of the sympatric species, *Boechera pallidifolia*. Further analysis of the data collected in association with the Northern Gunnison Basin Vegetation Classification project might be very informative. Revisiting the transect lines specifically to study *B. crandallii* would appear to be a good approach to determine the condition of known populations and studying the relationship between *B. crandallii* and *B. pallidifolia*. Statistical analyses of the plants' morphological traits associated with habitat conditions would be very valuable, and additional isozyme or molecular studies might be very informative.

The relative importance of the existing seed bank versus seed dispersal to species sustainability is not known. More information is needed on the life history and population dynamics of this species. The rate of colonization and availability of appropriate habitat influence how populations recover after significant disturbance. Therefore, research would have to be carried out before artificially establishing new populations or including this species in a vegetation restoration effort. The potential impact of non-native invasive species is also unknown. More information on how this species responds to increased competition and non-native species is important because invasive non-native species are a substantial problem in many regions of Colorado and Wyoming (Colorado Department of Agriculture Undated, Markin 1995, Sheley and Petroff 1999).

A study on the genetic structure of populations, especially at the geographic limits of its range, would determine the amount of genetic diversity within *Boechera crandallii*. The frequency with which cross pollination occurs and the degree to which inbreeding depression occurs would help in assessing the genetic vulnerability of this species and its sensitivity to a decline in either population size or population number (see Threats section). If outcrossing occurs, specific information on the pollinator species and their behavior would assist in assessing the vulnerability of the species to pollinator reduction. Therefore, studies on aspects of the reproductive biology of *B. crandallii* to determine whether all populations are inbred and whether the species exhibits a mixed mating system could contribute to the process of making bio-rational decisions during management planning. In addition, the impact of *Puccinia* (rust) species infection on fecundity also needs to be assessed, particularly in areas where additional stresses, (e.g., livestock grazing or pollution from coal bed methane developments) occur.

In conclusion, answers to several questions would assist in appreciating the vulnerability of *Boechera crandallii*. These main information needs to can be summarized thus:

- ❖ Clarifying the range, abundance, and genetic uniqueness of *Boechera crandallii* relative to *B. pallidifolia*;
- ❖ Understanding the impacts of current land management practices, which could be achieved by long-term monitoring of known sites of *Boechera crandallii*;
- ❖ Developing an understanding of habitat requirements of *Boechera crandallii*;
- ❖ Understanding aspects of the genetic diversity and reproductive biology of *Boechera crandallii*, especially as they relate to the potential for inbreeding and pollinator dependency.

DEFINITIONS

Allele – Form of a given gene (Allaby 1992).

Allelopathy – "The release into the environment by an organism of a chemical substance that acts as a germination or growth inhibitor of another organism" (Allaby 1992).

Apomixis (Apomictic) – Refers to a type of asexual reproduction in plants (i.e., reproduction without fertilization or meiosis (Allaby 1992).

Auriculate – "With auricles," which are ear-shaped lobes or appendages (Harrington and Durrell 1986).

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

Caespitose – Growing in dense low tufts.

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

Cauline – Of, or pertaining to, the stem (Harrington and Durrell 1986).

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

Habitat fragmentation – Continuous stretches of habitat become divided into separate fragments by land use practices such as agriculture, housing development, logging, and resource extraction. Eventually, the separate fragments tend to become very small islands isolated from each other by areas that cannot support the original plant and animal communities and that cannot be easily traversed by animals (arthropods in this context).

Headspace – In this context, headspace is the gas volume at the top of a vessel containing the experimental subject.

Heterozygote – A diploid or polyploid individual that has different alleles at least one locus.

Iteroparous – Experiencing several reproductive periods, usually one each year for a number of years, before it dies.

Malentity – A malentity, when in contact with the subject organism, is capable of having an adverse affect on that organism with no adverse consequence to itself. A malentity can adversely influence the subject organism accidentally (e.g., rain causing a flash flood) or intentionally (e.g., a herbicide).

Metapopulation – Is a composite population. That is, a population of populations in discrete patches that are linked by migration and extinction.

Microbiotic soil crust – These were formerly referred to as cryptogamic soil crusts. They are composed of moss, lichen, liverworts, fungi, algae, and cyanobacteria in varying proportions.

Monophyletic – Applied to a group of species that share a common ancestry being derived for a single interbreeding population (Allaby 1992).

Polymorphic (polymorphism) – Having several different forms.

Precambrian granodiorite – A group of coarse grained plutonic rocks (granodiorite) from before the Paleozoic (equivalent to approximately 90 percent of geologic time; Bates and Jackson 1984).

Quartz monzonite – A granitic rock in which quartz comprises 10 to 50 percent of the felsic constituents (Bates and and Jackson 1984).

Rank – NatureServe (2003) and the Heritage Programs Ranking system, see Internet site: http://www.natureserve.org/explorer/granks.htm. G2 indicates *Boechera crandallii* is "imperiled—Imperiled globally because of rarity or because of some factor(s) making it very vulnerable to extinction or elimination. Typically 6 to 20 occurrences or few remaining individuals (1,000 to 3,000) or acres (2,000 to 10,000) (800 to 4,000 hectares) or linear miles (10 to 50) (16 to 80 km). S2 designation indicates that the species is "imperiled—Imperiled in the subnation [state] because of rarity or because of some factor(s) making it very vulnerable to extirpation from the nation or subnation. Typically 6 to 20 occurrences or few remaining individuals (1,000 to 3,000).

S1 designation indicates that the species is "critically imperiled—Critically imperiled in the subnation [state] because of extreme rarity or because of some factor(s) making it especially vulnerable to extirpation from the subnation. Typically 5 or fewer occurrences or very few individuals (<1,000)."

Semelparous — (semelparity) Reproducing once and then dying.

Sib-mating – The mating between sibs.

Silique – A dry, dehiscent and 2-celled fruit (Harrington and Durrell 1986). Often used to designate a mustard fruit that is elongated and much longer than it is wide.

Talus – "Talus slopes are composed of rocks the size of a fist or larger, usually sharp and loose" (Zwinger and Willard 1972). "Rock fragments, usually coarse and angular, lying at the base of a cliff or steep slope from which they have been derived; also, the heap or mass of such broken rock, considered as a unit. Synonym: scree" (Bates and Jackson 1984).

References

4-Wheel Drive / Offroading. Undated. Your Guide to 4-Wheel Drive / Offroading. Internet site: http://4wheeldrive.about.com/ [Accessed March 2005].

Aasheim, R. 1980. Snowmobile impacts on the natural environment. In Off-road vehicle use: A management challenge. R. Andrews and P. Nowak, editors. USDA Office of Environmental Quality, Washington, D.C.

Allaby, M. 1992 . The concise Oxford dictionary of Botany. Oxford University Press, New York, NY.

Allard, R.W. 1960. Principles of plant breeding. John Wiley and Sons, New York, NY.

Al-Shebaz, I.A. 2003. Transfer of most North American species of *Arabis* to *Boechera* (Brassicaceae). Novon 13: 381-391.

Anderson R.A., S.R. Rushforth, and J.R. Johansen. 1983. Effects of long term grazing on cryptogam cover in Navajo National Monument, Arizona. Journal of Range Management 36(5):579-581.

Anderson, D.C., K.T. Harper, and S.R. Rushforth. 1982. Recovery of Cryptogramic Crusts from Grazing on Utah Winter Ranges. Journal of Range Management 35(3):355-359.

Andrewartha, H.G. and L.C. Birch. 1984. The ecological web: more on the distribution and abundance of animals. University of Chicago Press, Chicago, IL.

Austin, Gay. 2003. Region 2 USDA Forest Service, Gunnison National Forest, CO. Personal communication.

Barrett, S.C.H. and J.S. Shore. 1989. Isozyme variation in colonizing plants. Pages 106-126 *in* D.E. Soltis and P.S. Soltis, editors. Isozymes in plant biology. Advances in Plant Sciences Series Vol. 4. Dioscorides Press, Portland, OR.

Baskin, C.C. and J.M. Baskin. 2001. Seeds - ecology, biogeography, and evolution of dormancy and germination. Academic Press, New York, NY.

Bates, R.L. and J.A. Jackson. 1984. Dictionary of geological terms. Third Edition. Doubleday, New York, NY.

Belnap, J. 2002. Impacts of off-road vehicles on nitrogen cycles in biological soil crusts: resistance in different U.S. deserts. Journal of Arid Environments. 52(2):155-165.

Benson D.A., I. Karsch-Mizrachi, D.J. Lipman, J. Ostell, B.A. Rapp, and D.L. Wheeler. 2000. GenBank. Nucleic Acids Research 28(1):15-18.

Beymer R.J. and J.M. Klopatek. 1992. Effects of grazing on cryptogamic crusts in pinyon-juniper woodlands in Grand Canyon National Park. American Midland Naturalist 127:139-148.

Biota of North America Program. 1998. Internet site: http://www.csdl.tamu.edu/FLORA/b98/check98.htm [Accessed June, 2003].

Bond, W.J. 1995. Assessing the risk of plant extinction due to pollinator and disperser failure. *In*: J.H. Lawton and R.M. May, editors. Extinction rates. Oxford University Press, New York, NY.

Chamberlain, T.C. 1897. The method of multiple working hypotheses. Journal of Geology 5:837-848 (reprinted in Science 148:754-759).

Chew, F.S. 1975. Coevolution of pierid butterflies and their cruciferous food plants. I. The relative quality of available resources. Oecologia 20:117-127.

Chew, F.S. 1977. Coevolution of pierid butterflies and their cruciferous food plants. II. The distribution of eggs on potential food plants. Evolution 31:568-579.

Colorado Department of Agriculture. Undated. Colorado's Noxious Weed Management Program. Colorado Department of Agriculture, Lakewood, Colorado. Internet site: http://www.colostate.edu/Depts/ SoilCrop/extension/CEPEP/noxious_weeds.htm [Accessed May 2003].

Colorado Natural Heritage Program. 2002. Data compilation for *JnJ Associates* LLC, completed September 2002. Unpublished report. Colorado Natural Heritage Program, Fort Collins, CO.

Colorado Natural Heritage Program On-line Rare Plant Guide, Fort Collins, Colorado, USA. Internet site: http://ndis.nrel.colostate.edu/ndis/rareplants [Accessed January, 2003].Online 03/25/05 at: http://www.cnhp.colostate.edu/rareplants/intro.html.

Colorado Natural Heritage Program. Field Data Submission Forms. Colorado Natural Heritage Program, Fort Collins, Colorado, USA. Available at Internet site: http://www.cnhp.colostate.edu/help.html#data [Accessed March 2005].

Colorado State University, Bioresource and Agricultural Engineering News. June 2002. Cooperative Extension Addresses Coal Bed Methane Extraction. Internet site: http://www.ext.colostate.edu/pubs/bioagnl/bio0206.html#gunnison [Accessed June 2003].

Conservation Management Institute. 1996. McDonald's Rock-cress, *Arabis McDonaldiana*, Species Id ESIS701020. Endangered Species Information System, Fish and Wildlife, Information Exchange. Last updated 14 March 2002 Virginia Tech, Blacksburg, Virginia. Internet site: http://fwie.fw.vt.edu/WWW/esis/lists/e701020.htm [Accessed July 2003].

Crawford, D.J. 1983. Phylogenetic and systematic inferences from electrophoretic studies. Pages 257-287 *in* S.O. Tanksley and T.J. Orton, editors. Isozymes in plant genetics and plant breeding. Part A. Elsevier, Amsterdam, Denmark.

Davinroy, T.C. 1993. A Twenty-Five Year Study of Talus Movement, Colorado Front Range. Proceedings - Niwot Ridge (Colorado) Long-Term Ecological Research Workshop, 21 August 1993. Niwot Ridge Long-Term Ecological Research Station, CO.

Dorn, R.D. 2001. Vascular plants of Wyoming. Third Edition. Mountain West Publishing, Cheyenne, WY.

Durbin, T.D., M.R. Smith, R.D. Wilson, and S.H. Rhee. 2004. In-use activity measurements for off-road motorcycles and all-terrain vehicles. Transportation Research Part D - Transport and Environment 9(3):209-219.

Elliott, B. and R.L. Hartman. 2000. A general floristic survey of the San Isabel and Rio Grande national forests, south of the Arkansas and South Arkansas rivers. Unpublished report. Rocky Mountain herbarium, Department of Botany, University of Wyoming, Laramie, WY.

Elzinga, C.L., D.W. Salzer, and J.W. Willoughby. 1998. Measuring and monitoring plant populations. Bureau of Land Management Technical Reference 1730-1. U.S. Department of Interior, Bureau of Land Management, Denver, CO.

Environmental Media Services. 2001. Definitions for Public Land Designations, Last update: April 27, 2001. Internet site: www.ems.org [Accessed December 2003].

Ewan, J. and N.D. Ewan. 1981. Biographical dictionary of Rocky Mountain Naturalists 1682-1932. Frans A. Stafleu, Utrecht, The Netherlands.

Fahey, B. and K. Wardle 1998. Likely impacts of snow grooming and related activities in the West Otago ski fields. Science for Conservation 85. Published by Department of Conservation, Wellington, New Zealand. Document in PDF format available at Internet site: http://www.doc.govt.nz/Publications/004~Science-and-Research/Science-for-Conservation/PDF/sfc085.pdf.

Fertig, W. 2000. State Species Abstract – *Arabis crandallii*, Crandall's rockcress. Wyoming Natural Diversity Database Web site. Internet site: http://uwadmnweb.uwyo.edu/wyndd/ [Accessed June 2003].

Fertig, W. 2002. Region 2 sensitive species evaluation form. Attachment to Region 2 Regional Forester Sensitive species list in 2003. Unpublished document. USDA Forest Service, Denver, CO.

Fertig, W., L. Welp, and S. Markow. 1998. The Status of Rare Plants in Southwest Wyoming. Unpublished document prepared for the Bureau of Land Management, Wyoming State Office under Agreement # K910-A4-0011. Bureau of Land Management, Wyoming State Office, Cheyenne, WY.

Frankham, R. 1999. Quantitative genetics in conservation biology. Genetic Research, Cambridge 74:237-244.

Franklin, I.R. 1980. Evolutionary change in small populations. Pages 135-150 *in* M.E. Soulé and B.A. Wilcox, editors. Conservation Biology: An Evolutionary-Ecological Perspective. Sinauer, Sunderland, MA.

Franklin, I.R. and R. Frankham. 1998. How large must populations be to retain evolutionary potential? Animal Conservation 1:69-71.

Gelbard, J.L. and S. Harrison. 2003. Roadless habitats as refuges for native grasslands: interactions with soil, aspect, and grazing. Ecological Applications 13(2):404-415.

Goldsmith, F.B. 1991. Monitoring for conservation and ecology. Chapman and Hall, New York, NY.

Goodrich, S.K. 2003. Region 4 USDA Forest Service, Ashley National Forest, Utah. Personal communication.

Grant, V. 1981. Plant speciation. Second Edition. Columbia University Press, New York, NY.

Greene, E.L. 1901. *Arabis stenoloba*. Plantae Bakerianae 3:8.

Grime, J.P., J.G. Hodgson, and R. Hunt. 1988. Comparative plant ecology – a functional approach to common British species. Allen and Unwin, Inc., Winchester, MA.

Gross, K.L. 1981. Predictions of fate from rosette size in four "biennial" plant species: *Verbascum thapsus*, *Oenothera biennis*, *Daucus carota*, and *Tragapogon dubius*. Oecologia 48:209-213.

Gunnison Energy Corporation. 2002-2004. Gunnison Energy Corporation, a Denver-based corporation, has acquired oil and gas leases covering in excess of 90,000 acres of private and federal lands in the North Fork Valley of Western Colorado. Relevant web pages describing the project start at Internet site: http://www.northforkvalleyproject.com/index.php; Specifically for map: http://www.northforkvalleyproject.com/maps/wellmap.html [Accessed March 2005].

Guo, Q. 2004. Slow recovery in desert perennial vegetation following prolonged human disturbance. Journal of Vegetation Science 15(6):757-762.

Guralnik , D. 1982. Webster's New World Dictionary. Simon and Schuster, New York, NY.

Hamilton, M.B. and T. Mitchell-Olds. 1994. The mating system and relative performance of selfed and outcrossed progeny in *Arabis fecunda* (Brassicaceae). American Journal of Botany 81(10):1252-1256.

Hamrick, J.L. 1989. Isozymes and the analysis of genetic structure in plant populations. Pages 106-126 *in* D.E. Soltis and P.S. Soltis, editors. Isozymes in plant biology. Advances in Plant Sciences Series Vol. 4. Dioscorides Press, Portland, OR.

Harper, J.L. and J. White. 1974. The demography of plants. Annual Reviews Ecology and Systematics 5:419-463.

Harrington, H.D. and L.W. Durrell. 1986. How to identify plants. Third printing. Swallow Press, Athens, OH.

Harvard University Herbaria, Cambridge MA. Collections and publications database. Internet site: http://brimsa.huh.harvard.edu [Accessed February, 2003].

Hillborn, R. and M. Mangel. 1997. The ecological detective: confronting models with data. Princeton University Press, Princeton, NJ.

Houston, Kent. 2003. Region 2 USDA Forest Service, Shoshone National Forest, WY. Personal communication.

Jeffries D.L. and J.M. Klopatek. 1987. Effects of grazing on the vegetation of the blackbrush association. Journal Range Management 40(5):390-392.

Johnston, Barry C. 2003. Region 2 USDA Forest Service, Grand Mesa, Uncompahgre and Gunnison National Forests, Supervisor's Office, CO. Personal communication.

Johnston, Barry C. 2004. Region 2 USDA Forest Service, Grand Mesa, Uncompahgre and Gunnison National Forests, Supervisor's Office, CO. Personal communication.

Johnston, B.C., L. Huckaby, T.J. Hughes, and J. Pecor. 2001. Ecological types of the Upper Gunnison Basin: Vegetation-soil-landform-geology-climate-water land classes for natural resource management. Technical Report R2-RR-2001-0, May. USDA Forest Service, Rocky Mountain Region. Lakewood, CO.

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

Kaye, T.N. 2002. Effects of cattle grazing, insect interactions and population ecology of Snake River goldenweed (*Haplopappus radiatus*). Final Report. Unpublished report of the Bureau of Land Management Vale District, Oregon and the Institute for Applied Ecology, Corvallis, Oregon. Available in PDF format at Internet site: http://www.appliedeco.org/reports.html [Accessed January 2005].

Keddy, P.A., A.J. Spavold, and C.J. Keddy. 1979. Snowmobile impact on old field and marsh vegetation in Nova Scotia, Canada: An experimental study. Environmental Management 88(10):409-415.

Keiding, N. 1975. Extinction and exponential growth in random environments. Theoretical Population Biology 8: 49-63.

Kendall, B.E. and G.A. Fox. 2003. Unstructured individual variation and demographic stochasticity. Conservation Biology 17(4):1170-1172.

Lande, R. and G.F. Barrowclough. 1987. Effective population size, genetic variation, and their use in population management. Pages 87-123 *in* M.E. Soulé, editor. Viable populations for conservation. Cambridge University Press, Cambridge, U.K.

Lande, R.1988. Genetics and demography in biological conservation. Science 241:1455-1460.

Lande, R. 1995. Mutation and conservation. Conservation Biology 9:782-791.

Lande, R. and D.W. Schemske. 1985. The evolution of self-fertilization and inbreeding depression in plants. I. Genetic models. Evolution 39:24-40.

Lesica, P. 1987. A technique for monitoring non-rhizomatous, perennial plant species in permanent belt transects. Natural Areas Journal 7(2):65-68.

Lesica, P. and J.S. Shelly. 1992. Effects of cryptogamic soil crust on the population dynamics of *Arabis fecunda* (Brassicaceae). American Midland naturalist 128:53-60.

Lesica, P. and J.S. Shelly. 1995. Effects of reproductive mode on demography and life history in *Arabis fecunda* (Brassicaceae). American Journal of Botany 82(6):752-762.

Löve, A. and D. Löve. 1975. Nomenclatural notes on arctic plants. Botaniska notiser 128:498-523.

MacArthur, R.H. and E.D. Wilson. 1967. The theory of island biogeography. Princeton University Press, Princeton, NJ.

Mack, R.N. and J.N. Thompson. 1982. Evolution in steppe with few large hooved mammals. The American Naturalist 119(6):757-773.

Markin, G.P. 1995. Weeds of National Forest Lands of the Northern Rockies. In: Biological Control, Ecology and Management of Northern Rocky Mountain Forests. USDA Forest Service, Rocky Mountain Research Work Unit 4151. Available in PDF format at Internet site: www.fs.fed.us/rm/ecology/studies/biocontrol/weeds_NFL_report.pdf.

Marriott, H. 2003. Scoping comments for revision of Rawlins resource management plan (BLM): Plant biodiversity issues. Unpublished document. Available at Internet site: http://www.biodiversityassociates.org/greatdivide/MarriottGDRMPRarePlants1.pdf [Accessed march 2005].

Menges, E.S. 1991. The application of minimum viable population theory to plants. Pages 45-61 *in* D.A. Falk and K.E. Holsinger, editors. Genetics and conservation of rare plants. Oxford University Press, New York, NY.

Merriam, C.H. 1894. Laws of Temperature Control of the Geographic Distribution of Terrestrial Animals and Plants. National Geographic Magazine 6(1894):229-238. Online at: http://www.wku.edu/~smithch/biogeog/MERR1894.htm [Accessed April 2005].

Misak, R.F., J.M. Al Awadhi, S.A. Omar, and S.A. Shahid. 2002. Soil degradation in Kabd area, southwestern Kuwait city. Land Degradation and Development. 13(5):403-415.

Missouri Botanical Garden. TROPICOS Nomenclatural Data Base, Missouri Botanical Garden, St. Louis, Missouri, USA. Specimen listed under *Arabis crandallii*. Internet site: http://mobot.mobot.org [Accessed June 2003]; direct link: http://mobot.mobot.org/cgi-bin/search_vast?ssdp=01610481 [Accessed March 2005].

Mitchell-Olds, T. 2003. Max Planck Institute of Chemical Ecology, Jena, Germany. Personal communication.

Morefield, J.D. 1997 (minor editorial revisions June 2002). Current Knowledge and Conservation Status of *Arabis falcifructa* Rollins (Brassicaceae), the Elko rockcress. Nevada Natural Heritage Program, Department of Conservation and Natural Resources, Carson City, Nevada. Status report prepared for Bureau of Land Management, Nevada State Office, Reno, NV.

National Center for Biotechnology Information. 2001. Internet site: http://www.ncbi.nlm.nih.gov/Taxonomy/taxonomyhome.html/ [Accessed January, 2003].

National Oceanic and Atmospheric Administration. 2004. CoRIS - NOAA's Coral Reef Information System (http://coris.noaa.gov/welcome.html). Glossary section. Internet site: http://www6.nos.noaa.gov/coris/glossary.lasso?letter=p [Accessed July 2004].

NatureServe. 2003. NatureServe Explorer: An online encyclopedia of life [web application]. Version 1.8. NatureServe, Arlington, Virginia. Available http://www.natureserve.org/explorer [Accessed June 12, 2003].

Neumann, P.W. and H.G. Merriam. 1972. Ecological effects of snowmobiles. Can. Field Naturalist 86(3):207-212.

New York Botanical Garden. Herbarium records. Internet site: http://scisun.nybg.org:8890/ [Accessed May 2003].

Orthner, A.R. 1999. Flora of the Buffalo Peaks Wilderness area and vicinity, Mosquito range, Colorado. Unpublished M.S. thesis. University of Colorado, Boulder, CO.

Payne, G.F., J.W. Foster, and W.C. Leininger 1983. Vehicle impacts on northern Great Plains range vegetation Montana, livestock grazing, soils Journal of Range Management 36(3):327-331.

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

Pollard, J.H. 1966. On the use of the direct matrix product in analyzing certain stochastic population models. Biometrika 53:397-415.

Purdy, P. 2001. Monitoring ORVs not an easy job. Feb. 11, 2001. Denver Post (newspaper), Denver, CO.

Raguso, R.A. and B.A. Roy. 1998. 'Floral' scent production by *Puccinia* rust fungi that mimic flowers. Molecular Ecology 7:1127-1136.

Reese, D.L. 1976. Developments in Four Corner-Intermountain area in 1975. The American Association of Petroleum Geologists Bulletin 60(8):1239-1242.

Rollins, R.C. 1941. Monographic study of *Arabis* in western North America. Rhodora 43:289-483.

Rollins, R.C. 1966. Chromosome numbers of Cruciferae. Contributions from the Gray herbarium at Harvard University No. 197:43-65.

Rollins, R.C. 1993. Cruciferae of continental North America – Systematics of the mustard family from the Arctic to Panama. Stanford University Press, Stanford, CA.

Roy, B.A. 1993. Floral mimicry by a plant pathogen. Nature 362:56-58.

Roy, B.A. 1995. The breeding systems of six species of *Arabis* (Brassicaceae). American Journal of Botany 82(7): 869-877.

Roy, B.A. 2001. Patterns of Association between crucifers and their flower-mimic pathogens: host jumps are more common than coevolution or cospeciation. Evolution 55(1):41-53.

Roy, B.A. 2003. University of Oregon, Eugene, OR. Personal communication.

Roy, B.A. and P. Bierzychudek. 1993. The potential for rust infection to cause natural selection in apomictic *A. holboellii* (Brassicaceae). Oecologia 95:533-541.

Ryerson, D.K., D.A. Schlough, C.L. Foreman, G.H. Tenpas, and J.W. Pendleton. 1977. Effects of snowmobile traffic on several forage species and winter wheat. Agronomy Journal 69(5):769-772.

Scott, J.A. 1997. The butterflies of North America: a natural history and field guide. Stanford University Press, Stanford, CA.

Shaffer, M.L. 1981. Minimum population sizes for species conservation. Bioscience 31:131-134.

Sharbel, T.F. and T. Mitchell-Olds. 2001. Recurrent polyploid origins and chloroplast phylogeography in the *Arabis holboellii* complex (Brassicaceae). Heredity 87:59-68.

Sharbel, T.F., M-L. Voigt, T. Mitchell-Olds, L. Kantama, and H. de Jong. 2004. What Are B Chromosomes? Is the aneuploid chromosome in an apomictic *Boechera holboellii* a genuine B chromosome? Cytogenetic and Genome Research 106:173-183.

Sheley, R.L. and J.K. Petroff.1999. Biology and management of noxious rangeland weeds. Oregon State University Press, Corvallis, OR.

Silvertown, J.W. 1987. Introduction to plant population ecology. Second Edition. Longman Scientific and Technical, Harlow, England, UK.

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

St. Clair, L.L., B.L. Webb, J.R. Johansen, and G.T. Nebecker. 1984. Cryptogamic soil crusts: Enhancement of seedling establishment in disturbed and undisturbed areas. Reclamation and Revegetation Research 3:129-136.

Storch, R.L. 2001. Gunnison travel interim restrictions. Decision notice and finding of no significant impact. Portions of Gunnison, Hinsdale, Delta, Montrose, and Saguache Counties, Colorado, March, 2001. Forest Supervisor, Grand Mesa, Uncompahgre and Gunnison National Forests, Delta, CO.

Sugden, E.A. 1985. Pollinators of *Astragalus monoensis* Barneby (Fabaceae): new host records; potential impact of sheep grazing. Great Basin Naturalist 45(2):299-312.

USDA Forest Service. 1988. Range Plant Handbook Dover Reprint. Dover Publications, Inc., New York, NY.

USDA Forest Service. 2003. Transect data from data collected in the Northern Gunnison Basin Vegetation Classification Project. Unpublished data provided by Johnston personal communication 2003.

USDA Forest Service Grand Mesa-Uncompahgre-Gunnison National Forest. 2003. Revised Grand Mesa-Uncompahgre-Gunnison National Forest travel plan, USDA National Forest. Map at Internet site: www.fs.fed.us/r2/gmug/policy/gm_travel/fonsi_dec2003_map2.pdf [Accessed March 2005].

USDA Forest Service GMUG, SJ-RG and PISCC. 1999. TES Plant Management Strategy, Grand Mesa, Uncompahgre and Gunnison, San Juan, Rio Grande, Pike-San Isabel National Forests and Comanche-Cimarron National Grasslands. Five year action plan 1999 to 2003. USDA Forest Service GMUG, Delta, CO.

USDA Forest Service Region 2. 2003. Threatened, endangered and sensitive plants and animals. Supplement No.: 2600-2003-1. Unpublished document. USDA Forest Service, Denver, CO.

USDA Forest Service Rocky Mountain Region. 2003. Unpublished summary tables and spatial data provided for this assessment by USDA Forest Service, Rocky Mountain Region, Denver, CO.

USDI Bureau of Land Management Colorado. 2000. Colorado BLM State Director's Sensitive Species list (animals and plants). June 2000. Available at Internet site: http://www.co.blm.gov [Accessed March 2005].

USDI Bureau of Land Management Colorado. 2001. Proposed amendment to Standard Management and Management Unit Prescriptions for Off-Road Vehicle (OHV) use and designations in the Uncompahgre Basin Resource Management Plan, July, 1989. USDI Bureau of Land Management Colorado, document available at Internet site: http://www.co.blm.gov/ubra/ohv-ufo.htm [Accessed February 2005].

USDI Bureau of Land Management Wyoming. 2002. Wyoming BLM State Director's Sensitive Species list (September 20, 2002). Internet site: http://www.wy.blm.gov/botany/status.htm [Accessed March 2005].

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

U.S. Environmental Protection Agency. 1998. Climate Change and Wyoming. EPA 236-F-98-007n. Office of Policy, Planning and Evaluation, Climate and Policy Assessment Division, Washington D.C.

Vasek, F.C., H.B. Johnson, and G.D. Brum. 1975a. Effects of power transmission lines on vegetation of the Mojave Desert. Madroño 23:114131.

Vasek, F.C., H.B. Johnson, and D.H. Eslinger. 1975b. Effects of pipeline construction on creosote bush scrub vegetation of the Mojave Desert. Madroño 23:113.

Walker, S.R. and P.M. Santi. 2004. Influence of the Blue Mesa Reservoir on the Red Creek Landslide, Colorado. Environmental and Engineering Geoscience 10(1):13-26.

Ward, B.A. 1998. A floristic survey of south-central Wyoming. Unpublished M.S. thesis. University of Wyoming, Laramie, WY.

Webb, R.H. 1983. Compaction of desert soils by off-road vehicles. Pages 51-79 *in* R.H. Webb and H.G. Wilshire, editors. Environmental effects of off-road vehicles: Impacts and management in arid regions. Springer-Verlag, New York, NY.

Weber, W.A. 1982. New names and combinations, principally in the Rocky Mountain Flora – II. Phytologia 51(6): 369.

Weber, W.A. and R.C. Wittmann. 2001. Colorado Flora – western slope. Third edition. University Press of Colorado, Boulder, CO.

Wheeler D.L., C. Chappey, A.E. Lash, D.D. Leipe, T.L. Madden, G.D. Schuler, T.A. Tatusova, and B.A. Rapp. 2000. Database resources of the National Center for Biotechnology Information. Nucleic Acids Research 28(1): 10-4.

Wilshire, H.G. 1983. The impact of vehicles on desert soil stabilizers. Pages 31-50 *in* R.H. Webb and H.G. Wilshire, editors. Environmental effects of off-road vehicles: Impacts and management in arid regions. Springer-Verlag, New York, NY.

Wyoming Natural Diversity Database. 2002. Data compilation for *JnJ Associates* LLC, completed September 2002. Unpublished report. Wyoming Natural Diversity Database, University of Wyoming, Laramie, WY.

Wyoming Natural Diversity Database. 2003. Wyoming Natural Diversity Database, Laramie, WY. Internet site: http: //uwadmnweb.uwyo.edu/wyndd/ [Accessed March 2003].

Zwinger, A.H. and B.E. Willard. 1972. Land above the trees, a guide to American alpine tundra. Reprinted 1996. Harper and Row Publishers Inc., New York, NY.