Braya glabella ssp. *glabella* Richardson (smooth northern-rockcress): A Technical Conservation Assessment

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Rocky Mountain Region,
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Lynn Moore[1], Sandy Friedley[2], and Donald L. Hazlett, Ph.D.[3]

[1]Windom Floristics, 15000 West Tye Moore Road, Casper, WY 82604
[2]Ecosphere Environmental Services, 2257 Main Street, Patio Level, Durango, CO 81301
[3]New World Plants and People, P.O. Box 345, Pierce, CO 80650

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Authors' Biographies

Lynn Moore is a botanist and the owner of Windom Floristics. Lynn graduated from Fort Lewis College, Colorado with a Bachelor of Science in Biology in 1992 and continued her graduate work at the University of Wyoming, where she finished a Masters of Science degree in Botany in 1998. Lynn has worked as an independent botanical contractor in the Four Corners area since 1997. She has experience in threatened and endangered species surveys, noxious weed surveys, environmental assessments, wetland delineations, and floristic surveys. Lynn is currently working on the treatments of three families, the Geraniaceae, Fumariaceae, and the Papervaceae for the Flora of the San Juan Basin project. She actively researches the flora of the San Juan Mountains and adjacent areas through funding provided by small grants for floristic studies.

Sandy Friedley is a botanist with Ecosphere Environmental Services. Sandy graduated from the University of Colorado with a Bachelor of Arts in Environmental Biology and continued her graduate work at Western State College, Colorado, where she received a Master of Arts degree in Environmental Biology. Sandy has worked with Ecosphere since 1999, performing baseline botanical inventories, species-specific surveys, wetland delineations, due diligence environmental site assessments, and regulatory compliance and permitting

Donald L. Hazlett is an ecologist/botanist/ethnobotanist with New World Plants and People. He earned a Ph.D from the College of Forest Resources, University of Washington, a Master of Arts degree in ecology from the University of South Dakota, and a Bachelor of Arts degree from Augustana College, South Dakota. His Ph.D. work was on the succession of floristic diversity in a lowland tropical forest in Honduras. He returned to his home state of Colorado in 1985, but remained active in tropical ecology and ethnobotany by teaching field courses in Ecuador and Costa Rica until 1993. Don has taught many college level biology courses, founded a consulting business, and continues to develop his expertise in the flora of the Great Plains and ethnobotany. His consulting work has allowed him to gain field experiences in most western states. He also spent a summer in the Alaskan tundra and has worked in the Rocky Mountain alpine. His peer-reviewed publications include checklists of vascular plants from the Comanche and Pawnee National Grasslands. He is currently working on a similar publication for the Kiowa and Rita Blanca National Grasslands and is documenting the Spanish common names for native plants in Colorado and New Mexico.

Cover Photo Credit

Braya glabella ssp. *glabella* (smooth northern rock-cress). Photographed by Mollie MacCormac. Used with permission of the authors of the Flora of the Canadian Archipelago.

SUMMARY OF KEY COMPONENTS FOR CONSERVATION OF *BRAYA GLABELLA* SSP. *GLABELLA*

Braya glabella ssp. *glabella* Richardson (smooth northern-rockcress) is a circumboreal species, with occurrences in the montane, subarctic, and low arctic of Greenland, Eurasia, and the Canadian Arctic Archipelago. Occurrences in Colorado and Wyoming are significantly disjunct from the main range of the species. On National Forest System land in Region 2 and Region 4, *B. glabella* ssp. *glabella* is a plant of the high mountains, typically located in the alpine biogeographic zone.

Braya glabella ssp. *glabella* is not listed as threatened or endangered, nor is it a candidate for listing under the federal Endangered Species Act. The taxon is designated a sensitive species on National Forest System land in Region 2, but not Region 4. The Bureau of Land Management does not list it as a sensitive species in Colorado or Wyoming. The conservation status rank assigned by NatureServe to this taxon is G5TNR (species secure, infraspecific taxon not ranked). The Colorado Natural Heritage Program and the Wyoming Natural Diversity Database have both given *B. glabella* ssp. *glabella* a state rank of S1 (critically imperiled because of extreme rarity). In Canada, the taxon is not ranked in Alberta, British Columbia, Labrador, the Northwest Territories, or Nunavut; however, it is listed as S1 (critically imperiled) in Quebec and S2S3 (between imperiled and vulnerable) in the Yukon Territory.

The Colorado Natural Heritage Program reports nine occurrences for *Braya glabella* ssp. *glabella* located in Chaffee, Gunnison, Pitkin, and Park counties. The Wyoming Natural Diversity Database reports two occurrences on National Forest System land within USFS Region 4 in Sublette and Teton counties in Wyoming. Due to the close proximity of these occurrences to the western boundary of Region 2, they are included in this assessment.

Abundance information is scarce for this taxon, and existing data are based on casual field estimates. Based on the available Element Occurrence Record and herbarium label data, the total estimated population of *Braya glabella* ssp. *glabella* in Colorado and Wyoming is at least 500 plants. Because of a lack of data, this number may over or underestimate the actual population number by hundreds or thousands. No population trend data or inferences of population trend are possible with the existing data.

The nine documented occurrences of *Braya glabella* ssp. *glabella* in Colorado are all located on National Forest System land. The Pike-San Isabel, White River, and Gunnison national forests have three occurrences each. Four of these occurrences are located within designated wilderness areas; one occurrence on the San Isabel National Forest is partially located on private land. The two Wyoming occurrences are located in USFS Region 4 within the Gros Ventre Wilderness Area of the Bridger-Teton National Forest. No special management areas have been designated that include the conservation of this taxon or its habitat as an explicit goal.

Current threats to *Braya glabella* ssp. *glabella* are difficult to discern due to the remoteness of occurrences. Concern for the viability of the taxon in Region 2 is based on its limited distribution at the southern periphery of its range, small population sizes, and management of the fragile alpine habitats in which it occurs. Of the activities that typically occur or are planned for the Pike, San Isabel, White River, or Gunnison national forests, mining and recreation are likely to have the greatest effects on *B. glabella* ssp. *glabella*. Erosion from nearby jeep trails may affect a few occurrences. Other potential threats to the taxon include competition from invasive plant species, global warming, and air pollution.

Existing laws, regulations, and management policies do not adequately protect occurrences. The remote location of the majority of the occurrences provides some protection; however, land managers may be unaware of these occurrences, and this lack of information may lead to inappropriate management of the species' habitat.

As it is currently documented, *Braya glabella* ssp. *glabella* has limited abundance and a disjunct distribution on National Forest System land in Region 2. The extent of its distribution in Regions 2 and 4 is not known. There is limited information concerning microhabitat requirements and success of reproduction (sexual or asexual), and there is no information concerning the taxon's ability to adapt to changing environmental conditions.

Surveying potential habitat for new occurrences, protecting existing occurrences from negative impacts, documenting and monitoring the effects of current land-use activities, and preventing non-native plant invasions are key conservation elements for *Braya glabella* ssp. *glabella*. Priorities of future research include estimating the size and extent of known occurrences, surveying to locate additional occurrences, assessing imminent threats, investigating factors that affect microhabitat characteristics, exploring ecological limitations, and characterizing reproductive mechanisms, population structure, and demography.

TABLE OF CONTENTS

EDITORS: Janet Coles and Kathy Roche, USDA Forest Service, Rocky Mountain Region

List of Tables and Figures

Tables:

Figures:

INTRODUCTION

This assessment is one of many being produced to support the Species Conservation Project of the Rocky Mountain Region (Region 2) of the USDA Forest Service (USFS). *Braya glabella* ssp. *glabella* (smooth northern-rockcress) is the focus of an assessment because it is a plant whose population viability is identified as a concern. This concern reflects the limited distribution of small occurrences on the periphery of its range within USFS Regions 2 and 4. This taxon may require special management; therefore, knowledge of its biology and ecology is critical. This assessment addresses the biology of *B. glabella* ssp. *glabella* throughout its range in USFS Regions 2 and 4.

Goal

Species assessments produced as part of the Species Conservation Project are designed to provide forest managers, research biologists, and the public with a thorough discussion of the biology, ecology, and conservation status of certain species based on available scientific knowledge. The assessment goals limit the scope of the 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 assessment examines the biology, ecology, conservation, and management of *Braya glabella* ssp. *glabella* with specific reference to the geographic and ecological characteristics of USFS Regions 2 and 4. Although some of the literature on the taxon may originate from field investigations outside these regions, this document places that literature in the ecological and social contexts of the central Rocky Mountains. Similarly, this assessment is concerned with the reproductive behavior, population dynamics, and other characteristics of *B. glabella* ssp. *glabella* in the context of the current environment. The evolutionary environment of the taxon is considered in conducting the synthesis, but placed in a current context.

In producing the assessment, the authors reviewed refereed literature, non-refereed publications, research reports, and data accumulated by resource management agencies. A lack of credible scientific information often hampers the assessment of a rare or infrequent plant species, and this is the case for *Braya glabella* ssp. *glabella*. Taxonomists typically provide the initial information for a plant species, and the authors of this assessment consulted 12 taxonomic references. The most comprehensive of these were the classic Brassicaceae monograph by Rollins (1993) and an online description associated with the Flora of the Canadian Arctic Archipelago (Aiken et al. 2003). Other information resources contained many inconsistencies. For example, the herbarium label and Element Occurrence Record (EOR) information provided by the Natural Heritage Programs in Colorado and Wyoming, although essential to this assessment, had slight disagreements between the elevation on the herbarium label and the elevation found when label coordinates were checked against a topographic map. Fortunately, most of these differences were minor. The Rocky Mountain Herbarium and the University of Colorado Museum provided herbarium label data. Useful information was gleaned from two unpublished theses (Price 1979, Harris 1985). The authors also consulted references regarding geology, ecological classification, genetics, pollination biology, seed dispersal, management options, environmental impacts, and other biology or conservation issues discussed in this assessment.

Treatment of Uncertainty

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

Overall, knowledge of *Braya glabella* ssp. *glabella* is sparse and incomplete. The information

presented in this assessment is based on herbarium labels, information synthesized from the Wyoming Natural Diversity Database (WYNDD) and the Colorado Natural Heritage Program (CNHP), and anecdotal observations. The authors utilized personal communications with botanists who have experience with the species and information regarding other members of the genus *Braya* to draw inferences where possible.

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 (http://www.fs.fed.us/r2/projects/scp/assessments/index.shtml). Placing the documents on the Web makes them available to agency biologists and the public more rapidly than publishing them as reports. More important, Web publication facilitates their revision, which will be accomplished according to guidelines established by Region 2.

Peer Review

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

MANAGEMENT STATUS AND NATURAL HISTORY

Braya glabella ssp. *glabella* is considered disjunct in Colorado and Wyoming. The main range of the species is concentrated in the montane, subarctic, and low arctic of Greenland, Eurasia, Alaska, and the Canadian Arctic Archipelago.

Management Status

Braya glabella ssp. *glabella* is neither listed nor a candidate for listing under the federal Endangered Species Act. USFS Region 2 designated it as a sensitive species based on a 2002 evaluation (Fertig and Laursen 2002, Johnston 2002, USDA Forest Service 2003). In this evaluation, it was determined that this taxon warrants USFS sensitive species status because it occupies a very narrow ecological niche on the southern edge of its range in Colorado and Wyoming and because the occurrences in Colorado are reported as small and isolated. Some habitat may have been lost historically due to impacts from hard rock mining in the mountains of central Colorado, and increasing recreation use may affect individuals and/or their habitat (Fertig and Laursen 2002, Proctor and Austin 2002). The taxon is not designated as a sensitive species in any other USFS region or by the Bureau of Land Management (BLM) in Colorado or Wyoming.

NatureServe (2006) has given this taxon a global conservation status rank of G5TNR (species secure, infraspecific taxon not ranked). CNHP and WYNDD rank *Braya glabella* ssp. *glabella* as S1 (critically imperiled because of extreme rarity). In Canada, the taxon is not ranked in Alberta, British Columbia, Labrador, the Northwest Territories, or Nunavut; however, it is listed as S1 (critically imperiled) in Quebec and S2S3 (between imperiled and vulnerable) in the Yukon Territory (NatureServe 2006).

Existing Regulatory Mechanisms, Management Plans, and Conservation Strategies

CNHP reports 9 EORs for *Braya glabella* ssp. *glabella* in Colorado. Three occurrences are on lands managed by the Pike-San Isabel National Forest, three are on the White River National Forest, and three are on the Gunnison National Forest. (Colorado Natural Heritage Program 2003). One of the Pike-San Isabel National Forest occurrences is partially located on private land. The White River National Forest occurrences are located within the Collegiate Peaks Wilderness Area, and one of the Gunnison National Forest occurrences is located within the Fossil Ridge Wilderness Area. The remoteness of these locations and use restrictions within wilderness areas (e.g., prohibition of motorized vehicles) may afford these occurrences some protection.

In Wyoming, WYNDD reports two occurrences of *Braya glabella* ssp. *glabella* on the Bridger-Teton National Forest in Region 4. However, the locations of the Region 4 occurrences are sufficiently close enough to Region 2 to warrant consideration in this assessment and will be discussed concurrently with the Region 2 occurrences. The Wyoming occurrences are located in the Gros Ventre Wilderness Area of the Jackson Ranger District of the Bridger-Teton National Forest (Wyoming Natural Diversity Database 2004).

Braya glabella ssp. *glabella* is not listed as occurring in any units of the National Park System (Information Center for the Environment 2002).

Figure 1 shows the distribution of *Braya glabella* ssp. *glabella* in North America and its conservation status in the states and provinces where it occurs. The Wyoming occurrences do not appear in **Figure 1** due to nomenclatural differences. WYNDD uses the species name *B. glabella*, without specifying subspecies *glabella*. **Figure 2** is a map showing the location of known occurrences in Region 2 as well as on the Bridger-Teton National Forest in Region 4.

No specific management or conservation plan is in place for the protection of *Braya glabella* ssp. *glabella* on National Forest System lands. However, within Region 2, it is considered a sensitive species, so the USFS requires that activities be managed to avoid disturbances that would result in a trend toward federal listing or a loss of population viability (USDA Forest Service Manual, Region 2 supplement, 2670.22). The White River National Forest Land and Resource Management Plan Revision (USDA Forest Service 2002), the Pike and San Isabel National Forests Land and Resource Management Plan (USDA Forest Service 1984), and the Grand Mesa, Uncompahgre, and Gunnison National Forests Land and Resource Management Plan (USDA Forest Service 1991) provide guidelines for management of each individual forest. All areas of potential habitat must be surveyed before activities that could affect sensitive species are allowed. *Braya glabella* ssp. *glabella* is not considered a sensitive species on the Bridger-Teton National Forest in Region 4.

Although there is only one documented occurrence on private land in Region 2, it is likely that the taxon occurs elsewhere on private lands. There are no laws in place that protect this species on private lands.

Braya glabella ssp. *glabella* has no specific legal protection that prevents the destruction of individuals or habitat. As of this writing, no conservation strategy has been written for this species at a state, national or regional level by the USFS or any other federal agency.

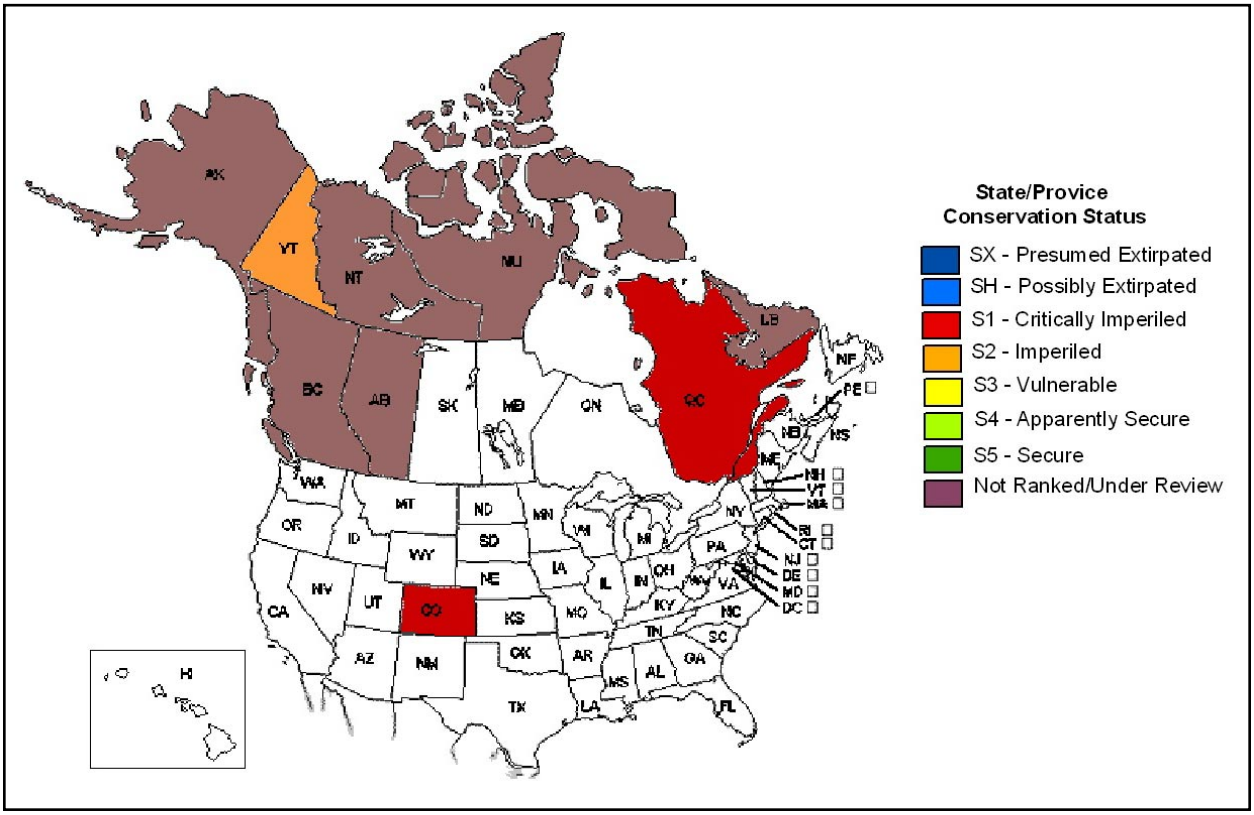

Figure 1. Map of the distribution of *Braya glabella* ssp. *glabella* in North America, showing its conservation status in the states and provinces where it occurs (NatureServe 2006). The Wyoming occurrences are not included in this figure due to nomenclatural differences. WYNDD uses the species name *B. glabella*, a broader concept than is used elsewhere in North America.

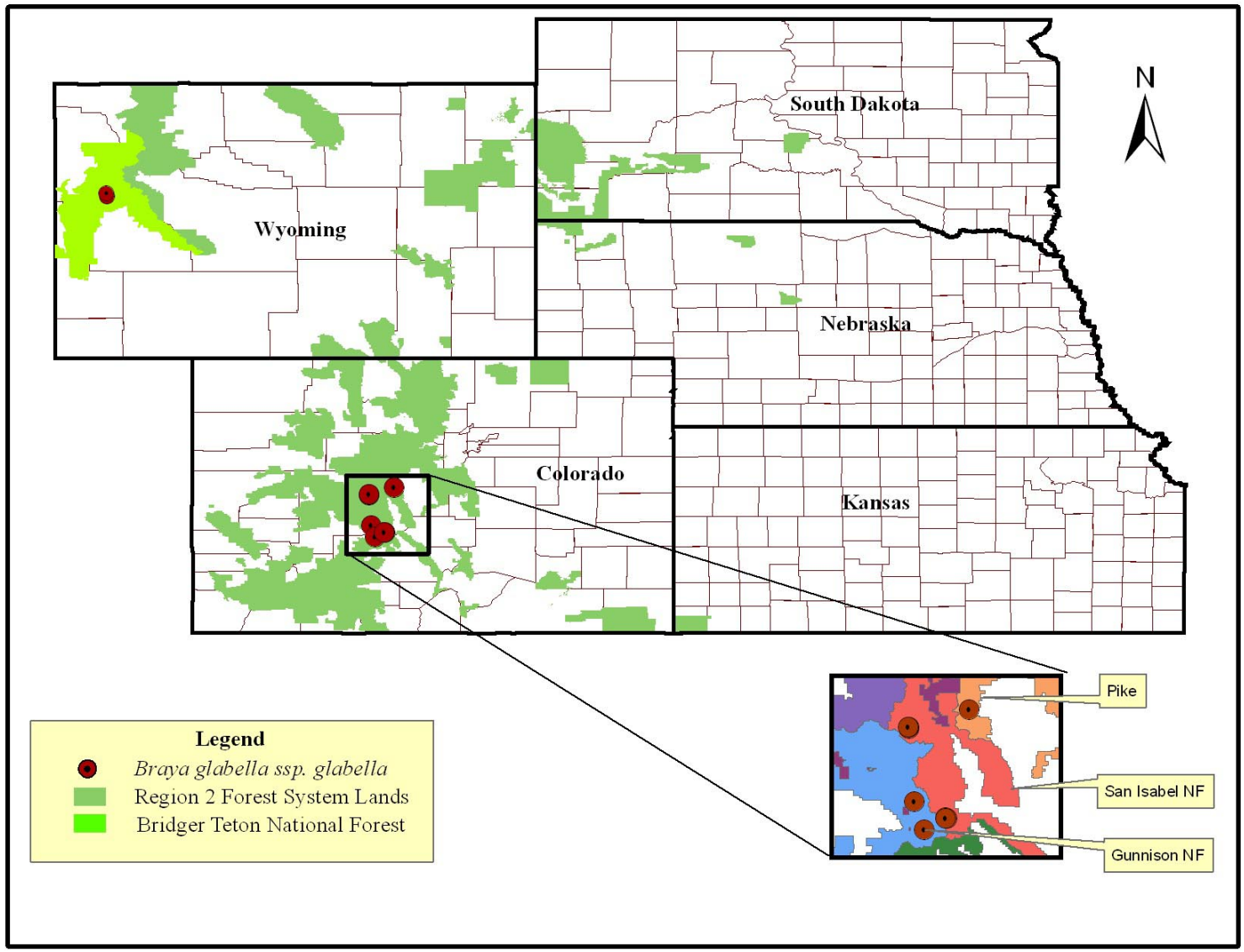

Figure 2. Distribution of *Braya glabella* ssp. *glabella* occurrences on National Forest System lands in USDA Forest Service Region 2 and on the Bridger-Teton National Forest in Region 4.

There are no reported instances in which an occurrence was extirpated because of human activities or the failure to enforce existing regulations. However, this does not necessarily indicate that current regulations or their enforcement are adequate for ensuring the persistence of this taxon.

Biology and Ecology

Systematics and general species descriptions

The mustard family (Brassicaceae or Cruciferae, order Capparales) occurs worldwide and is most abundant in the cold and temperate regions of the northern hemisphere. This family has approximately 350 genera and 3,500 species worldwide, of which 99 genera and 778 species occur in North America (Rollins 1993). This makes North America less diverse in mustards than the Old World and has led to suggestions that the centers of diversity for this family are the Mediterranean and southwestern/south-central Asia (Rollins 1993, Zomlefer 1994). Nonetheless, Rollins (1993) insisted that North America be considered a center of diversity, albeit a lesser one. He argued that 39 mustard genera are endemic to North America and that most of the 667 native North American taxa are also endemic to North America. The Brassicaceae is a natural family, clearly related to the Capparaceae, and it is thought that the two families are derived from a now-extinct common ancestor (Rollins 1993). Mustard genera of agricultural importance include *Brassica* (e.g., cabbage, rape), *Raphaus* (radish), and a number of well-known ornamentals such as *Hesperus*, *Lunaria*, and *Malcolmia*.

The nine synonyms for *Braya glabella* ssp. *glabella* reflect in part the variability within the species, sometimes even within an occurrence. *Braya glabella* is highly polymorphic, making the delineation of infraspecific taxa difficult. When the species is examined across its full range, numerous overlapping forms become apparent (Harris 2006a). Recent molecular evidence reinforces the difficulty of recognizing more than one subspecies within the *B. glabella* species group (Warwick et al. 2004, Harris 2006a). Nonetheless, readily identifiable subspecies do exist. Plants growing where the subspecies ranges overlap, however, may be difficult to classify (Harris 2006a).

The extreme variability of the genus *Braya* has often led to a conservative approach in past treatments, with authors opting to ignore infraspecific variation. This approach may be counterproductive, as some *Braya* species can be reliably subdivided into distinctive entities that may be biologically and phylogenetically important (Harris 2006b). Harris (2006b) proposed three subspecies of North American *B. glabella*. He assigned high arctic populations to subspecies *purpurascens* while montane, subarctic, and low arctic entities belong to subspecies *glabella*. A third subspecies, *prostrata*, was applied to plants in the northern Canadian Arctic Archipelago north of Ellesmere Island, typically north of 80° N latitude (Harris 2006b). The upcoming publication of the genus *Braya* in the Flora of North America will recognize these three subspecies of *B. glabella* (Harris personal communication 2006c).

Although there is disagreement among taxonomists regarding the recognition of *Braya glabella* ssp. *glabella* as a distinct subspecies (Aiken personal communication 2004, Al-Shebaz personal communication 2004), this taxon is to be included in the Flora of North America (Harris 2006a, 2006b). *Braya glabella* ssp. *glabella* is the only subspecies of *B. glabella* that occurs in the central Rocky Mountains of Colorado and Wyoming (Harris 2006a, 2006b, personal communication 2006c). This taxon is a readily identifiable entity occurring on National Forest System land in Regions 2 and 4. This assessment is concerned only with the taxon *B. glabella* ssp. *glabella* and excludes any discussion of the other two subspecies of *B. glabella*. The taxonomic classification of *B. glabella* ssp. *glabella* is summarized in **Table 1**.

History of the species

The first collections of *Braya glabella* ssp. *glabella* from Colorado were made by Katherine Matthews on July 30 and August 10, 1984, between 3,870 and 3,880 m near the Gunnison-Pitkin county line. These collections remained misidentified in the University of Colorado herbarium as *B. humilis* for almost 10 years. In 1987, Barbara A. Siems collected a *B. glabella* ssp. *glabella* specimen from Chaffee County (*Siems #1592*). This specimen was originally identified as *B. purpurascens*, but Dr. William Weber determined it to be *B. glabella* ssp. *glabella* in 1993. The Siems specimen prompted a closer look at all the *Braya* collections from the University of Colorado herbarium, resulting in the relabeling of the 1984 Matthews collections as *B. glabella* ssp. *glabella*. Specimens from this area were sent to J. Harris, and several were verified as being *B. glabella* ssp. *glabella* (Harris personal communication 2006c). This determination was reaffirmed using DNA in 2004 (Warwick et al. 2004).

Table 1. Classification of *Braya glabella* ssp. *glabella* (Aiken et al. 2003, Harris 2006a).

***Braya glabella* ssp. *glabella* Richardson**
Family: Brassicaceae (Cruciferae)
Genus: *Braya*
Species: *Braya glabella* ssp. *glabella*
Citation: Richardson. 1823. Botanical Appendix to Captain Franklin's Narrative of A Journey to the Shores of the Polar Sea. 1:743.
Synonyms: *Braya alpina* Sternb. & Hoppe var. *glabella* (Richardson) S. Wats.; *Braya alpina* ssp. *americana* Hook.; *Braya alpina* var. *americana* (Hook.) S. Wats.; *Braya humilis* (C.A. Mey.) B.L. Robins. var. *americana* (Hook.) Boivin; *Braya americana* (Hook.) Fern.; *Braya bartlettiana* Jordal; *Braya bartlettiana* Jordal var. *vestita* Hultén; *Braya henryae* Raup
Vernacular Name: smooth northern-rock-cress, alpine braya
Type: Described from Northwestern Canada: Copper Mountains, north of Dismal Lake, half way between the north arm of Great Bear Lake and Coronation Gulf.

Non-technical description

Braya glabella ssp. *glabella* is a perennial herb with one to many leafless stems, 3.5 to 17 cm (1.4 to 6.7 inches) tall. Flowering stems and leaves are densely pubescent with simple or two to three branched hairs. The somewhat fleshy basal leaves are entire or occasionally with one or two weak teeth per side, linear to broadly spoon-shaped, and 1 to 6 cm (0.4 to 2.4 inches) long. The inflorescence is a head-like cluster of white to purple-tinged, 4-petaled flowers, 2.5 to 4.5 mm (0.1 to 0.2 inches) long, often loosely elongated in fruit. Fruits are oval to oblong, pubescent siliques 5 to 15 mm (0.2 to 0.6 inches) long with broad replum margins and a thick style 0.5 to 2 mm long (0.02 to 0.08 inches) (Rollins 1993, Spackman et al. 1997, Harris 2006a).

The vegetative traits of *Braya glabella* ssp. *glabella* used to distinguish it from other *Braya* species in North America are the entire leaf blade margins, only one or two stems, the absence of glandular hairs on leaves, and a small transition zone between roots and both leaves and stems. Significant reproductive characters include the more oval-elliptic to oblong or oblong-lanceolate siliques, the presence of only a "few to several" seeds, and a biseriate rather than uniseriate seed arrangement.

Braya humilis is the only other *Braya* found in the central Rocky Mountains. These two species have been observed growing together in Mineral Basin in Colorado (Neely personal communication 2004). *Braya humilis* has leafy stems; narrow, linear fruits; and grayish white petals. *Braya glabella* ssp. *glabella* has scapose or leafless stems or occasionally a single small leaf; fruits that are broader (oval to oblong); and petals that appear white and sometimes tinged with purple. Care should be taken to check *Braya* occurrences for both species when encountered in the field.

Sources of descriptions, photographs, drawings

Harris (2006b) gives the most useful description for *Braya glabella* ssp. *glabella* in his upcoming treatment of *Braya* in the Flora of North America. Aiken et al. (2003) also provides a technical description with detailed characteristics of this taxon. **Figure 3** is a line drawing of *B. glabella* ssp. *glabella*, and **Figure 4** is a photograph showing its habit, siliques, and flowers. Additional illustrations and photographs can be found in the Colorado Rare Plant Field Guide (Spackman et al. 1997) or online at the CNHP Web site (http://www.cnhp.colostate.edu).

Distribution and abundance

The distribution of *Braya glabella* ssp. *glabella* is best described as circumboreal. It occurs in the floristic region defined by Takhtajan (1986) as the Holarctic Kingdom. The taxon occurs in the montane, subarctic, and low arctic zones in Greenland, Canada, the United States, and Eurasia. In Asia, *B. glabella* ssp. *glabella* occurs in arctic Siberia (Rollins 1993). In North America, it occurs from the Canadian Arctic Archipelago and Hudson Bay area west to the Rocky Mountains of Alberta and north to Alaska. Disjunct occurrences occur in the Rocky Mountain alpine biogeographic zone of Colorado and Wyoming. *Braya glabella* ssp. *glabella* is most abundant in Canada where it is known from the provinces of Alberta, British Colombia, Labrador, Northwest Territories, Quebec, and Yukon Territory (Aiken et al. 2003, Harris 2006b). All *B. glabella* ssp. *glabella* occurrences in the United States are located on National Forest System land

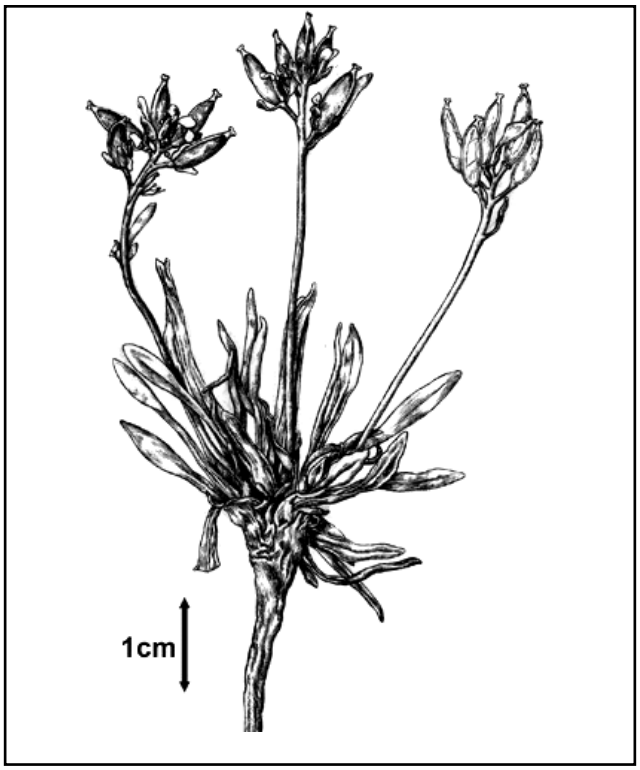

Figure 3. Line drawing of *Braya glabella* ssp. *glabella*. Drawing by S. Bergh and L. Barstad based on a collection from Svalbard. Used with permission of the authors of the Flora of the Canadian Archipelago (Aiken et al. 2003).

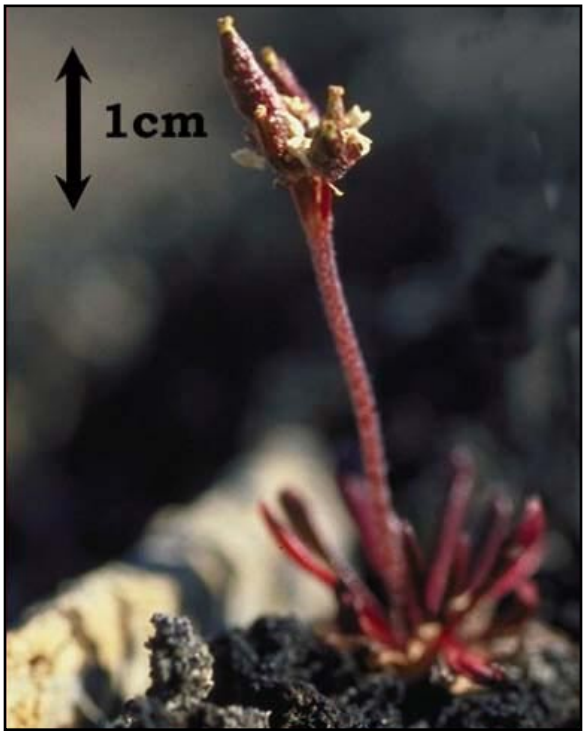

Figure 4. Photograph of *Braya glabella* ssp. *glabella*, showing habit, fruits and flowers. Photograph by Mollie MacCormac, used with permission of the authors of the Flora of the Canadian Archipelago (Aiken et al. 2003).

within Regions 2 and 4. The Colorado occurrences represent the southernmost records for this taxon. The closest previously documented location of *B. glabella* ssp. *glabella* to the contiguous United States is in Jasper National Park in Canada.

Dr. William A. Weber's review of the biogeographical origins of the southern Rocky Mountain flora (2003) contains the hypothesis that the modern alpine flora developed during the Tertiary period (65 million to 2 million years before present) and antedates the modern Arctic flora. He believes that a flora of high mountain origin extended from the Altai in middle Asia across the North Pole by way of Greenland. This flora became fragmented and depauperate through species extinctions and development of various mountain ranges in North America. The alpine species that are found in the southern Rocky Mountains today are remnants of the older flora. He cites *Braya glabella* ssp. *glabella* as one of the elements supporting his conclusion (Weber 2003).

Known occurrences of *Braya glabella* ssp. *glabella* in Regions 2 and 4 are small and isolated. Only four of the nine occurrences of *B. glabella* ssp. *glabella* in Colorado have abundance information (**Table 2**). In 1985, Betsy Neely considered an occurrence of 200 plants in Chaffee County (EOR 001*CO) as the "best" of the Colorado occurrences. Neely tagged approximately 120 of the *B. glabella* ssp. *glabella* plants at EOR 001*CO for a field study in 1985 (Neely personal communication 2004). These tagged individuals have not been revisited to determine their status. EOR 002*CO was estimated to have 190 plants, with 80 at EOR 003*CO, and five at EOR 009*CO. An accurate estimate of the total number of plants of *B. glabella* ssp. *glabella* in Region 2 is not possible with the available data. Based on these four observations, a conservative total plant estimate for the state of Colorado is 475 individuals. These plants are all located in a 75 by 30 square km (47 by 19 square mile) area at elevations ranging from 3,000 to 4,100 m (9,900 to 13,450 ft.) in Chaffee, Gunnison, Pitkin, and Park counties.

In Wyoming, only two EORs are reported for *Braya glabella* ssp. *glabella* in Sublette and Teton counties. These occurrences are within 5 km of each other, and both are on the Bridger-Teton National Forest in Region 4. According to general comments on one specimen label from Rocky Mountain Herbarium, fewer than five plants were estimated at one occurrence. No abundance data were provided on the other label.

Population trend

As of April 2004, EOR 001*CO, with 120 plants tagged by Betsy Neely in 1985 (*Neely #3170*) had not been revisited (Neely personal communication 2004). In 1988, Tim Hogan and Barbara Siems were able to relocate the population that Siems had discovered the previous year in Chaffee County, Colorado (EOR 004*CO). Other than this, no effort has been made to revisit Colorado *Braya glabella* ssp. *glabella* occurrences or to estimate changes in the density or extent of these occurrences. Therefore, it is not possible to determine a trend for the Colorado or Wyoming populations.

Habitat

In Colorado, *Braya glabella* ssp. *glabella* occurs in the South Central and North Central Highlands section of the Southern Rocky Mountain Province (McNab and Avers 1994). In Wyoming, it occurs in the Overthrust Mountain section of the same Province. The primary habitat for *B. glabella* ssp. *glabella* within Region 2 is alpine tundra (Siems and Neely 1990, Neely personal communication 2004, Harris 2006b). When site information for *B. glabella* ssp. *glabella* in Region 2 is compared to the coarse-scale ecological system classification by Rondeau (2001), the taxon occurs in the Alpine Tundra Dry Meadow Ecological System.

Harris (2006b) reports that across its entire range, *Braya glabella* ssp. *glabella* occurs on barren, usually calcareous soils and gravels, disturbed sites, lake- and seashores, scree slopes, and solifluction lobes. Within Region 2, this taxon occupies barren and disturbed calcareous substrates between 3,400 and 4,000 m (11,200 to 13,200 ft.) elevation. Sites also include partially vegetated and less disturbed calcareous soils, gravel soils, talus, scree, and solifluction lobes (Siems and Neely 1990). Landforms include ridge tops, saddles, and steep slopes.

Braya glabella ssp. *glabella*, like other alpine *Braya* species, occupies limestone barrens characterized by coarse, shallow calcareous soils, including disturbed areas with loose limestone gravel. In summer, these plants receive no shade, and in winter, they are often windswept, exposing the plants to extreme winter cold and scouring wind. *Braya glabella* ssp. *glabella*, as well as other species of *Braya*, shows a marked preference for soils disturbed by natural processes, such as solifluction lobes, scree slopes, or lakeshores, and areas

Table 2. Summary of abundance and habitat data for occurrences of *Braya glabella* ssp. *glabella*. Data were compiled from Element Occurrence Record (EOR) data forms (Colorado Natural Heritage Program 2003, Wyoming Natural Diversity Database 2004), herbarium specimen labels, and USGS 7.5 minute topographic maps. An asterisk indicates an EOR. For comparison, specimen data from two Alaska and three Canadian (Northwest Territory) specimens are included.

EOR or Label No./State (Collector No.)	County	Area (ha)	Number of occurrences	Total number of plants	Land management/ ownership	Elevation (m)	Slope (%) / Aspect	Habitat characteristics and plant associations	Herbarium[1]
001*/CO *Neely #3170*	Chaffee	Not recorded	1?	Approx. 200	USDA Forest Service (USFS) San Isabel National Forest	3,740	30 to 40 North	Rocky slope, little soil with *Dryas* sp., *Carex rupestris*, *Oxytropis deflexa*, *Senecio* sp. (125 plants were tagged). Called the best Colorado population.	RM, CS
002*/CO *Neely #3183*	Gunnison	Not recorded	1?	Approx. 190	USFS Gunnison National Forest	3,810	20 to 40 Northwest	Rocky slope with *Dryas* sp., *Carex rupestris*, *Potentilla* sp., *Arenaria* sp., and *Festuca* sp.	CS
003*/CO *Neely #3174*	Gunnison	0.01	1?	Approx. 80	USFS Gunnison National Forest; Fossil Ridge Wilderness	3,657	>25 Southeast	Black organic soil and gravel with *Dryas* sp., *Carex rupestris*. *Kobresia* sp., and *Arenaria obtusifolia*.	CS
004*/CO *Siems #1592; Weber et al. #17980*	Chaffee	Not recorded	1?	Not applicable (N/A)	USFS San Isabel National Forest & Private	3,627	0 to >25 West-southwest	Near *Braya humilis* colonies, *Erigeron leiomeris*, *E. compositus*, and *Antennaria* sp.	CS, COLO
005*/CO *Matthews #1556, #1698*	Pitkin/Gunnison	Not recorded	1?	N/A	USFS White River National Forest, Collegiate Peaks Wilderness	3,880	>25 Southeast	*Askellia* sp., *Salix* sp., *Tryphane* sp., *Erigeron vagus*, and *Muscaria monticola*.	COLO
006*/CO	Pitkin	<0.4	1?	N/A	USFS White River National Forest, Collegiate Peaks Wilderness	3,535	<10 East	*Aster* sp.	Not applicable (N/A)
007*/CO	Pitkin	<0.4	1?	N/A	USFS White River National Forest, Collegiate Peaks Wilderness	3,475	<10 East	*Aster* sp.	N/A
008*/CO *Kelso et al. #151*	Chaffee/ Gunnison	Not recorded	1?	N/A	USFS Gunnison National Forest	3,890	15 to 25 West	*Dryas octopetala*, *Castilleja rhexifolia*, *Antennaria alpina*, and *Carex rupestris*.	COLO
009*/CO	Park	Not recorded	1?	5	USFS Pike National Forest	3,475	>25 Northwest	Not applicable (N/A)	N/A

Table 2 (concluded).

EOR or Label No./State (Collector No.)	County	Area (ha)	Number of occurrences	Total number of plants	Land management/ ownership	Elevation (m)	Slope (%) / Aspect	Habitat characteristics and plant associations	Herbarium[1]
001*/WY *Fertig #18520*	Sublette	Not recorded	1?	<5	USFS Region 4 Bridger-Teton National Forest	3,322	<15 East	50 percent vegetation cover; Saddle, dolomite with *Phlox pulvinata*, *Astragalus kentrophyta*, *Castilleja pulchella*, *Smelowskia* sp., *Carex nardina*, and *Dryas* sp.	RM
002*/WY *Hartman #49496*	Teton	Not recorded	1?	N/A	USFS Region 4 Bridger-Teton National Forest	3,475	<15 East	Ridge, dolomite.	RM
1158/AK (Murray '61)	Not applicable (N/A)	Not applicable (N/A)	Not applicable (N/A)	N/A	Not applicable (N/A)	<100	Not applicable (N/A)	N/A	N/A
1006/AK (Murray '93)	N/A	N/A	N/A	N/A	N/A	<100	Not applicable (N/A)	N/A	N/A
18970/NWT (Gillett '82)	N/A	N/A	N/A	N/A	N/A	<100	Not applicable (N/A)	N/A	N/A
1545/NWT (Boivin '48)	N/A	N/A	N/A	N/A	N/A	Near ocean	Not applicable (N/A)	N/A	N/A
82-312/NWT (Utech '82)	N/A	N/A	N/A	N/A	N/A	<100	Not applicable (N/A)	N/A	N/A

[1]Herbarium:

COLO University of Colorado Museum, Boulder, Colorado
CS Colorado State University, Fort Collins, Colorado
RM Rocky Mountain Herbarium, Laramie, Wyoming

occasionally disturbed by hoofed animals or human activities. Reports of occurrences from turf habitats almost certainly came from small disturbed areas within an otherwise stable turf environment (Harris personal communication 2006c).

Within Region 2, *Braya glabella* ssp. *glabella* occurs most often on rocky slopes and disturbed alpine soils with minimal vegetation cover; however, it has been reported in areas with up to 50 percent vegetation cover. In areas with higher vegetation cover, *B. glabella* ssp. *glabella* is associated with alpine graminoids, cushion plants, and plants with a rosette growth form (**Table 2**). At least 26 plant species are reported on herbaria labels and within EOR data as growing in association with *B. glabella* ssp. *glabella* (**Table 3**). Data from 11 occurrences indicate that the most common associates are *Carex rupestris* (curly sedge) and *Dryas octopetala* (mountain avens). Instead of being truly associated with *B. glabella* ssp. *glabella*, the frequent listings of these two plant species may simply be due to fact that these are common, often dominant, and striking alpine plants that are easy to identify. Any definitive associations between *B. glabella* ssp. *glabella* and other plant species would require additional field investigations.

Only on one occasion did an EOR contain an estimate of the vegetation cover where *Braya glabella* ssp. *glabella* occurred. This was in Wyoming (EOR 001*WY) where the cover was estimated at less than 50 percent (Wyoming Natural Diversity Database 2004).

Table 3. Scientific and common names of associated taxa reported in Element Occurrence Records and on herbarium specimen labels for *Braya glabella* ssp. *glabella*. The number in parentheses after each species is the number of herbarium labels listing the taxon.

Scientific Name	Common Name	Family
Antennaria sp. (1)	pussytoes	Asteraceae
Antennaria alpina (1)	alpine pussytoes	Asteraceae
Arenaria sp. (1) (possibly *Minuartia*)	sandwort	Caryophyllaceae
Askellia sp. (1)	alpine hawksbeard	Asteraceae
Aster (2) (possibly *Erigeron*)	aster	Asteraceae
Astragalus kentrophyta var. *implexus* (1)	mat milkvetch	Fabaceae
Braya humilis (1)	low northern milkvetch	Brassicaceae
Carex nardina (1)	spike sedge	Cyperaceae
Carex rupestris (4)	curly sedge	Cyperaceae
Castilleja pulchella (1)	beautiful Indian paintbrush	Scrophulariaceae
Castilleja sulphurea (1) (syn. = *C. rhexifolia*)	sulphur Indian paintbrush	Scrophulariaceae
Dryas octopetala (5)	eightpetal mountain-avens	Rosaceae
Erigeron compositus (1)	cutleaf daisy	Asteraceae
Erigeron leiomerus (1)	rockslide yellow fleabane	Asteraceae
Erigeron vagus (1)	rambling fleabane	Asteraceae
Festuca sp. (1)	fescue	Poaceae
Kobresia sp. (1)	bog sedge	Cyperaceae
Minuartia obtusiloba (1) (syn. = *Arenaria*)	twinflower sandwort	Caryophyllaceae
Minuartia rubella (1) (syn. = *Tryphane*)	beautiful sandwort	Caryophyllaceae
Oxytropis deflexa (1)	nodding locoweed	Fabaceae
Phlox pulvinata (1)	cushion phlox	Polemoniaceae
Potentilla sp. (1)	cinquefoil	Rosaceae
Salix sp. (1)	willow	Salicaceae
Saxifraga caespitosa ssp. *monticola* (1) (syn. = *Muscaria monticola*)	tufted alpine saxifrage	Saxifragaceae
Senecio sp. (1)	groundsel	Asteraceae
Smelowskia sp. (1)	candytuft	Brassicaceae

No community cover estimates were recorded for any other occurrence.

Reproductive biology and autecology

Little work has been done to investigate the biological and ecological characteristics of *Braya glabella* ssp. *glabella*. The following section is a summary of work by Harris (1985), Rollins (1993) Aiken et al. (2003), and Warwick et al. (2004).

Braya glabella ssp. *glabella* is a perennial, as are the vast majority of alpine plants. It is not known to propagate vegetatively. Alpine perennials often develop polyploids, and molecular evidence indicates that it is likely that *B. glabella* ssp. *glabella* resulted from a polyploid event (Warwick et al. 2004). Recent molecular DNA sequence data from a mixed *B. glabella* ssp. *glabella*/*B. humilis* population provided strong evidence against hybridization occurring between these two taxa (Warwick et al. 2004). *Braya glabella* ssp. *glabella* individuals were found to have DNA sequences more similar to *B. glabella* ssp. *glabella* populations from across North America than to individuals of *B. humilis* growing 2 feet away. Likewise, Colorado *B. humilis* plants have DNA sequences similar to other *B. humilis* populations from across North America (Warwick et al. 2004, Harris personal communication 2006c).

The base chromosome number of n = 7 has been well established in *Braya glabella* ssp. *glabella* as well as in other taxa in the genus. Chromosome counts reported for *B. glabella* ssp. *glabella* in the Canadian Rockies, Alaska, Colorado, and northern Canada were all octoploids, 2n = 56 (Mulligan 1965, Johnson and Packer 1968, Dawe and Murray 1979, Harris 1985, Murray and Kelso 1997). Past chromosome counts for *B. glabella* ssp. *glabella* reporting a tetraploid (2n = 28) condition are suspect and likely due to counting a different taxon, *B. thorild-wulffii*, a confirmed tetraploid. These two taxa are easily confused in the immature stages (Harris personal communication 2006c).

Current literature indicates that relationships commonly exist between most higher plants and mycorrhizal fungi (Barbour et al. 1987), but there are no reported mycorrhizal associations for *Braya glabella* ssp. *glabella*. Mycorrhizal relationships have been documented in dry meadow alpine communities and are important for fixing both nitrogen and phosphorus (Theodose and Bowman 1997). Mycotrophy was found to be widespread in all alpine fellfield plant communities that were examined in the mountains of Montana and Wyoming (Lesica and Antibus 1986). Lesica and Antibus (1986) found an increase in vesicular-arbuscular mycorrhizae (VAM) density on plants growing on calcareous soils in alpine fellfield or cushion plant communities. This study reported that members of the Brassicaceae, Caryophyllaceae, and Selaginellaceae showed relatively low levels of VAM colonization. Calcareous soils tend to be nutrient deficient, and VAM infection may assist plants in nutrient uptake (Lesica and Antibus 1986). It is possible that *B. glabella* ssp. *glabella* may have an endomycorrhizal relationship. Regardless of the lack of information concerning any mycorrhizal association that *B. glabella* ssp. *glabella* may have, this taxon may ultimately benefit from the products of mycorrhizal relationships other alpine community members contribute to the substrate.

Conversely, there is evidence suggesting a detrimental effect of mycorrhizae on rare plants. Hartnett and Wilson (1999) found that the cover of rare forb species increased when treated with fungicide and compared with controls. This study was done in a tall grass prairie community where nitrogen is more readily available in the soils through decomposition of organic matter. In contrast, alpine environments have limited nutrient resources. Mycorrhizal fungi are a means by which plants in nutrient-limited environments can better exploit nutrients.

Given the severe environmental stress associated with alpine habitats, there are a number of shared attributes among alpine plant species (Billings 1974, Thilenius 1975, Billings 1988). Significant among these are adaptations to the stresses associated with a short growing season, low temperature, limited nutrients, and low water availability. Rapid growth during a short growing season is an important adaptation for most arctic and alpine plants (Billings 1973, 1974, 1988). No autecological research data are available in this regard for *Braya glabella* ssp. *glabella*, but if characteristics established by the study of other alpine species hold, *B. glabella* ssp. *glabella* would exhibit several adaptive traits. Many alpine plants may have significant belowground nutrient storage capabilities, physiological processes may occur at very low temperatures, osmotic concentrations of plant fluids could help prevent freezing, and the physiognomy of the plant may create a phytomicroclimate in the plant that is several degrees warmer than the surrounding environment (Thilenius 1975). These possible adaptations to low temperatures and a short growing season are reasonable avenues for future *B. glabella* ssp. *glabella* autecology studies.

Harris (1985) investigated the breeding system of *Braya glabella* ssp. *glabella*, and although outcrossing

almost certainly occurs occasionally, *B. glabella* ssp. *glabella* is self-compatible. In fact, pollination usually occurs before the flowers open. It is not apomictic, as emasculated flowers do not produce seeds (Harris 1985). For long-term persistence, occasional outcrossing would best promote genetic heterozygosity. This system would require a pollinator, presumably a generalist pollinator, known to frequent this species and other alpine plants. In this case, there would be a selective advantage for *B. glabella* ssp. *glabella* to have the same flowering phenology and to grow near plant species with which it shares a pollinating agent or agents. Price (1979) indicated that most showy alpine flowers are insect pollinated. He reported that *Draba*, a small-flowered alpine mustard, was pollinated primarily by Diptera (flies) in the Syrphidae, Muscidae and Anthmyiidae families. These may also be the pollinators for *B. glabella* ssp. *glabella*, a plant of similar stature and showiness. After flowering in July and August, the inflorescence of *B. glabella* ssp. *glabella* is a congested, capitate raceme. As fruits develop in August and September, it becomes an elongated raceme.

Braya glabella ssp. *glabella* is similar to many other rare plants in that more is known about its genetic variation than about its reproductive biology. This is in part due to the relative ease of genetic studies and the difficulties inherent in fieldwork investigating reproductive biology. *Braya glabella* ssp. *glabella* is a perennial; however, how long a single plant can live is unknown. The initial establishment of *B. glabella* ssp. *glabella* is by seed. Taxonomic descriptions indicate that this taxon produces 10 to 16 seeds per fruit, and if each of the average of six flowers per inflorescence makes one fruit, the average annual seed production per plant could be between 50 to 100 seeds.

Seed viability in all species of *Braya* was found to be high. Harris had no trouble germinating seeds for his studies during his revision of the genus (Harris 1985, personal communication 2006c). Harris' germination experiments were performed under controlled greenhouse conditions and often resulted in 100 percent germination rates. The small, localized nature of *B. glabella* ssp. *glabella* occurrences may in part be due to poor germination or seedling establishment in harsh and often unpredictable alpine environmental conditions.

The seeds of *Braya longii* and *B. fernaldii* from Labrador, Newfoundland, Canada are thought to be wind dispersed for short distances. Gómez and Zamora (1996) indicated that wind is a factor in the dispersal of other alpine mustards. This may also be the case for *B. glabella* ssp. *glabella* seeds. Based on seed characteristics, the small and localized occurrences, and widely disjunct distribution, this taxon most likely lacks a long-distance dispersal mechanism.

Billings (1974) suggested that seeds of alpine plants establish only occasionally, and once established, they store most photosynthate products for several years in belowground storage organs. In general, these carbohydrate stores accumulate until environmental cues trigger bolting and flowering. There are no soil seed bank or seed viability studies for *Braya glabella* ssp. *glabella* other those by Harris (1985). However, since Brassicaceae are often well represented in soil seed banks, it is reasonable to suggest that some of the seeds produced by *B. glabella* ssp. *glabella* remain viable in the soil seed bank for two or more years. Research is needed to affirm the longevity and viability of *B. glabella* ssp. *glabella* seeds.

Demography

Based on abundance estimates derived from the sparse data available, it is possible that fewer than 500 individuals occur in Colorado and Wyoming. This number is significant because 500 individuals is suggested as an effective minimum plant population size necessary to maintain genetic variation needed to adapt to a changing environment (Lande 1988). *Braya glabella* ssp. *glabella* may be close to this minimum number, but its effective population size may be even smaller as there is probably no genetic exchange between Colorado and Wyoming occurrences, or between Region 2/4 occurrences and populations in the main part of the taxon's range. If more demographic data were available, it could be input into population viability analyses and used to assess the minimum viable population size for *B. glabella* ssp. *glabella* (Lande 1988, Menges 1991). No population viability analysis is possible with existing data.

The life history of *Braya glabella* ssp. *glabella* has not been investigated. A comprehensive research program is needed to identify age at reproduction, plant longevity, pollination systems, seed production, seed dispersal, and seed establishment. Currently, we recognize this taxon as flowering, setting seed, and being restricted to a specific habitat type. Although few data are available, it is useful to construct a generalized life cycle diagram for *B. glabella* ssp. *glabella* (**Figure 5**) as a starting point for generating research questions. It is not known if this taxon has a juvenile stage or how old plants are before they become reproductive. Question marks in the diagram depict areas in need of research; these include nearly all stages of this taxon's

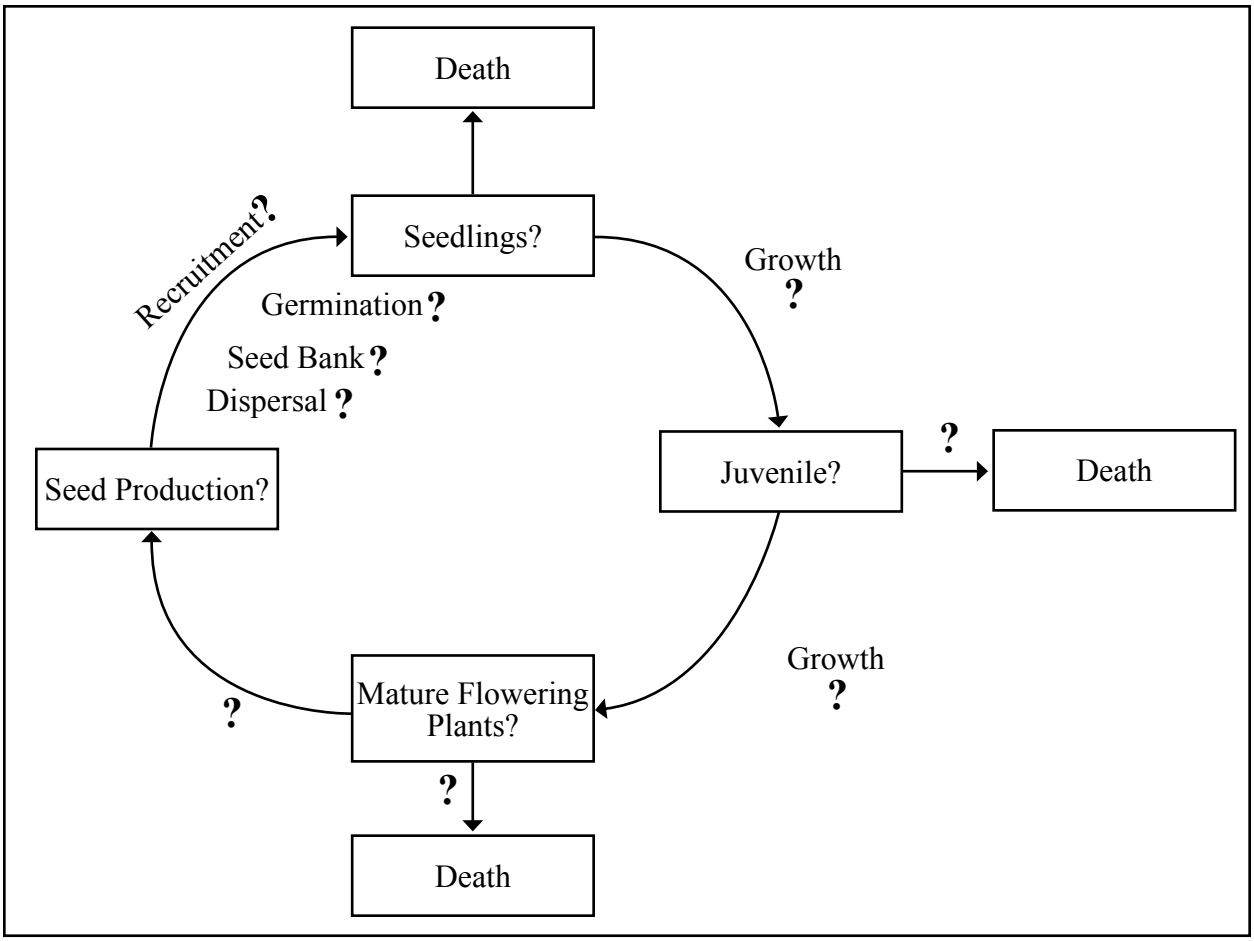

Figure 5. Generalized life cycle diagram of *Braya glabella* ssp. *glabella* based on inferences and what is known about the taxon.

life cycle. One of the few known aspects of the *B. glabella* ssp. *glabella* life cycle is that the racemose inflorescence elongates as the fruits develop. This elongation of the silique also increases the height of the seed above ground, which may increase its availability to herbivores or wind dispersal.

Community ecology

Braya glabella ssp. *glabella*, this taxon is best categorized as a stress tolerator within Grime's autecological classification system (1979), as are most alpine species. Harsh alpine environmental conditions appear to be more of an obstacle to establishment and survival for this taxon than is competition from other plants. Its preference for barren, coarse-textured limestone substrates suggests that this species avoids competition by occupying habitats in which most alpine species cannot survive. However, at least one collection from Colorado notes the presence of this taxon along jeep trails and naturally disturbed areas such as solifluction lobes, suggesting that it may utilize elements of a ruderal strategy as well (Grime 1979). Disturbed areas in the alpine can remain barren for long periods, as soil development is very slow.

The role of herbivory in the ecology of *Braya glabella* ssp. *glabella* is unknown. Herbivory was not identified in any occurrence reports. In the alpine, herbivory may occur from native fauna including mammals (e.g., pikas, ptarmigan, marmots) and insects (Emerick and Mutel 1992). Native herbivory could result in seed predation or leaf damage; however, there are no reports of this happening to this particular taxon.

Some ecologists have identified stages of plant succession in the alpine tundra (Churchill and Hanson 1958). Other ecologists doubt if alpine tundra ever develops into a stable climax community (e.g., Knight 1994). In the difficult alpine environment, abiotic factors are important mediators of community composition and plant distribution. An alpine tundra plant community or plant association can be described as "a collection of strangers"

whose membership is defined by recent historical accidents, chance effects in seedling dispersal, and the ways in which colonists match the characteristics of place (Drury 1998). For example, snow depth and exposure to wind can affect the ability of alpine plants to survive and thus their distribution (Billings 1974, Thilenius 1975, Billings 1988).

Of the 25 plant species listed as occurring with *Braya glabella* ssp. *glabella* (**Table 3**), none is known to facilitate its establishment. *Braya glabella* ssp. *glabella* is not known to alter microsite conditions in a way that favors the establishment of other plant species.

Although envirograms (Andrewartha and Birch 1984) have traditionally been applied to animal/environmental interactions, they can also be useful in evaluating plant/environment interactions. An envirogram is a series of webs that converge at a centrum. The centrum is a key environmental component that in some way affects the survival of a species (Andrewartha and Birch 1984). Three envirograms were developed for *Braya glabella* ssp. *glabella*. The first is for the key environmental resources of light, soil water, and nutrients. The second envirogram is for the life cycle components of growth and development, flowering/ fruiting, seedling development, growth and development, and malentities. Malentities (the term used by Andrewartha and Birch for "negative perturbations") include adverse human influences to a habitat, adverse weather, and atypical levels of herbivory. The third envirogram includes these malentities as a centrum.

An envirogram should be considered an analytical tool that pulls together all aspects of a plant's environment as a sequence of webs. Closest to the centrum components are Web 1 components, consisting of those factors that affect a centrum. Web 2 components affect Web 1 components, Web 3 components affect Web 2 components, and so on. Web "n" components are the most distant from the centrum and therefore are often beyond the ecological and biological scope of a species. The construction of these web diagrams (**Figure 6**, **Figure 7**, **Figure 8**) is a means to examine both the entire range of environmental components associated with a plant species and to identify environmental components that are most in need of research. The soil water, light, and nutrients environmental resources centra for *Braya glabella* ssp. *glabella* are marked on **Figure 6**. From these centra, environmental factors that affect these key components at different levels are diagrammed in Webs 1 to 4. Envirograms can assist managers in recognizing the potential impacts of management decisions on the persistence of a species.

Included in the reproduction centrum for *Braya glabella* ssp. *glabella* are flowering and fruiting, seedling establishment, growth and development, and malentities (**Figure 7**). There are many unknown components in this diagram.

The malentities (**Figure 8**) identified for *Braya glabella* ssp. *glabella* include extreme weather conditions, herbivory, human impacts, and air pollution. Included at the Web 4 level are the possible impacts associated with global warming. Individual threats that make up the malentities centrum are discussed in the next section.

A system of color codes aids in interpreting each centrum. The resources centrum is green, the reproduction centrum is yellow, and the malentities centrum is blue. When a web is referred back to another centrum, the reference is color coded to the indicated centrum.

CONSERVATION

Threats

All known occurrences of *Braya glabella* ssp. *glabella* in Colorado and Wyoming are located on National Forest System land. Current threats to the long-term persistence of *B. glabella* ssp. *glabella* in Region 2 and Region 4 are difficult to identify due to the remoteness of occurrences and lack of knowledge concerning the taxon's biology and ecology. The threats listed relate to specific comments noted on herbarium sheets or recorded on EORs from CNHP and WYNDD. The remote location of the majority of the occurrences provides some protection to the taxon; however, land managers may be unaware of these occurrences, and this lack of information may result in management decisions that fail to account for the taxon.

Of the activities that typically occur or are planned for the Pike, San Isabel, White River, or Gunnison national forests, recreation and mining are most likely to affect *Braya glabella* ssp. *glabella* directly. Other potential threats to the taxon include competition from invasive weeds, herbivory, global warming, and air pollution.

Recreation near *Braya glabella* ssp. *glabella* occurrences primarily consists of hiking, off-road

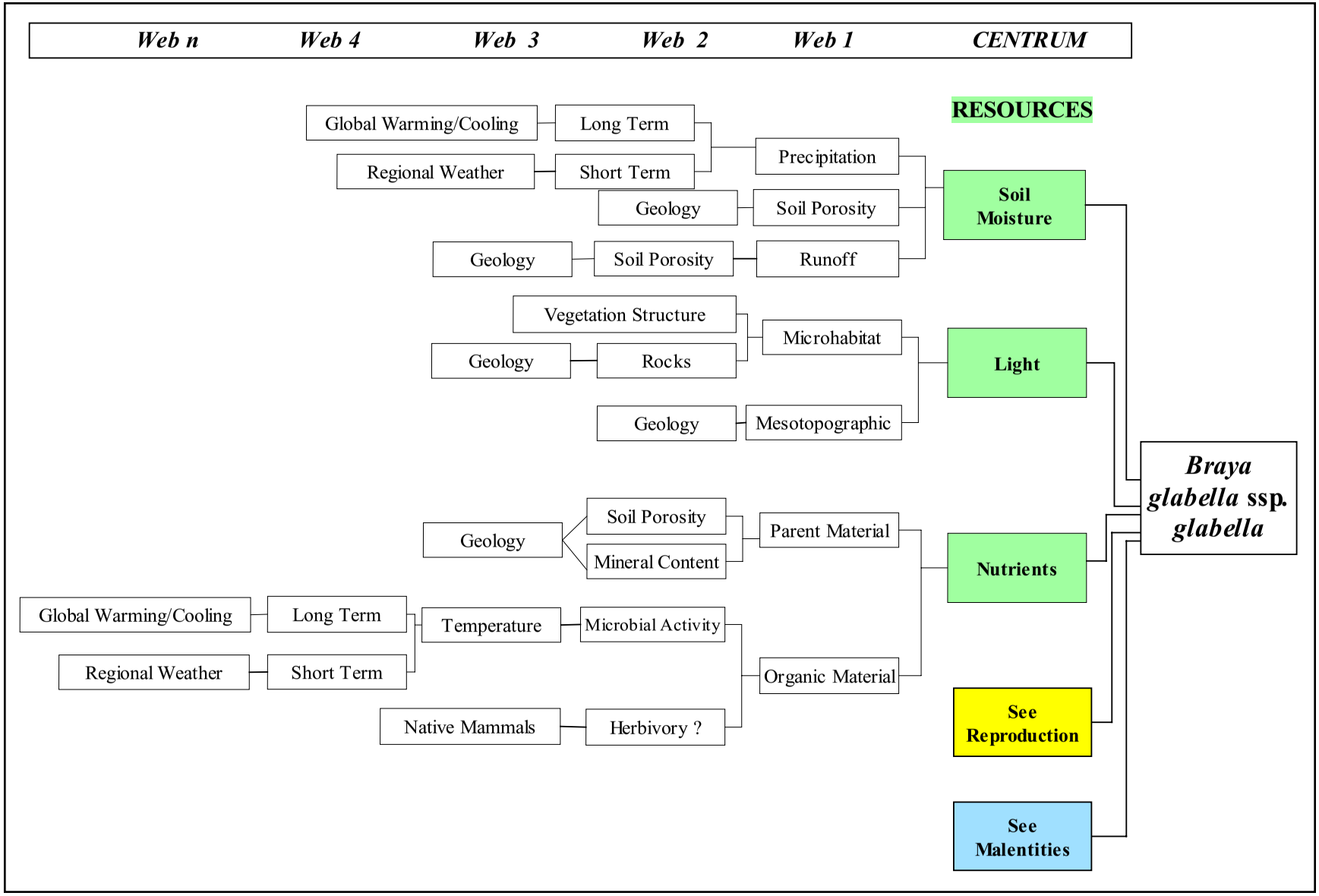

Figure 6. Envirogram for *Braya glabella* ssp. *glabella*, environmental resources centrum. Green boxes indicate resources, yellow indicates reproductive factors, and

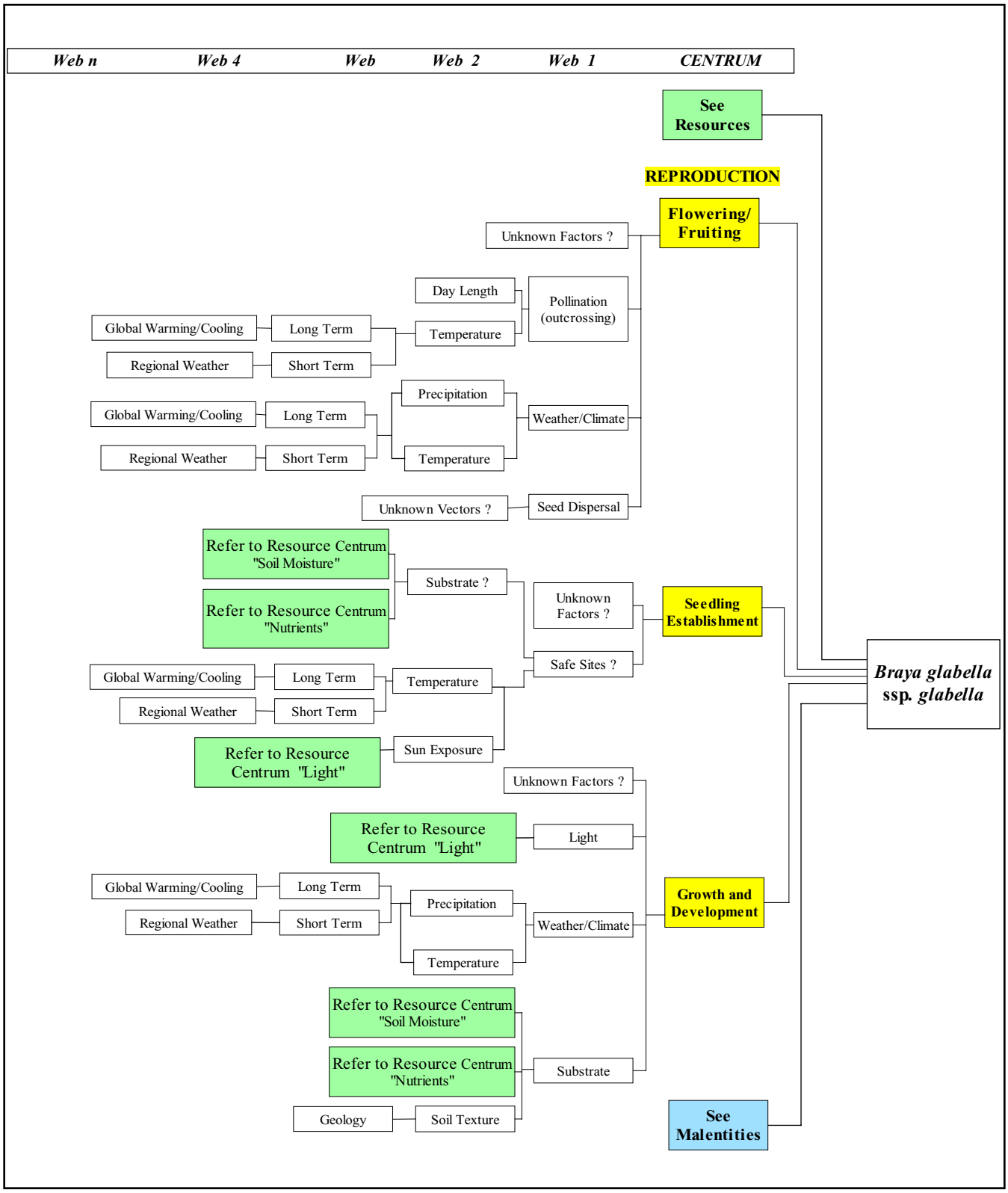

Figure 7. Envirogram for *Braya glabella* ssp. *glabella*, reproduction centrum. Green boxes indicate resources, yellow indicates reproductive factors, and blue indicates malentities.

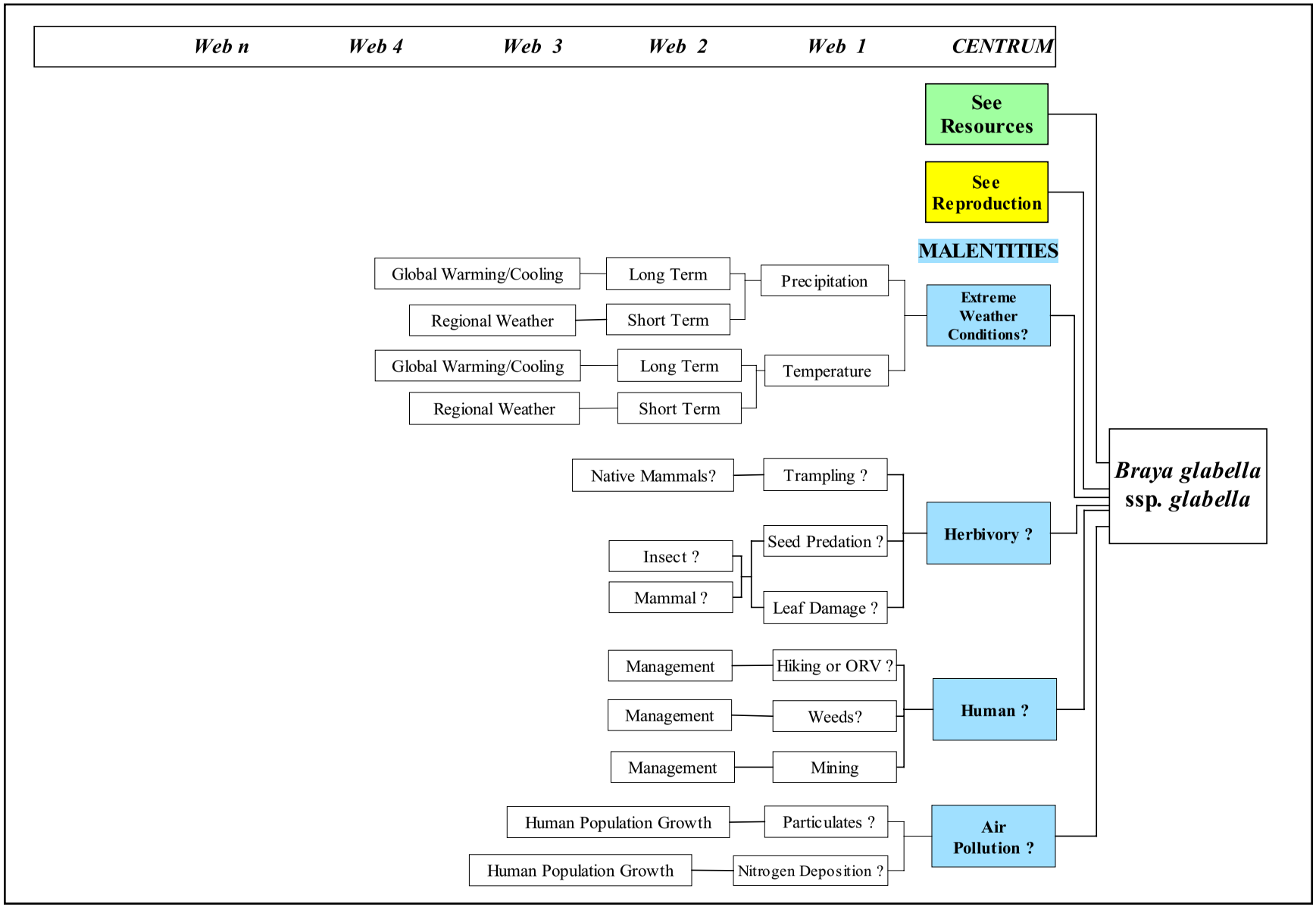

Figure 8. Envirogram for *Braya glabella* ssp. *glabella*, malentities centrum. Green boxes indicate resources, yellow indicates reproductive factors, and blue indicates malentities.

vehicle (ORV), and four-wheel drive use. One occurrence (EOR 002*CO) is located within and adjacent to a jeep trail. This is the only occurrence showing impacts from vehicle use; the EOR for this location recorded trampling of individual plants by four-wheel drive vehicles. Four other occurrences (001*CO, 004*CO, 008*CO, and 009*CO) are located within a quarter mile (400 m) of established jeep trails or hiking trails and may occasionally be crushed by wandering recreationists. Four of the nine occurrences within Region 2 (003*CO, 005*CO, 006*CO, and 007*CO) are located in wilderness areas, which are closed to motorized recreation; however, pack trails are within a quarter mile (400 m) of the occurrences, and individual plants may be subject to occasional trampling by hikers or browsing pack stock. The Wyoming occurrences (001*WY and 002*WY) are located away from established pack trails. Indirect impacts from ORV and four-wheel drive vehicle use include habitat fragmentation, increased erosion, and introduction of invasive plants. None of the Colorado or Wyoming occurrences are located in areas designated for snowmobile recreation (USDA Forest Service 1984, 1991, 2002).

No reports of direct impacts from mining activities have been reported. As noted in the Distribution and Abundance section, *Braya glabella* ssp. *glabella* was only recently discovered in Colorado, so it is not known what the extent of its range was prior to the intensive and destructive mining practices of the 19th century. This taxon may have been greatly impacted by mining as most of the occurrences are located near old mines, and individual occurrences may have been larger prior to the mining era. Undiscovered occurrences of *B. glabella* ssp. *glabella* could be associated with patented mining claims. It is unknown to what extent the locations of *B. glabella* ssp. *glabella* occurrences overlaps with unpatented mining claims on National Forest System land. Mining activities have generally been curtailed in Colorado; however, with rising prices of gold and other metals, new mining claims could be filed that may affect this taxon. Should mining occur within the vicinity of *B. glabella* ssp. *glabella* occurrences, effects may include habitat fragmentation, alteration of hydrology, increased erosion, and direct impact to individual plants from construction and operation of roads and mines.

Based upon herbarium label data and EOR records, invasive plants do not appear to pose a threat at present. No Colorado or Wyoming state- or county-listed noxious weeds are found with *Braya glabella* ssp. *glabella* occurrences. Several invasive plants, including yellow toadflax (*Linaria vulgaris*), spotted knapweed (*Centaurea biebersteinii*), and scentless chamomile (*Matricaria perforata*) have been observed at or above treeline in Colorado and may eventually pose a threat to *B. glabella* ssp. *glabella* (Ray 2001). There is no information available to predict the introduction or spread of invasive species into alpine habitat.

Global warming has been identified as a potential threat to alpine communities. In Colorado and Wyoming, both lower elevation and alpine snow covers are very sensitive to changes in climate. Potential impacts because of global warming include a reduction of snow cover extent, duration, and depth. Additional impacts may include alteration of species composition, geographic range, health, and productivity (U.S. Environmental Protection Agency 1998). Global warming could result in upper treeline encroaching on alpine habitats (Colorado Department of Public Health and Environment 1998).

Three Colorado occurrences (001*CO, 004*CO, and 009*CO) are located in or near the urbanized Front Range. Nitrogen emissions from fixed, mobile, and agricultural sources have increased dramatically along the Front Range of Colorado (Baron et al. 2000). In other high-elevation ecosystems in the Rocky Mountains, nitrogen deposition has altered soil nutrient cycling and vegetation species composition; native plants that evolved under nitrogen-poor conditions have been replaced by invasive species that are able to take advantage of increased nitrogen levels (Baron et al. 2000). Possible effects of nitrogen deposition on a terrestrial ecosystem include alteration of mycorrhizal fungi, loss of lichen communities, enhancement of non-native species invasions, and alteration of fire cycles by increasing fuel loads (Fenn et al. 2003). A study of nutrient availability, plant abundance, and species diversity in alpine tundra communities determined that the addition of nitrogen resulted in an increase in species diversity in a dry alpine meadow (Theodose and Bowman 1997). Because *Braya glabella* ssp. *glabella* is probably a poor competitor, any increase in vegetation within its habitat is likely to be detrimental to the species.

Conservation Status of Braya glabella ssp. *glabella in Region 2*

Little information is available concerning the biology, abundance, trend, habitat capability, or ecological strategies for *Braya glabella* ssp. *glabella*. The primary concern for the viability of the taxon is based on its small, disjunct occurrences located at the southern periphyer of the taxon's range. Management

of the fragile alpine habitats in which it occurs is also a source of concern. The disjunct occurrences of *B. glabella* ssp. *glabella* in Colorado and Wyoming may serve as important sources of genetic diversity for this taxon. It is possible that populations near the periphery of the species' range have alleles not present in other populations, so loss of these populations might result in a significant loss of genetic diversity (Glisson 2004).

All nine of the occurrences in Colorado (three within the Collegiate Peaks Wilderness and one within the Fossil Ridge Wilderness) and both occurrences in Wyoming are located on National Forest System land; the only opportunities for conservation of the species lie with the USFS. There have been no studies or observations to assess whether the distribution or abundance of *Braya glabella* ssp. *glabella* is declining or has been impacted by human activities within Regions 2 and 4. There is no strong evidence that any individual occurrences are at risk.

Because they are small and isolated, occurrences of *Braya glabella* ssp. *glabella* in Colorado and Wyoming may be at risk from genetic or environmental stochasticity. Minimum viable population size has not been determined for this species. Plants tagged by Betsy Neely in 1985 in EOR 001*CO could be relocated, but as of April 2004, this site had not been revisited (Neely personal communication 2004). There are no other established demographic monitoring sites for *B. glabella* ssp. *glabella*, nor have records been maintained noting changes in population size at any of the known occurrences.

Factors that could affect long-term viability of the taxon include geographic isolation, limited dispersal capability, and/or minimal potential for seedling recruitment, particularly in sparsely vegetated alpine habitats. No information was identified indicating that any occurrences located on National Forest System land within Region 2 have declined or disappeared because of environmental stochasticity, natural catastrophes (e.g., extreme weather conditions, global warming, air pollution), or land management practices (mining or recreation).

Management of Braya glabella ssp. *glabella in Region 2*

Implications and potential conservation elements

The USFS has developed no management plans that explicitly incorporate conservation of *Braya glabella* ssp. *glabella*. Detailed biological and ecological studies of this taxon and its associated habitat have not been conducted. No information is available documenting impacts of management on the taxon.

Although there has been no analysis of the effects of management prescriptions on *Braya glabella* ssp. *glabella* habitat, some inferences can be made based on the nature of these alpine areas. In Colorado, three occurrences are located within the Collegiate Peaks Wilderness Area and one is within the Fossil Ridge Wilderness Area. Wilderness designation provides some level of protection from activities such as motorized recreation. The remote, rugged terrain that provides habitat for *B. glabella* ssp. *glabella* is likely to be resilient to impacts that might cause light or moderate disturbance (e.g., infrequent recreational use such as hiking). Occurrences outside wilderness boundaries would likely withstand occasional human visitation without severe effects, but frequent or moderate-to-heavy ORV use would probably degrade these sites. Proximity to jeep trails may also provide a vector for weed introduction. Management changes might be necessary if human use of areas supporting occurrences of *B. glabella* ssp. *glabella* increases or changes.

Any alteration of soils, moisture, temperature regimes, or community composition may limit the reproduction and growth of *Braya glabella* ssp. *glabella*, especially in the fragile alpine habitats in which it occurs. Activities potentially occurring on National Forest System lands that may threaten individuals or occurrences of *B. glabella* ssp. *glabella* include mining, recreation, and competition from invasive species. The consequences of management actions may include habitat fragmentation, soil compaction, erosion, trampling of individuals, and loss of fitness, or alteration of habitat. No experimental data are available on the response of this taxon to management actions.

Tools and practices

It will be necessary to gather basic information concerning the distribution, biology, and ecology of *Braya glabella* ssp. *glabella* before specific tools and practices to benefit the species can be defined. Managers will be better able to manage and conserve occurrences and habitat as they acquire information from surveys for new occurrences, censuses of known occurrences, research into habitat characteristics and reproductive behaviors, monitoring studies to define demographic variables, and studies to determine the effects of management and natural disturbance on population viability.

Documented habitat descriptions consistently note that this species occurs on barren, usually calcareous soils and gravels, gravel bars, disturbed sites, scree slopes, or solifluction terraces. Due to the strong interest by Wyoming botanists in calcareous habitats, many areas of known limestone and dolomite substrates have been surveyed (Hartman personal communication 2006). It is likely that undocumented occurrences of *Braya glabella* ssp. *glabella* exist, but because this type of habitat is uncommon, it is unlikely that large numbers of new occurrences remain undiscovered. Except in the Mosquito Range of Colorado, much of this potential habitat lies on public land, and especially on National Forest System land. Efforts to locate new occurrences when fruits are present (July through August) are the most likely to be successful.

Periodically estimating the number of plants in known occurrences is an economical and efficient method for documenting general trends in *Braya glabella* ssp. *glabella*'s abundance and for identifying visible impacts or threats at visited sites. Repeated site visits also provide the opportunity to identify additional occurrences nearby. Recording the precise GPS locations of occurrences would assist managers in planning, simplify occurrence relocation, and help in mapping and identifying potential habitat. Because some occurrences are in the vicinity of other rare plant taxa, surveys would provide important information for several rare species with an economy of effort.

However, periodic estimates of population size alone may not provide adequate information for management decisions (Elzinga et al. 1998). Individual plants tagged by Betsy Neely in 1985 (*Neely #3170*) could be relocated and provide information regarding life span, recruitment, and mortality within this occurrence. The establishment of additional permanent demographic monitoring transects may yield information to determine reproduction, trends, disease, predation, mortality, and threats (Elzinga et al. 1998). Monitoring designs should take into account the patchy, clumpy distribution of *Braya glabella* ssp. *glabella* plants within an occurrence. Utilization of photo plots would provide a snapshot of plant vigor and distribution at the time of sampling. Pavlik (1994) discusses guidelines for trend analyses, demographic monitoring, and management of plant species with only a few, highly localized occurrences.

Additional quantitative data documenting the condition of the communities where *Braya glabella* ssp. *glabella* grows would make information available to describe baseline conditions should there be an increase or decrease in *B. glabella* ssp. *glabella* abundance. This information may also provide clues as to possible limiting factors controlling the distribution of the taxon. Variables to be measured include cover or density of all plant species within occurrences; soil surface conditions, including rock type and size; and microhabitat characteristics, including slope, aspect, position on slope, ground cover and geologic substrate.

Ideally, habitat monitoring describes how well an activity meets the objectives or management standards for the habitat (Elzinga et al. 1998). Habitat monitoring is most effective when research has shown a clear link between a habitat parameter and the condition of a species (Elzinga et al. 1998). Without additional knowledge of specific factors controlling the growth and distribution of *Braya glabella* ssp. *glabella*, it would be difficult to establish an effective habitat monitoring program.

Once there is a basic understanding of *Braya glabella* ssp. *glabella* and its habitat, conservation priorities and techniques can be developed. Managers can use the information to help guide decisions on management prescriptions such as livestock stocking levels, recreational carrying capacity, and sustainable uses of habitat. It may be appropriate for some occurrences to receive recognition in special management areas or research natural areas. USFS managers should be aware of the potential for *B. glabella* ssp. *glabella* when they are considering exchanges of parcels of alpine habitat.

The mission of the Center for Plant Conservation is to conserve and restore the rare native plants of the United States. No plant material of *Braya glabella* ssp. *glabella* has been stored with the Center for Plant Conservation. Development of a germplasm bank with an institution specializing in the conservation of rare plant species is desirable in case restoration of an occurrence becomes necessary.

Information Needs

The most pressing need for *Braya glabella* ssp. *glabella* is more information on its abundance and distribution on National Forest System land within Region 2. Potential habitat occurs on the Pike-San Isabel, Gunnison, and Shoshone national forests in Region 2 and on the Bridger-Teton National Forest in Region 4. Alpine outcrops of limestone in the Gros Ventre and Wind River mountains in Wyoming and the Mosquito and West Elk ranges in Colorado offer the highest potential for finding new occurrences. Botanists

and USFS personnel should be on the lookout for new occurrences when working in these areas.

Current evidence suggests that habitat requirements for *Braya glabella* ssp. *glabella* need to be more rigorously defined, as it is unclear what constitutes sustainable habitat. Given that this taxon prefers poorly vegetated substrates, its ability to tolerate competition is probably low.

The factors that limit population size and abundance of *Braya glabella* ssp. *glabella* are not known. Important information could be extracted from revisiting the tagged plants at occurrence 001*CO. Careful monitoring of this occurrence could provide information about longevity, recruitment, and mortality.

The impacts of common alpine recreational activities on *Braya glabella* ssp. *glabella* are unknown. Revisiting and monitoring known occurrences is important in order to understand the implications of current and future management prescriptions. Occurrence 002*CO, located on American Flag Mountain on the Gunnison National Forest, should be monitored for impacts resulting from motorized recreation.

So little is known about *Braya glabella* ssp. *glabella* that virtually any information would be new and valuable. Suggestions for specific research topics include:

- collecting quantitative data and precise descriptive information for habitat characteristics of high quality occurrences, including substrate, aspect, elevation, slope, closely associated plant species, and GPS location. These data would provide a baseline for habitat monitoring

- evaluating the reproductive and ecological characteristics of the taxon, such as pollination mechanisms (outcrossing), seed germination, seedling establishment, herbivory, flowering/fruiting, and dispersal vectors. These data would provide a basis to assess the factors controlling the growth and distribution of *B. glabella* ssp. *glabella*

- quantifying demographic parameters for *B. glabella* ssp. *glabella*, including vital rates, recruitment, survival, reproductive age, lifespan and proportion of occurrences reproducing, seed viability, and seed bank dynamics

- assessing and describing impacts to the taxon or community caused by accident, natural event, management prescription, or illegal activities.

DEFINITIONS

Alleles – any of the different forms of a gene occupying the same locus (Lincoln et al. 1982).

Apomixis – reproduction without fertilization, in which meiosis and fusion of the gametes are partially or totally suppressed (Lincoln et al. 1982).

Environmental stochasticity – variation over time in the populations operational environment (Menges 1991).

Heterozygosity – having two different alleles at a given locus of a chromosome pair (Lincoln et al. 1982).

Locus – the position of a given gene on a chromosome (Lincoln et al. 1982).

Longevity – the average life span of the individuals of a population under a given set of conditions (Lincoln et al. 1982).

Outcrossing – mating or crossing of individuals that are either less closely related than average pairs in the population, or from different populations (Lincoln et al. 1982).

Phytomicroclimate – the environment created within the confines of a plant body, and within the various parts of the plant body, such as leaf or stem (Thilenius 1975).

Polymorphisim (polymorphic – adj.) – the co-occurrence of several different forms (Lincoln et al. 1982).

Polyploid – having more than two sets of homologous chromosomes (Lincoln et al. 1982).

Self-compatible – used of a plant that can self-fertilize (Lincoln et al. 1982).

Silique – a dry, dehiscent fruit of the Brassicaceae family, typically more than twice as long as wide, with two valves separating from the persistent placentae and septum (replum) (Harris and Harris 1994).

Vital rates – the class-specific annual rates of survival, growth, and fecundity (Morris et al. 1999).

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