Ipomopsis globularis (Brand) W.A. Weber (Hoosier Pass ipomopsis): A Technical Conservation Assessment

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

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Cover Photo Credit

Ipomopsis globularis (Hoosier Pass ipomopsis). Photograph by Susan Spackman. Used with permission.

SUMMARY OF KEY COMPONENTS FOR CONSERVATION OF *IPOMOPSIS GLOBULARIS*

Ipomopsis globularis (Brand) W.A. Weber (Hoosier Pass ipomopsis or globe gilia) is an extremely narrow endemic with a global distribution that is limited to an approximately 20 by 30 mile (32 by 48 km) area in the Mosquito Range and adjacent Hoosier Ridge of Colorado in Lake, Park, and Summit counties. Found primarily in dry, gravelly, calcareous soils above tree line, this species is known from nine occurrences, each including a mix of National Forest System lands and private lands. The total occurrence size of *I. globularis* is estimated to be between 6,000 and 11,000 plants. Although it is likely that more plants will be found with additional inventory effort, it is not likely that the species will be found to be common. Enough inventory work has taken place within the range of *I. globularis* and surrounding areas to indicate that this is a very rare species. NatureServe and the Colorado Natural Heritage Program both rank this species as imperiled (G2 and S2, respectively). In 1993, USDA Forest Service Region 2 designated it as a sensitive species. However, *I. globularis* was not included on the list of sensitive species designated by the Region 2 Regional Forester in November 2003; it was placed into the category of "Not R2 Sensitive Species, But Should Be Considered for Other Emphasis Species Lists." This species has not been documented on Bureau of Land Management (BLM) public lands although there are BLM public lands in the vicinity of known occurrences. It is not included on the BLM Colorado State Sensitive Species List. It is not listed as threatened or endangered on the Federal Endangered Species List.

There are several threats to the persistence of *Ipomopsis globularis*. In order of decreasing priority these are motorized recreation, mining, exotic species invasion, effects of small population size, collection for horticultural trade, non-motorized recreation, global climate change, and pollution. Motorized recreation is rapidly increasing in areas where this species grows, and it is extremely difficult to enforce regulations or to close access to protect populations. The entire global range of *I. globularis* is vulnerable to mining development; however, the scale and timeframe within which mining activity might occur is unknown. Historic mining is widely evident in this species' habitat. Land ownership patterns are extremely complex within the range of *I. globularis* and even within individual occurrences. Despite its narrow range, this species is found on lands administered by three ranger districts on two national forests (South Park and Leadville of the Pike-San Isabel, and Dillon of the Arapaho as administered by the White River), and hundreds if not thousands of private landowners. These complex land ownership patterns make conservation efforts difficult. To date, there is only one portion of one occurrence protected within the Hoosier Ridge Research Natural Area in the Pike San Isabel National Forest.

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INTRODUCTION

This assessment is one of many being produced to support the Species Conservation Project for the USDA Forest Service (USFS) Rocky Mountain Region (Region 2). *Ipomopsis globularis* is the focus of an assessment because it was formerly a sensitive species in Region 2, and there are concerns regarding its level of imperilment. Within the National Forest System, a sensitive species is a plant or animal species 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 (USDA Forest Service Region 2 2002). A sensitive species may require special management, so knowledge of its biology and ecology is critical. This assessment addresses the biology and ecology of *I. globularis* throughout its range. This introduction defines the goal of the assessment, outlines its scope, and describes the process used in its production.

Goal of Assessment

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

Scope of Assessment

This assessment examines the biology, ecology, conservation status, and management of *Ipomopsis globularis* with specific reference to the geographic and ecological characteristics of the USFS Rocky Mountain Region. Similarly, this assessment is concerned with the reproductive behavior, population dynamics, and other characteristics of *I. globularis* in the context of the current environment rather than under historical conditions. The evolutionary environment of the species is considered in conducting the synthesis, but placed in a current context.

In producing the assessment, refereed literature, non-refereed publications, research reports, and data accumulated by resource management agencies were reviewed. The assessment emphasizes refereed literature because this is the accepted standard in science. Non-refereed publications and reports were used in the assessment when information was unavailable elsewhere, but they were regarded with greater skepticism. Unpublished data (e.g., Natural Heritage Program records) were important in estimating the geographic distribution of this species. These data required special attention because of the diversity of persons and methods used in collection. Because basic research has not been conducted on many facets of the biology of *Ipomopsis globularis*, literature on its congeners was used to make inferences.

Treatment of Uncertainty in Assessment

Science represents a rigorous, systematic approach to obtaining knowledge. Competing ideas regarding how the world works are measured against observations. However, because our descriptions of the world are always incomplete and observations 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 (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 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 as sound approaches to understanding. In this assessment, the strength of evidence for particular ideas is noted, and alternative explanations are described when appropriate.

Treatment of this Document as a Web Publication

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

Peer Review of this Document

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

Ipomopsis globularis was listed as a sensitive species in USFS Region 2 until the latest revision of the sensitive species list, which was signed by the Regional Forester in November 2003. It appears that the main reason the species was not included on the most recent sensitive species list is that there was a misunderstanding regarding its full distribution. Although Johnston (2002a) reports that the species is known from 25 to 30 occurrences in five Colorado counties, this effort was only able to identify a total of nine occurrences in three counties. Further, Johnston (2002a) indicates that the species is found in several protected areas; this effort did not find this to be the case.

Ipomopsis globularis is found primarily on lands administered by the South Park Ranger District and the Leadville Ranger District of the Pike-San Isabel National Forest, and the Dillon Ranger District administered by the White River National Forest. Land ownership patterns are complex in the Mosquito Range, with many patented mining claims creating a unique land use pattern. All nine of the occurrences include some National Forest System land and some private lands.

Ipomopsis globularis is not found on lands managed by the Bureau of Land Management (BLM) although there is BLM public land in the vicinity of some occurrences. *Ipomopsis globularis* is not listed on the BLM Colorado State Sensitive Species List. NatureServe considers *I. globularis* to be globally imperiled (G2). Found only in Colorado, this species is also considered imperiled (S2) by the Colorado Natural Heritage Program (Colorado Natural Heritage Program 2003). It is considered imperiled because it is known from nine occurrences, only five of which include a large (1,000 or more individuals estimated) number of individuals. For explanations of NatureServe's ranking system, see the Definitions section of this document. It is not listed as threatened or endangered on the Federal Endangered Species List. *Ipomopsis globularis* was formerly listed as a Category 3C species by the U.S. Fish and Wildlife Service (O'Kane 1988), which means that the species has been proven to be more abundant or widespread than was previously believed, and/or it is not subject to any identifiable threat (Spackman et al. 1997b). The Category 3C status was based on a 1981 status report (Johnston et al. 1981) that is now out of date, primarily because of additional information that is available about the threats to *I. globularis*. This species is threatened by mining, recreation, exotic plants, horticultural trade, global climate change, and pollution.

Ipomopsis globularis is found within one protected area, the Hoosier Ridge Research Natural Area (RNA), which prohibits recreational facilities, roads, trails, livestock grazing, and mining. However, the RNA is small, with a large portion of the occurrence falling outside the RNA boundaries. *I. globularis* is not specifically mentioned in the management objectives for the RNA. Further, residential development is occurring within 1/8 of a mile of the RNA, enforcement of restrictions is difficult, and the RNA designation has been challenged by local mining interests (Ray 2001). The RNA is surrounded by the Bross Sheep and Goat allotment, that is currently is not being grazed and the USFS does not have plans to allow grazing within this allotment (Ray 2001, Johnston personal communication 2003). The area outside the RNA is designated a "B" travel area, which restricts vehicle traffic to designated routes. However, illegal motorcycle use was observed in this area in 1999 (Coles personal communication 2003).

Existing Regulatory Mechanisms, Management Plans, and Conservation Strategies

No management plans have been drafted that specifically address the conservation needs of *Ipomopsis globularis*. To facilitate awareness of this species and its habitat during planning and implementation of management activities, the Colorado Natural Heritage Program has identified and provided information to the USFS (Colorado Natural Heritage Program 2003), Summit County (Spackman et al. 1997a), and Park County (Spackman et al. 2001a) regarding the Mosquito Range Potential Conservation Area (PCA), which has been identified by the Colorado Natural Heritage Program (2003) and includes all of the known occurrences of *I. globularis*, has been supplied to the USFS (Colorado Natural Heritage Program 2003), Summit County (Spackman et al. 1997a), and Park County (Spackman et al. 2001a) by the Colorado Natural Heritage Program to facilitate awareness of this species and its habitat during planning and implementation of management activities. Potential Conservation Areas are an estimate of the primary area supporting the long-term survival of targeted species and plant communities, based on an assessment of the biotic and abiotic factors affecting the persistence and population viability of the targets within the area.

Ipomopsis globularis has no legal protection unto itself that would prevent the destruction of individuals or of its habitat. As of this writing, a conservation strategy has not been written for this species at a national or regional level by the USFS or any other federal agency. There are no laws in place that protect this species on private lands with many of the known occurrences. Thus, current laws and regulations protecting this species are clearly inadequate to effectively conserve the species within its native range. Given current human population growth trends and land use plans within the entire global range of this species, extinction is a possibility, although not likely given the remote nature of some of the occurrences. Changes in existing land use plans are needed to ensure the long-term viability of populations. Establishing management plans and monitoring for decreases in population size and for habitat destruction as identified by O'Kane (1988) might also confer protection needed to ensure the long-term persistence of *I. globularis*.

Biology and Ecology

Classification and description

Ipomopsis globularis (Brand.) W.A. Weber is a member of the Phlox family, or Polemoniaceae. The Polemoniaceae is a small, monophyletic family with approximately 379 species in three subfamilies, eight tribes, and 26 genera (Porter and Johnson 2000). This family probably diversified in the mid-Tertiary, but may have originated 100 million years ago or earlier (Porter and Johnson 2000), and has diversified greatly over the past 20 million years (Grant and Grant 1965). The family Polemoniaceae is in class Magnoliopsida (dicots), subclass Asteridae, order Solanales (USDA Natural Resources Conservation Service 2003). The Polemoniaceae is most diverse in western North America (Heywood 1993, Zomlefer 1994), with the center of species diversity in California where approximately half (180 species) of all species in the family reside (Patterson 2002). Along with the Apiaceae and the Brassicaceae, it has proven difficult to confidently circumscribe genera within the Polemoniaceae due to morphological similarities between the species (Dorn 2003).

The genus *Ipomopsis* was first described in 1803 by André Michaux to include what is now known as *I. rubra* (Michaux 1803 as cited in Grant 1956). However, as Polemoniaceous species were described from North America, other members of what are now included in *Ipomopsis* were placed most often in *Gilia*. *Gilia* has historically been one of the more enigmatic genera of Polemoniaceae. It is a classic example of a "garbage can" genus, where taxa, that did not fit well into other genera, were placed (Porter 2002 personal communication). In most early 20th century floras, *Ipomopsis* was treated as a section within the genus *Gilia*. The most widely adopted concept of the genus *Ipomopsis* was circumscribed by Dr. Verne Grant, when he moved all members of the *I. aggregata* complex into the genus from *Gilia* (Grant 1956). Most modern treatments of the Polemoniaceae follow this circumscription, as there is now considerable morphological and molecular phylogenetic evidence to support its treatment at the generic level (Grant 1956, Porter and Johnson 2000, Dorn 2003). The differing base chromosome number of *Gilia* and *Ipomopsis* also supports the recognition of *Ipomopsis* as a separate genus (Grant 1959). However, some notable contemporary sources (e.g., Cronquist et al. 1984) still treat all *Ipomopsis* species within *Gilia*. Grant (1992) placed the genus *Ipomopsis* in the tribe Gileae with *Gilia*, *Eriastrum*, and *Langloisia*. However, based on a robust analysis of morphological and molecular gene sequence data, Porter and Johnson (2000) include *Ipomopsis* within the newly circumscribed tribe Loeseliae (Porter and Johnson 1998), which does not include *Gilia*. In a further revision of *Ipomopsis* presented in Porter et al. (2003), chloroplast and nuclear DNA sequence data suggest that *Ipomopsis* as circumscribed by Grant (1956) is well supported, but it is only monophyletic if four species are removed. As circumscribed by Grant (1956), *Ipomopsis* contains 27 species.

There has been some uncertainty regarding the taxonomy of plants described as *Ipomopsis globularis* through the years, and contemporary sources still disagree on the taxonomic placement of these plants. The classification as *I. spicata* ssp. *capitata* (=*I. globularis*) is preferred by Wilken and Hartman (1991), Porter and Johnson (2000), and Porter et al. (2003), and will be used in the treatment to be developed for the Flora of North America Project (Wilken personal communication 2004). This classification is clearly supported by morphological cladistic analyses (Wilken personal communication 2004). However, the name *I. globularis* is still used by Weber and Wittmann (2001) and Kartesz (1999); the second of these is used as a nomenclatural standard by the Network of Natural Heritage Programs (NatureServe 2003) and by the PLANTS database (USDA Natural Resources Conservation Service 2003). For the purposes of this paper, the name *I. globularis* is used and *I. spicata* ssp. *capitata* is considered to be a direct synonym.

Resolving taxonomic issues for rare species is fundamental to their protection (Standley 1992). However, regardless of whether the plants discussed herein are placed in a subspecific status under *Ipomopsis spicata* or regarded as a full species, *I. globularis* is a distinctive element of the flora of Colorado.

Within the genus *Ipomopsis*, Grant (1956) included *I. spicata* ssp. *capitata* (=*I. globularis*) in section Microgilia, which he circumscribed based on morphological characters. Using nuclear and chloroplast DNA sequences, Porter et al. (2003) reclassified *I. spicata* ssp. *capitata* in section Elaphocera, which is based on *I. congesta* as a type specimen for this section (Porter et al. 2003). The closest relatives to *I. globularis* are apparently members of the *I. congesta* and *I. spicata* complexes.

History of knowledge

Ipomopsis globularis was discovered in 1862 by Hall and Harbour who collected it on a trip to the Rocky Mountains of Colorado. The species was originally classified by Asa Gray in 1870 in *Gilia*, a genus closely related to *Ipomopsis*, and was described as a variety of *G. spicata*, *G. spicata* ssp. *capitata* (Johnston et al. 1981). In 1907, Brand included it in his monograph of the Polemoniaceae (Brand 1907) and listed it as a full species, using the name *G. globularis*. In 1922, Rydberg (1922) listed the species as *G. globularis*, and in 1954 Harrington (1954) listed the species as *G. spicata* ssp. *capitata*. In 1966, Weber (1966) proposed that the species be transferred to *Ipomopsis*. Since 1966, the species has remained in *Ipomopsis*, but its treatment as a full species, *I. globularis*, versus a subspecies, *I. spicata* ssp. *capitata*, is still in question (Wilken and Hartman 1991, Weber and Wittmann 1992 and 2001). For the purposes of this paper, the name *I. globularis* is used and *I. spicata* ssp. *capitata* is considered to be a direct synonym. Drs. J. Mark Porter, Leigh Johnson, and Dieter Wilken are currently using DNA sequences (of both nuclear and chloroplast DNA) to estimate phylogenetic relationships within *Ipomopsis*. This ongoing research will add further refinements to our understanding of the relationships within the Polemoniaceae (Porter personal communication 2003).

From the time of its discovery until the 1980s, *Ipomopsis globularis* was known to Colorado botanists from five general areas in the vicinity of the Mosquito Range, Colorado: Hoosier Ridge, North Star Mountain, Mount Lincoln, Boreas Pass, and Weston Pass. In 1991, Dieter Wilken and Ronald Hartman revised this group of *Ipomopsis*, and in the process discovered two early collections (at PH and US) in the late 1800s from Mount Elbert and Gray's Peak (Wilken and Hartman 1991), a range extension to the west (Mt. Elbert) and north (Gray's Peak) from the Mosquito Range; as far as known, the populations at these two locations have not been thoroughly searched for since the original collections. Some botanists conjecture that there may not be suitable habitat for *I. globularis* on those peaks (Jennings personal communication 2003), but these two areas are not well-searched by botanists, and new finds are being reported every few years. Because the populations at these two sites are poorly known, they are not otherwise discussed. In the early 1980s, *I. globularis* was considered for listing as threatened or endangered on the Endangered Species List. In 1981, Barry Johnston, J. Scott Peterson, and William Harmon wrote a status report for *I. globularis* for the U.S. Fish and Wildlife Service (Johnston et al. 1981). They recommended listing as *I. globularis* as a Category 3C species, which indicates that the species was not in need of protection from the Endangered Species Act (Spackman et al. 1997b). In 1988, O'Kane published *Colorado's Rare Flora* (O'Kane 1988), which included *I. globularis*, and suggested that although the species was not in immediate danger of large-scale habitat loss, the species should be monitored for decreases in population size and for habitat destruction that could result from mining and four-wheel drive recreation. At this time, *I. globularis* became better known to the botanical community, and awareness of its imperilment was raised.

During the 1990s and early 2000s, numerous botanists who were aware of the significance of occurrences of *Ipomopsis globularis* conducted botanical research in the Mosquito Range and surrounding mountains (Chumley 1998, Orthner 1999, Abbott personal communication 2003, Hogan personal communication 2003, Johnston personal communication 2003, Madsen personal communication 2003, Redner personal communication 2003, Yeatts personal communication 2003). Four new locations were documented, bringing the total to nine known occurrences.

Non-technical description

Johnston et al. (1981, p. 5) described *Ipomopsis globularis* as follows: "perennial herb, with leaves mostly basal, long and narrow. Usually a single stem 4 to 6 inches tall with a few pinnately-dissected leaves and surmounted by a ball-shaped inflorescence (>1 cm. in diameter) of pinkish-white or bluish-white flowers." Flowers have a heavy fragrance (Spackman et al. 1997b, Weber and Wittmann 2001), and stems and inflorescences are densely wooly (Spackman et al. 1997b). Flowers of pressed specimens may appear brown (Harrington 1954). All members of *Ipomopsis* have tubiform or salverform flowers (Grant 1956, Grant 1959).

Ipomopsis globularis is not likely to be confused with other alpine species in Colorado (Spackman et al. 1997b). However, it is possible to confuse this species with *I. congesta*, which is found at slightly lower elevations (Jennings personal communication 2003). *I. congesta* has exerted stamens, a smaller inflorescence (<1 cm. [0.4 inches] in diameter), and it is less woolly overall (Jennings personal communication 2003). Other alpine species of *Ipomopsis* in the Bighorn Mountains of Wyoming and Montana, and possibly other northern mountain ranges, resemble *I. globularis* in its dwarf appearance and capitate head (Yeatts personal communication 2003). However, these species are distinct from *I. globularis*.

Published descriptions and other sources

The best single source for a description, illustration, and photographs of *Ipomopsis globularis* and its habitat is the *Colorado Rare Plant Field Guide* (Spackman et al. 1997b). See **Figure 1**, **Figure 2**, and **Figure 3** for additional photographs and the illustration included in Spackman et al. (1997b). A photograph and a range map are also included in *Rare Plants of Colorado* (Colorado Native Plant Society 1997). Another photograph is also available through the Rocky Mountain Rare Plants Alpine Seed catalog on the World Wide Web site at www.rmrp.com. The original description of this species is found in Brand (1907), and additional descriptions are available in floras (Rydberg 1922, Harrington 1954), and in Wilken and Hartman's revision of the *I. spicata* complex (Wilken and Hartman 1991). Weber and Wittmann (2001) is the most readily available and up-to-date source with keys for field identification, but it does not include a full description. Photographs of the plant and its habitat are also included in Johnston et al. (1981), but this source is not easily obtained. A digital image of Hall and Harbor's holotype specimen can be obtained online from the New York Botanical Garden's Web site (New York Botanical Garden 2003).

Distribution and abundance

Ipomopsis globularis is a narrowly endemic species known only from an approximately 20 by 30 mile (32 by 48 km) range in Lake, Park, and Summit counties, Colorado. Its global distribution is limited to National Forest System and private lands in the vicinity of the Mosquito Range of Colorado (**Figure 4** and **Figure 5**). All of the known occurrences are within 30 miles (48 km) of each other and collectively occupy less than 4,000 acres (1,619 ha) (Colorado Natural Heritage Program 2003). It is likely that occurrence size varies from year to year. Loraine Yeatts (personal communication 2003) has observed large differences in total number of individuals at Hoosier Pass during different years.

Ipomopsis globularis grows in gravelly calcareous soils in alpine areas in the vicinity of the Mosquito Range (Spackman et al. 1997b, Johnston et al. 1981). The elevation range of *I. globularis* is 10,500 to 13,800 feet (3,200 to 4,206 m). Please see **Table 1** for summary data on the nine known occurrences.

Figure 1. Close up photo of *Ipomopsis globularis*. Photograph by Susan Spackman, used with permission.

Figure 2. Habitat of *Ipomopsis globularis*. Photograph by Susan Spackman, used with permission.

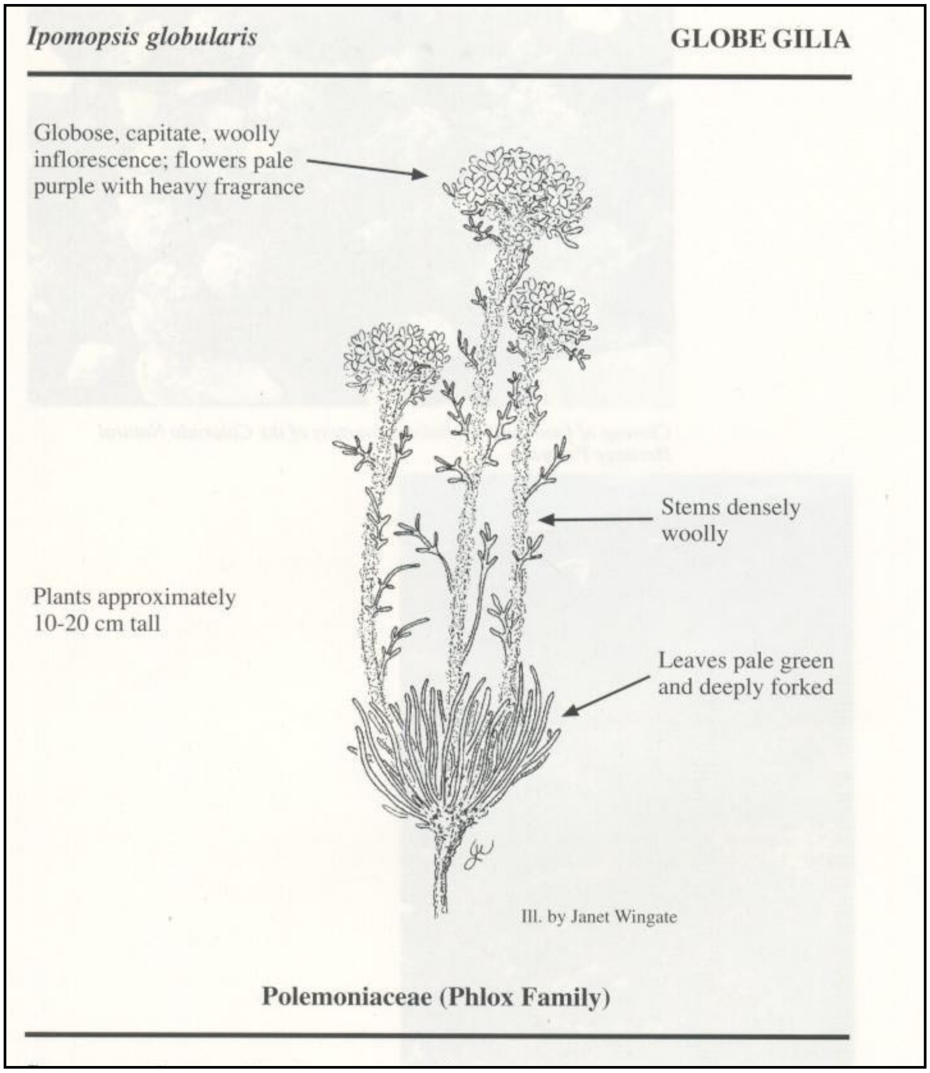

Figure 3. Illustration of *Ipomopsis globularis* showing the diagnostic characteristics. Illustration by Janet Wingate, used with permission.

There have been several botanical surveys specifically targeting *Ipomopsis globularis* (e.g., Spackman et al. 1997a, Orthner 1999, Spackman et al. 2001a, Spackman et al. 2001b, Bingham personal communication 2003). While these surveys have led to the discovery of additional small occurrences or sub-occurrences, they have not found other large occurrences. However, there is potential habitat that remains to be searched. Limited access to remote areas and private land has made it difficult to search areas thoroughly within the known distribution of *I. globularis*. While it is possible that it is limited to the range as currently known, further focused inventory work is necessary to verify this.

There has been no rigorous quantification of the total number of individuals of *Ipomopsis globularis*. It is known from nine occurrences, but the vast majority of the individuals are found in five or six occurrences (**Table 1**). The largest occurrences are found at Hoosier Ridge, Mount Lincoln, Boreas Pass (including a sub-occurrence on Mount Silverheels), Weston Pass, Dolly Varden Gulch, and possibly Cooper Creek. However, several of these occurrences have not been visited in over 10 years and were never rigorously quantified. Estimates for the Weston Pass occurrence range from 200 to 3,000 plants (Colorado Natural Heritage Program 2003). Sizes of the other occurrences are much lower or have not been estimated (Colorado Natural Heritage Program 2003).Wide variation in the number of flowering individuals from year to year makes it difficult to assess accurately the total number of individuals.

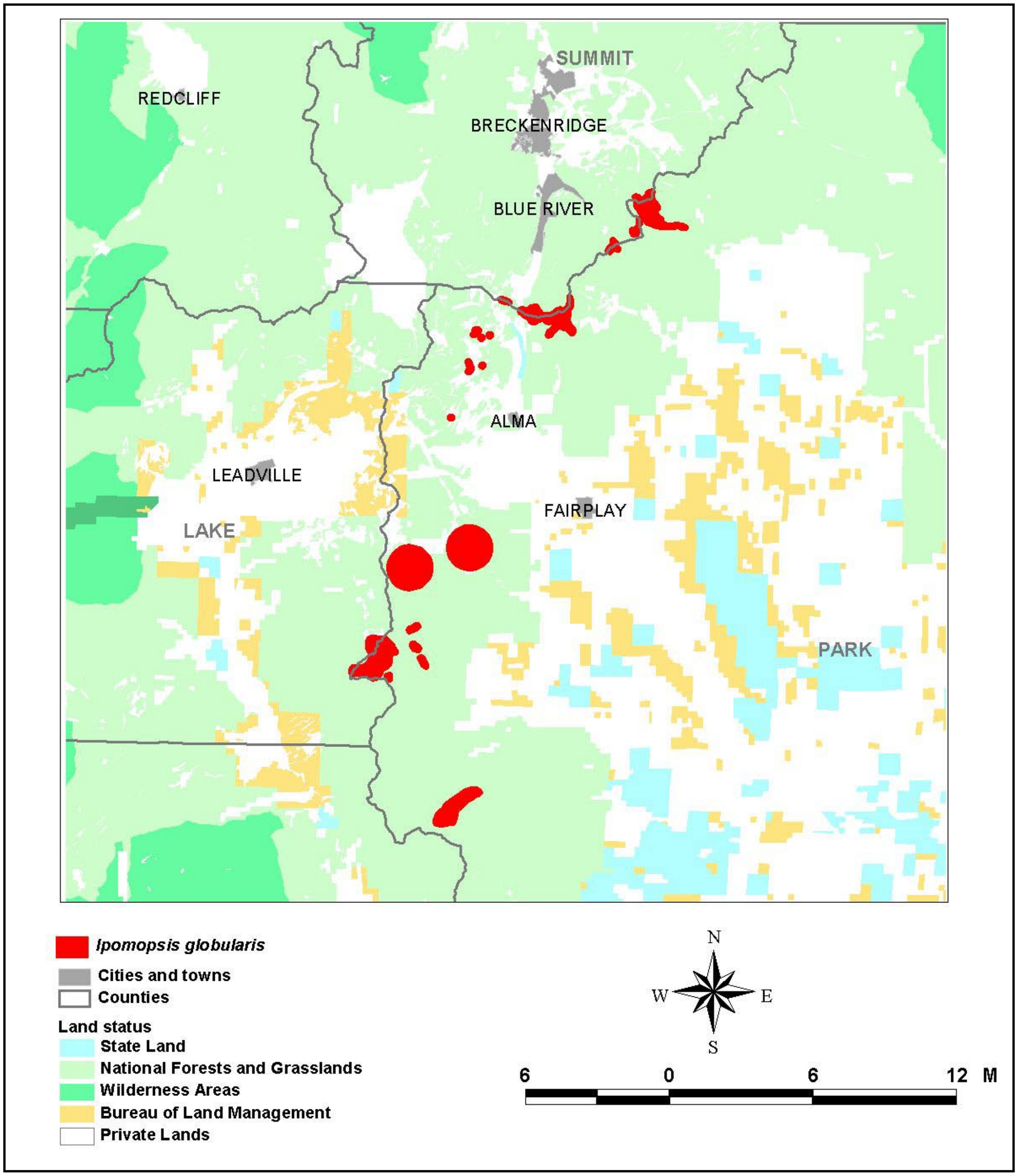

Figure 4. Global distribution of *Ipomopsis globularis*. Occurrences in Summit County are in the White River National Forest, remaining occurrences are in the Pike-San Isabel National Forest. All occurrences include some National Forest System lands and some private lands. Occurrences may be represented by more than one polygon (these are considered to be sub-occurrences.)

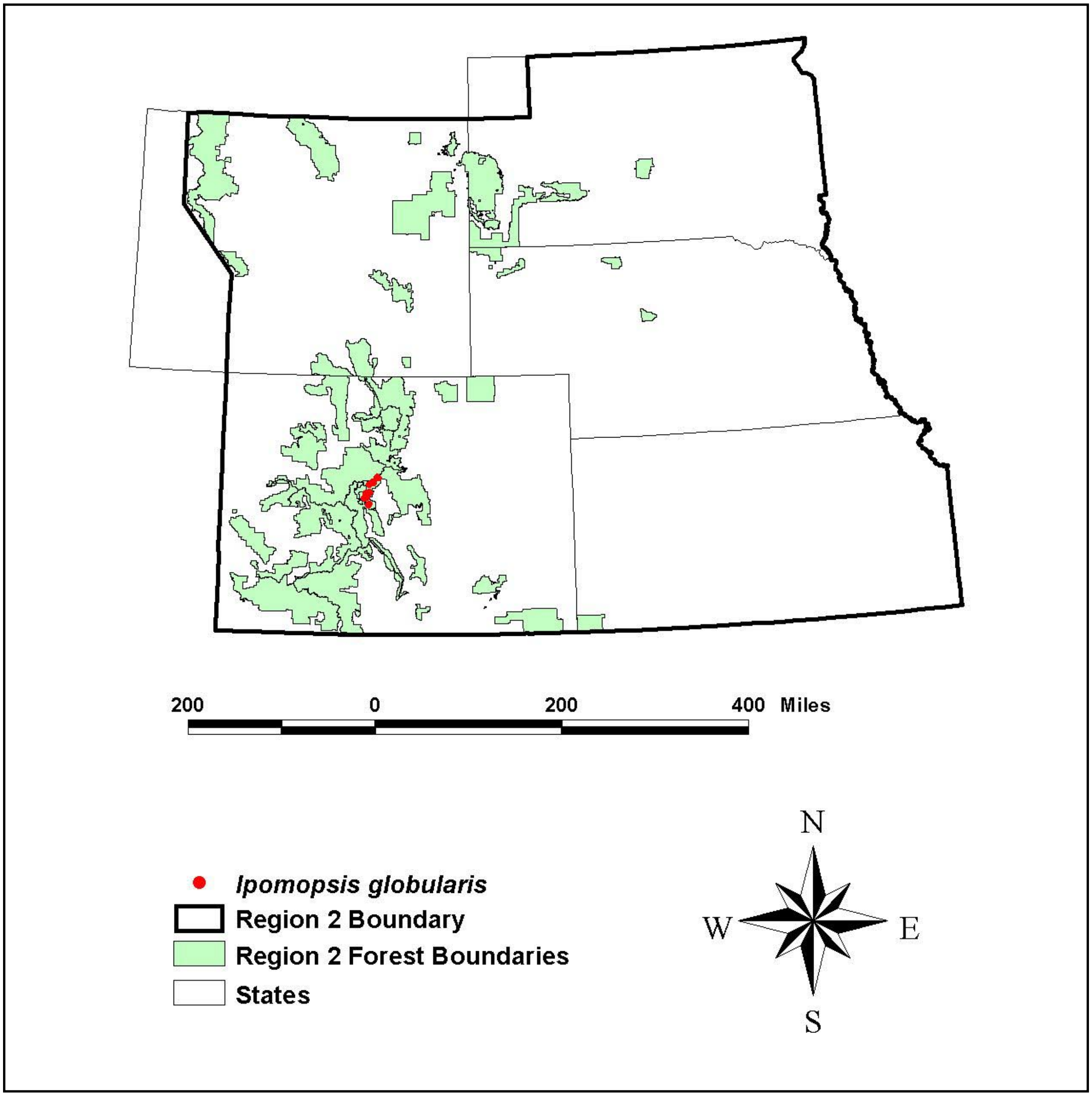

Figure 5. Distribution of *Ipomopsis globularis* in relation to lands managed by the USDA Forest Service Rocky Mountain Region.

Similarly, the total area occupied by *Ipomopsis globularis* has not been rigorously quantified. While some botanists have reported visual estimates of the total acreage of certain occurrences, others have drawn large polygons on maps that represent much larger areas, presumably including some areas of unoccupied habitat (Colorado Natural Heritage Program 2003). Thus, the estimate of total occupied area for the species ranges from 77 to 3,065 acres (31 to 1,240 ha). The known occupied habitat is certainly less than 4,000 acres (1,618 ha).

The full geographic distribution of *Ipomopsis globularis* habitat is not known. Apparently, suitable locations have been observed and searched to no avail. Outcrops of Leadville limestone and Manitou dolomite within the elevation range of *I. globularis* have not been mapped at a detailed scale, and it is not definitively known to what geologic and soil substrates *I. globularis* are limited. *I. globularis* may have very specific physiological requirements for germination and growth that might prevent its spread to other locations. However, it may also be dispersal-limited, precluding

Table 1. Summary information on the nine known occurrences of *Ipomopsis globularis*. Source: Colorado Natural Heritage Program 2003.

Name	Element occurrence number	Date of last observation	Reported area (acres) /Calculated area from arc view[1]	Estimated occurrence size	Elevation (ft.)	Land ownership/ management
Hoosier Ridge	001	July 11, 2003	9/808	2,000	11,540 to 13,200	White River National Forest (WRNF), Pike National Forest (PNF), private
North Star Mountain	003	August 2000	2/5	200 to 300	11,760 to 12,200	PNF, WRNF, possibly private
Mount Lincoln	004	July 19, 1985	1/41	3,000	12,000 to 13,800	PNF and private
Boreas Pass	008	July 15, 2003	8/878	1,210	10,520 to 13,010	PNF, WRNF, and private
Weston Pass	010	July 28, 2000	17/1326	200 to 3,000	11,600 to 12,695	PNF, San Isabel National Forest, and private
Cooper Creek	011	July 17, 1985	Not reported	Locally frequent	12,160 to 12,320	PNF and private
Dolly Varden Gulch	012	July 22, 1994	40/7	100 to 1,000	12,400 to 12,800	PNF and private
Sheep Mountain	014	July 09, 1985	Not reported	Not reported	12,200	PNF and private
Horseshoe Gulch	016	July 16, 1985	Not reported	Not reported	12,400	PNF and private
Totals	—	—	77/3,065	6,710 to 10,510+ (est. 6,000 to 11,000)	—	

[1]The first number reported under area is the number of acres of occupied habitat reported by an observer. The second number is the area calculated in Arc View from the map provided by an observer. There may be more than one observer for each occurrence.

its colonization of sites that are otherwise suitable. Reduction of its habitat through natural processes, such as climate change, may also be responsible for its limited distribution.

Two hypotheses have been offered by Grant and Wilken (1986, 1988) to explain the diversification of *Ipomopsis*. One suggests that dispersal led to allopatric populations that diversified through speciation and genetic drift. A more plausible hypothesis suggests that a widely distributed common ancestor had a somewhat continuous distribution in the cool, moist phases of the Pleistocene. The distribution of this ancestor then became discontinuous following mountain orogeny, formation of canyons, and contraction of its habitat, leading to divergence and speciation within the isolated populations and an increase in the diversity of the genus in Colorado, New Mexico, and Arizona.

Population trend

There are no quantitative data that could be used to infer the population trend of *Ipomopsis globularis*. Occurrence size estimates presented in **Table 1** are rough, and there has been no population monitoring that could provide insight into population trend. Human impacts to individuals and habitat for *I. globularis* resulting from recreational use and mining strongly suggest that there has been a downward trend. Loss of habitat and anthropogenic disturbance of habitat has probably caused a downward trend since the area was settled approximately 140 years ago.

Occurrence sizes are likely to fluctuate naturally due to annual climatic variation. As *Ipomopsis globularis* is probably a stress-tolerant species, it is likely that while drought probably reduces or eliminates recruitment of seedlings, juvenile plants may be capable of surviving one or more bad years. In favorable years, particularly large numbers of plants have been observed to flower (Yeatts personal communication 2003). This makes it difficult to assess the population size accurately in any given year.

Habitat

Ipomopsis globularis is apparently restricted to dry, gravelly, calcareous soils in alpine areas in the vicinity of the Mosquito Range (Spackman et al. 1997b). The soils are usually underlain with heavily mineralized Leadville limestone or Manitou dolomite (O'Kane 1988). Soils have also been described as rocky, cobbly, sandy, fine, reddish, and reddish brown (Colorado Natural Heritage Program 2003), and plants have been documented in alpine meadows and on talus and scree slopes (Colorado Natural Heritage Program 2003). Although Leadville limestone and Manitou dolomite are exposed in many locations in Colorado, such as Glenwood Canyon (Chronic 1980, Foutz 1994), outcrops at high elevations are rare and may be restricted to the Mosquito Range (Tweto 1979). This may be partially responsible for the restricted range of *I. globularis*.

Ipomopsis globularis is found on flat to steeply sloping terrain, and it has been documented on all aspects, though least frequently on a northerly orientation (Colorado Natural Heritage Program 2003). At Horseshoe Gulch it is reported from a north-facing slope; at Boreas Pass it is found on south-, northeast-, and northwest-facing slopes; all other locations that document aspect report a southern, western, or eastern orientation (Colorado Natural Heritage Program 2003). *Ipomopsis globularis* ranges from 10,500 to 13,800 feet (3,200 to 4,206 m) in elevation, and it occurs wholly in the Southern Rocky Mountain Ecoregion in the Ecoregional classification of Bailey (1995).

Data compiled from 1949 to 2003, provided by the Western Regional Climate Center (2003), was used to obtain information on the local climate at *Ipomopsis globularis* sites. The closest weather station with a similar elevation to the occurrences of *I. globularis* is Climax, Colorado, at approximately 11,500 feet (3,353 m) in Summit County. During the fall, winter, and spring the Climax weather station receives snow every month, with snow depths measuring 2 to 49 inches (5 to 122 cm) until mid summer when the ground is free of snow cover (July-September). *I. globularis* is probably most actively growing in July and August when precipitation from rain is greater than two inches (5 cm) per month, and average maximum temperatures are at their highest. Average maximum temperatures are 64.5 °F (18.0 °C) in July, and 62.4 °F (16.9 °C) in August (Western Regional Climate Center 2003).

The Mosquito Range and adjacent areas have a long history of mining, particularly for gold and silver. These and other associated minerals might have some influence on the soil chemistry of the area and may be partially responsible for the edaphic conditions to which *Ipomopsis globularis* is adapted. Disturbance from historic mining activities is widely evident. In summer months during the late 1800s and early 1900s, herdsmen drove their cattle and sheep over mountain passes in this area to reach lush valleys and hillsides (Pritchard 1992). This too may have influenced the local vegetation. There is no known documentation of the pre-settlement plant communities of the area.

There are numerous observations suggesting that disturbance plays a role in the autecology of *Ipomopsis globularis*. It has been found along mining roads and four-wheel-drive trails, on loose scree and talus slopes, and in areas that are grazed by elk and mountain goats (Colorado Natural Heritage Program 2003). It is commonly found on barren, gravelly tundra with around 50 percent bare ground cover, and it may take advantage of the barren soils around old mines at Weston Pass (Colorado Natural Heritage Program 2003). However, while *I. globularis* has some affinity for disturbed areas, it also persists in climax vegetation, such as grassy meadows with little bare ground cover and other areas with well-developed tundra vegetation (Colorado Natural Heritage Program 2003). Although *I. globularis* has been documented in areas with disturbances (e.g., historical mining, recreational use), more observations are needed to determine how the plants are responding to the disturbances.

Many areas that support *Ipomopsis globularis* also support occurrences of other rare plant species. The Mosquito Range is considered to be a "hot spot" for rare and imperiled plant species on a global level (Colorado Natural Heritage Program 2003). See **Table 2** for a complete list of the plants of concern in the Mosquito Range.

The definitions of high quality and marginal habitat are not clearly understood for *Ipomopsis globularis*. Areas with natural vegetation with minimal

Table 2. Plants of concern known from the Mosquito Range of Colorado. Species in bold are endemic to the Mosquito Range. Species are listed in approximate order of imperilment. Explanations of global and state ranks are included in the **Definitions** section of this document. Species ranked G5 or G4 and S1 or S2 are found in the Mosquito Range in occurrences that are disjunct from the primary part of the species' range.

Scientific Name	Common Name	Global Rank	State Rank	Federal Status
Draba weberi	**Weber's draba**	**G1**	**S1**	
Eutrema penlandii	**Penland's eutrema**	**G1G2**	**S1S2**	**T-FWS**[1]
Botrychium pallidum	pale botrychium	G2	S2	
Draba exunguiculata	Garys Peak draba	G2	S2	USFS[2]
Draba grayana	Gray's draba	G2	S2	USFS
Ipomopsis globularis	**Hoosier Pass ipomopsis**	**G2**	**S2**	
Physaria alpina	Avery Peak twinpod	G2	S2	
Ptilagrostis porteri	Porter's false needlegrass	G2	S2	USFS, BLM[3]
Machaeranthera coloradoensis	Colorado tansyaster	G2?	S2	USFS
Aquilegia saximontana	Rocky Mountain blue columbine	G3	S3	
Astragalus molybdenus	Leadville milkvetch	G3	S2	
Botrychium echo	reflected grapefern	G3	S3	
Draba streptobrachia	alpine tundra draba	G3	S3	
Saussurea weberi	Weber's saw-wort	G3	S2	BLM
Draba porsildii	Porsild's draba	G3G4	S1	
Scirpus rollandii	Rolland's bulrush	G3Q	S2	BLM
Braya humilis	low northern-rockcress	G4	S2	
Draba borealis	boreal draba	G4	S2	
Draba fladnizensis	Austrian draba	G4	S2S3	
Parnassia kotzebuei	Kotzebue's grass of Parnassus	G4	S2	USFS
Ranunculus karelinii	ice cold buttercup	G4G5	S2	USFS
Eriophorum altaicum var. *neogaeum*	Whitebristle cottongrass	G4T?	S3	USFS
Draba lonchocarpa var. *lonchocarpa*	lancepod draba	G4T4	S2	
Salix calcicola	woolly willow	G4T4	S1	
Botrychium lunaria	common moonwort	G5	S2S3	
Crepis nana	dwarf alpine hawksbeard	G5	S2	
Draba incerta	Yellowstone draba	G5	S1	
Draba oligosperma	fewseed draba	G5	S2	
Oxytropis parryi	Parry's oxytrope	G5	S1	
Phippsia algida	icegrass	G5	S2	
Papaver radicatum ssp. *kluanense*	rooted poppy	G5T3?	S3	
Armeria maritima ssp. *sibirica*	Siberian sea thrift	G5T5	S1	USFS

[1] T-FWS – Listed as threatened by the U.S.Fish and Wildlife Service, therefore it is not included on sensitive species list for USDA Forest Service or Bureau of Land Management.

[2] USFS – Designated sensitive by the USDA Forest Service Region 2.

[3] BLM – Designated sensitive by the Bureau of Land Management, Colorado Office.

impact from human activities supporting dense occurrences probably contain the best examples of high quality habitat. The best sites are likely found at Hoosier Ridge, North Star Mountain, Boreas Pass, Cooper Creek, and Weston Pass (Colorado Natural Heritage Program 2003). Documentation of these and additional such sites is a high research priority for *I. globularis*.

Reproductive biology and autecology

In the Competitive/Stress-Tolerant/Ruderal (CSR) model of Grime (2001), the characteristics of *Ipomopsis globularis* most closely approximate those of a stress-tolerant ruderal species. Ruderal species typically tolerate disturbance and are able to colonize disturbed sites. As with many species of *Gilia* and *Ipomopsis*, *I. globularis* can be found on moderately disturbed sites (e.g., talus and scree slopes). Another consistent feature of ruderal species in the CSR model is an annual or short-lived perennial life history (Grime 2001). The life span of *I. globularis* not known, but it is a perennial and may persist for several years as a rosette awaiting favorable conditions for flowering.

Ipomopsis globularis also has attributes of a stress-tolerator as defined by Grime (2001). In alpine habitats, the dominant source of stress is low temperature. Low growing season temperatures retard metabolic processes and inhibit biomass accumulation, limiting productivity. In a discussion of stress-tolerant ruderals, Grime (2001) notes that areas with a combination of severe stress and disturbance in terrestrial habitats tend to be devoid of vegetation, since there are no plant strategies that can cope with both simultaneously (hence the "untenable triangle"). The role of disturbance in the autecology of *I. globularis* also typifies it as an *r*-selected species, as does its lack of strong competitive interactions (Pianka 1970).

Reproduction

The reproductive biology of *Ipomopsis globularis* has not been studied. Like all members of *Ipomopsis*, *I. globularis* has perfect, actinomorphic flowers. Based on the floral biology of many of its congeners (Grant 1956, Anderson 1988), it is most likely facultatively xenogamous, meaning that it mostly outcrosses but may also be self-compatible. *Ipomopsis sancti-spiritus* has been shown to be self-compatible, but it requires a pollinator for fertilization to occur (Maschinski 1996 as cited in USDI Fish and Wildlife Service 2002). In *I. sancti-spiritus*, Maschinski (1996) observed fruits in 57 percent of self-pollinated flowers, while outcrossing resulted in mature fruit 9.5 to 77 percent of the time, depending on the pollen donor. The variation in percent of mature fruit of outcrossed flowers observed in this experiment suggests that there is discrimination between paternal pollen sources. This has also been observed in *I. aggregata* (Waser and Price 1989).

In pollination studies conducted in 2000, Spackman et al. (2001b) observed 11 species of insects making contact with the flowers of *Ipomopsis globularis* (**Table 3**). *Ipomopsis globularis* has several adaptations that promote outcrossing. The strong aroma and large inflorescences are especially effective characteristics for drawing pollinators. *Ipomopsis* includes both diploids and natural allotetraploids. The number of chromosomes is not known for *I. globularis*.

Pollinators and pollination ecology

The pollination ecology of the Polemoniaceae has been the topic of extensive study, particularly in the genera *Ipomopsis* and *Gilia*. Although highly specialized breeding systems are found in some members of the Polemoniaceae, *I. globularis* appears to be a generalist pollinated by a broad suite of insects. *Ipomopsis globularis* has a relatively shallow corolla tube when compared with specialists such as *I. aggregata*, which largely depends on hummingbirds for its pollination (Grant and Grant 1965). Plants with very little floral specialization are considered 'promiscuous plants' because they utilize unspecialized, generalist pollinators as pollen vectors (Grant 1949, Bell 1971). Reliance on a broad suite of pollinators for pollinator services probably buffers promiscuous plants from population swings of any one pollinator (Parenti et al. 1993).

Spackman et al. (2001b) observed insect visitation and pollination of *Ipomopsis globularis* at three sites in 2000. The researchers collected a total of 81 insects that were making contact with the flowers (**Table 3**), and they found that *I. globularis* is visited primarily by fly and ant species. Of the 81 insects collected, well over 50 percent (52) were flies (50 of which were *Thricops villicrura* Coquillet), and nearly 25 percent (19) were ants (all *Formica neorufibaris gelida* Wheeler.) Similar insect visitor assemblages were found at each of the three locations. *Thricops villicrura* and *F. neorufibaris gelida* were the dominant visitors at all three sites. Other taxa visiting *I. globularis* included several hemipteran species, a wasp species (*Agathis* sp.), and a moth species (*Lasionycta impingens* Walker). One moth individual was collected during an after-dark observation period.

Table 3. Insects collected during visitation to *Ipomopsis globularis* at three sites in the Mosquito Range and Hoosier Ridge of Colorado. Numbers indicate the total number of individuals collected.

Taxon	Weston Pass	North Star Mountain	Boreas Pass
Order: Diptera (flies)			
Family: Empididae			
Rhamphomyia sp.			1
Family: Muscidae			
Thricops villicrura Coquillet	5	32	13
Family: Phoridae		1	
Family: Tachinidae		1	
Order: Hemiptera (true bugs)			
Family: Alydidae			
Alydus sp.	1	1	
Family: Lygaeidae			
Geocoris uliginosa Say	2		
Lygaeus kalmii Stal			1
Family: Pentatomidae			
Chlorochroa congrua Uhler			1
Family: Thyreocoridae		1	
Order: Hymenoptera (bees, wasps, ants)			
Family: Braconidae			
Agathis sp.	1		
Family: Formicidae (ants)			
Formica neorufibaris gelida Wheeler	5	6	8
Order: Lepidoptera (butterflies and moths)			
Family: Noctuidae			
Lasionycta impingens Walker		2	

Although not collected, the researchers also observed a species of *Bombus* visiting *I. globularis* at the North Star Mountain site.

Spackman et al. (2001b) also made incidental observations of insect visitor behavior and noted that ants probed the flowers of *Ipomopsis globularis* with their heads and also completely entered the flowers. The ants would literally disappear inside the flowers and were observed to stay inside individual flowers for up to 10 minutes. Flies spent long periods of time (up to 15 minutes) at one inflorescence moving from one flower to the next. Flies on *I. globularis* were observed to put their mouthparts and legs into the flowers (Spackman et al. 2001b).

In her research on *Ipomopsis polyantha*, Collins (1995) had results suggesting that greater habitat diversity, availability of a wide range of nectar and pollen resources, proximity to natural habitat, and availability of water enhance the diversity of pollinators for *I. polyantha*, while disturbance and proximity to a highway diminish pollinator resources. These factors may also affect the species composition of pollinators present.

Phenology

Ipomopsis globularis bears numerous flowers in a globose inflorescence (Harrington 1954). As an alpine plant species found in habitats with relatively short growing seasons, *I. globularis* has a relatively short period of flowering. It is most likely to flower in July through early August, but it may not flower for that full length of time (Spackman et al. 1997b). By late August, most flowers have dried and given way to fruits (Spackman et al. 1997b). Because *I. globularis* occurs in xeric sites, the periodicity of successful recruitment may coincide with wet or otherwise favorable years during which seedlings can become established.

Fertility and propagule viability

Seed germination requirements for *Ipomopsis globularis* have not been investigated. The seeds of *I. sancti-spiritus* appear to have no special germination requirements, but the highest percentage of germination occurs after four to eight weeks of cold treatment (Maschinski 1996). Most long-lived species of *Ipomopsis* require cold-stratification of six to eight weeks (Wilken personal communication 2004).

The seeds of many species of *Ipomopsis* and other members of the Polemoniaceae are coated with a mucilaginous substance that may play a role in their dispersal. Bray (1898 as cited in Grant 1959) hypothesized that this mucilaginous coating caused the seeds of an ancestral member of *Ipomopsis* to stick to the feet of migratory birds, resulting in the establishment of the genus in South America. Other biologists have speculated that a mucilaginous seed coat may help to anchor the seed in place during radicle emergence (Wilken personal communication 2004). The seed coat of *I. globularis* has not been observed. The seeds are probably dispersed primarily by wind and water.

The formation of the mucilaginous coat upon hydration of the seed appears to help remove germination inhibitors in the seeds of *Eriastrum densifolium* ssp. *sanctorum*, another member of the Polemoniaceae (Wheeler 1991). Collins (1995) observed that hydrated seeds of *Ipomopsis polyantha* germinated three days faster than non-hydrated seeds, probably because of the additional time required for the mucilaginous coat to remove the germination inhibitors from the seeds. When the seeds were first wetted to induce the formation of the mucilaginous coat and then germinated in soils, the germination time was reduced (Collins 1995). Collins (1995) also determined that *I. polyantha* has approximately 245.7 pollen grains per ovule.

The longevity and dormancy of the seeds of *Ipomopsis globularis* has not been studied.

Dispersal mechanisms

Movement of soil by humans may have spread *Ipomopsis globularis* plants to a small extent, resulting in occasional small increases in its distribution. Historical mining activity at Weston Pass, Dolly Varden Gulch, and North Star may have distributed seeds.

Phenotypic plasticity

Ipomopsis globularis does not exhibit a great degree of phenotypic plasticity. Plants vary in size, stature, and reproductive effort, probably due to year-to-year variations in climate. There is some variation in the purple to white coloring of the corolla (Colorado Natural Heritage Program 2003).

Studies of other members of the Polemoniaceae have suggested some degree of plasticity in response to various types of biomass removal. There has been much debate in the literature over the response of *Ipomopsis aggregata* to browsing by herbivores. Some studies indicate that early grazing of inflorescences results in higher reproductive output (overcompensation) (e.g., Paige 1992, Paige 1999, Paige et al. 2001), while other studies (e.g., Juenger and Bergelson 1997, Juenger and Bergelson 2000) did not observe overcompensation but negative impacts on *I. aggregata* such as delayed phenology, altered plant architecture, and reduced plant fitness. Overall, overcompensation does not occur in most populations of *I. aggregata* (Wilken personal communication 2004). The specific response of *I. globularis* to browsing by herbivores has not been studied. An overview of plant tolerance to consumer damage is presented in Stowe et al. (2000).

Mycorrhizal relationships

Roots of *Ipomopsis globularis* have not been assayed for the presence of mycorrhizal symbionts. Arbuscular mycorrhizal (AM) fungi have been reported to form symbioses with members of the genera *Gilia* (Laspilitas.com 1995) and *Phlox* (Bethlenfalvay and Dakessian 1984). AM fungi belong to a group of nondescript soil fungi (Glomales) that are difficult to identify because they seldom sporulate (Fernando and Currah 1996). They are the most abundant type of soil fungi (Harley 1991) and infect up to 90 percent of all angiosperms (Law 1985). AM fungi are generally thought to have low host specificity, but there is increasing evidence for some degree of specificity between some taxa (Rosendahl et al. 1992, Sanders et al. 1996). While this group has not previously been thought of as particularly diverse, recent studies are suggesting that there is unexpectedly high diversity at the genetic (Sanders et al. 1996, Varma 1999) and single plant root (Vandenkoornhuyse et al. 2002) levels. As root endophytes, the hyphae of these fungi enter the cells of the plant roots where water and nutrients are exchanged in specialized structures.

Hybridization

For the most part, it appears that hybridization is unlikely in *Ipomopsis globularis* since there are no congeners in the immediate vicinity with which it could exchange pollen. Its closest relatives are found at lower elevations, so gene flow between species is unlikely. However, there is an occurrence of *I. congesta* ssp. *frutescens* that has been documented at the lowest known elevations of *I. globularis* (10,500 feet [3,200 m]) in close proximity to the occurrence of *I. globularis* at Weston Pass (Hogan personal communication 2003, Yeatts personal communication 2003). It is not known if these two species would hybridize.

Hybridization has played a major role in the evolution of many groups in the Polemoniaceae, including *Ipomopsis* section *Ipomopsis* (Grant 1959, Porter et al. 2003). The influence of hybridization is so strong in some groups that Grant (1959 p. 203) wrote "if we are to base our ideas of macroevolution on inductive methods of inquiry we will have to give up, in many plant groups, the old symbolism of the phylogenetic tree in favor of the symbolism of a phylogenetic net." Hybridization is ongoing between many taxa in the family and contributes to many of the taxonomic difficulties in the genus *Ipomopsis*. There have been numerous studies of the hybridization between *I. aggregata* and *I. tenuituba* (e.g., Grant and Wilken 1988, Wolf and Soltis 1992, Wolf et al. 1993, Campbell et al. 1997, Wolf et al. 1997, Campbell et al. 1998, Melendez-Ackerman and Campbell 1998, Alarcon and Campbell 2000, Campbell and Waser 2001, Wolf et al. 2001, Campbell et al. 2002a and 2002b. Natural hybrids occur between *I. aggregata* and *I. tenuituba* that are less resistant to damage to the developing seeds by fly larvae (Campbell et al. 2002a and 2002b). The overall fitness of these hybrids depends largely on which species is the maternal parent (Campbell and Waser 2001).

Demography

Keeping genetic integrity and eliminating inbreeding and outbreeding depression are important management considerations for *Ipomopsis globularis*. Since it is likely a primarily outcrossing species, *I. globularis* is vulnerable to inbreeding depression in small populations or in populations with limited pollinator activity. Given the moderate degree of disturbance and fragmentation of the habitat for *I. globularis*, it is possible that genetic diversity is being lost. Maintaining distinct genetic populations and natural levels of gene flow are also important for its conservation. Hybridization may lead to extinction by outbreeding depression in naturally small populations of *I. aggregata* (Ellstrand 1992).

The lifespan of *Ipomopsis globularis* has not yet been determined through demographic studies or observations in the greenhouse. There are no data regarding the proportion of individuals within an occurrence that are reproducing in a given year. In favorable years, many or most of the plants probably set seed. For a hypothetical lifecycle graph for *I. globularis*, please see **Figure 6**.

No Population Viability Analysis (PVA) has been performed for *Ipomopsis globularis*. Apparently there has never been a PVA of any member of the genus *Gilia* or other members of the Polemoniaceae from which inferences could be drawn for this report. One species of *Ipomopsis* (*I. sancti-spiritus*) is currently listed endangered (USDI Fish and Wildlife Service 1999, USDI Fish and Wildlife Service 2002), but there has been no PVA of this species to date. Monitoring and preliminary quantitative assessment of population viability have been conducted for *I. sancti-spiritus* (Maschinski 2001), and conducting a viability workshop is among the recommendations for the recovery of this species (USDI Fish and Wildlife Service 2002). Even though the minimum viable population size is not known for *I. globularis*, small populations by the standards of the 50/500 rule of Soulé (1980) may still be viable and of conservation importance.

The optimal conditions for reproduction are not known for *Ipomopsis globularis*, but observations suggest that it responds positively to high soil moisture during wet summers.

The role of the mucilaginous seed coat has not been explored for *Ipomopsis globularis*, but it has been implicated in the dispersal of the genus *Ipomopsis* to other continents by birds (see the Reproductive biology and autecology section of this document for details). *I. globularis* may be an effective colonist of four-wheel-drive trails and gravel piles associated with historic mining activities (Colorado Natural Heritage Program 2003). Given our knowledge of this species' current distribution, seeds landing on unsuitable substrates (soils not derived from calcareous substrates) are not likely to reach maturity. Pollinator-mediated pollen dispersal is largely limited to the flight distances of pollinators (Kearns and Inouye 1993).

As a habitat specialist, *Ipomopsis globularis* is naturally limited by the availability of calcareous habitat. It is not known if *I. globularis* is seed-limited

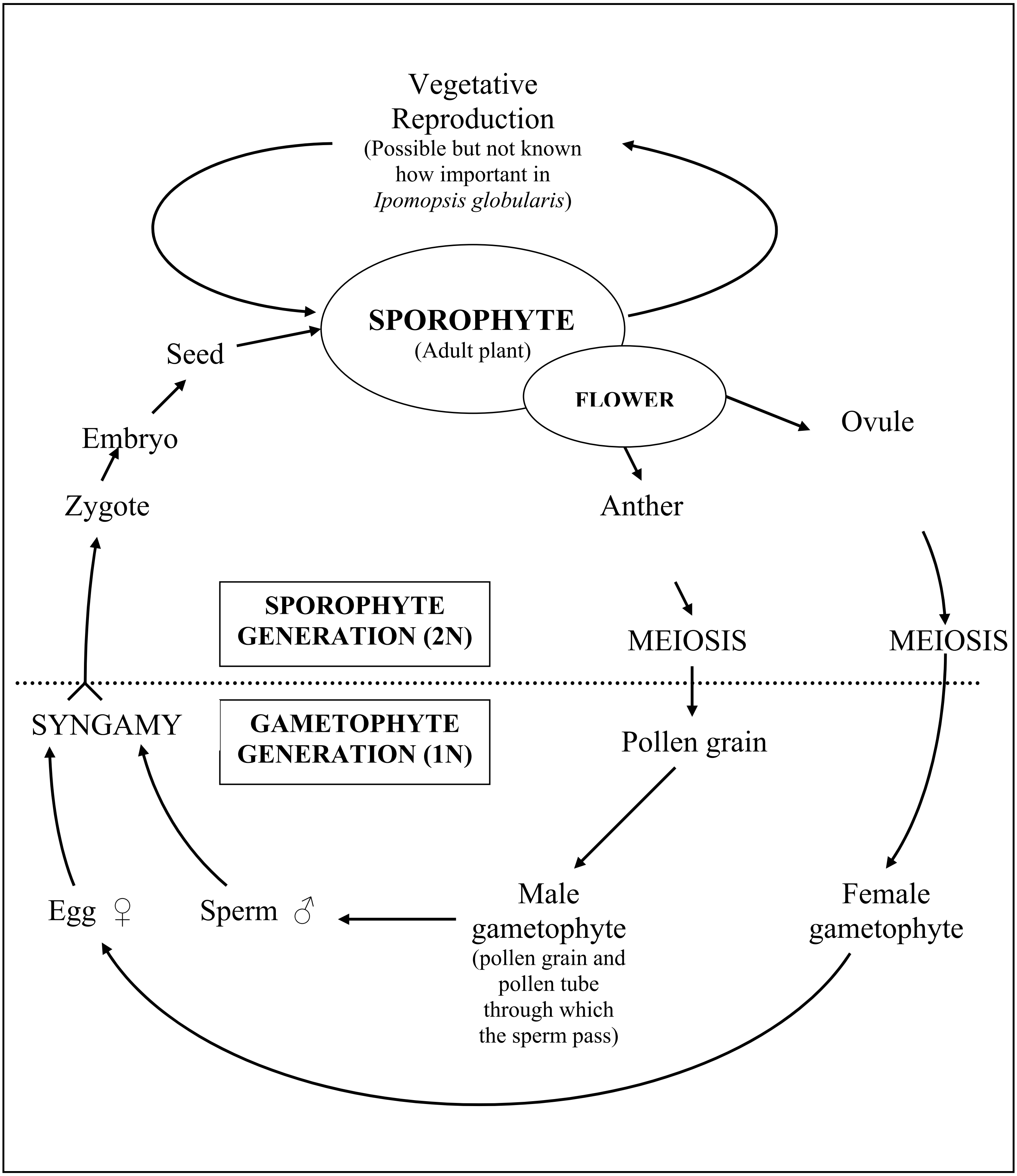

Figure 6. Life cycle diagram for *Ipomopsis globularis* (after Stern 1994).

or what factors control seedling recruitment success. Plant fecundity does not appear to be contributing to the limited distribution of this species.

Community ecology

The habitat of *Ipomopsis globularis* has been subjected to some modification and land use practices for at least 140 years (Pritchard 1992). Thus, some of the natural vegetation and associated species for *I. globularis* may have been disrupted or removed. A list of all associated species that have been documented with *I. globularis* is included in **Table 4**.

Several other rare plant species are known to occur with *Ipomopsis globularis* in the Mosquito Range. These are listed in **Table 2**.

Herbivores

The relationship of *Ipomopsis globularis* with herbivores has not been observed. The specific responses of *I. globularis* to consumer damage have not been investigated, but there are numerous studies of *I. aggregata* exploring the effects of browsing and grazing. Some studies (e.g., Juenger and Bergelson 2000) suggest that browsing and grazing (simulated in clipping experiments) significantly reduce the production of flowers, fruits, and seeds. Other studies (e.g., Paige 1992) suggest that the plants are benefited by grazing through a plastic response known as overcompensation, where reproductive fitness is improved by herbivory.

Competitors

There has been no formal study of the community ecology and interspecific relationships of *Ipomopsis globularis*. As a habitat specialist *I. globularis* may be a poor competitor, which may leave it vulnerable to negative impacts from introduced species. Dr. J. M. Porter (personal communication 2002) offered some generalities regarding the Polemoniaceae that are relevant to *I. globularis* in the absence of information specific to this species. Members of this family share many traits with respect to competitors and habitat affinities. They are often found on eroding, chronically disturbed slopes, particularly throughout the deserts and badlands of western North America. Even in the tropics, they are typically found in light gaps or along rivers where there is disturbance of some sort. Most species tend to avoid competition. They are somewhat ruderal, but not typically found in seral communities. Sites such as wasting slopes and badlands are chronically disturbed and maintained in a state of arrested succession, which probably excludes many potential competitors that are not well adapted to these sites. Although *I. globularis* is not always found in disturbed sites, it appears to do well with some disturbance as it has been found along mining roads and four-wheel-drive trails, and on loose scree and talus slopes (Colorado Natural Heritage Program 2003).

Parasites and disease

Herbarium specimens observed showed no signs of parasites or disease. The seeds of *Ipomopsis* are reportedly susceptible to fungal infection in moist environments (Wilken 1995). Floral larceny occurs when insects take pollen or nectar (sometimes by piercing the corolla) from a flower without pollinating it, and this has been well studied in *I. aggregata* (Irwin et al. 2001). The impacts of larceny on plant fitness, recruitment, and population dynamics have been assessed in recent studies, and while this has not been observed in *I. globularis*, it is worth noting in future research. As a generalist, *I. globularis* is probably less susceptible to parasitism of this nature than a specialist like *I. aggregata*.

Symbioses

There have been no reports of symbiotic or mutualistic interactions between *Ipomopsis globularis* and other species.

Figure 7 and **Figure 8** are envirograms that illustrate the malentities and resources for *Ipomopsis globularis*, respectively. An envirogram is a graphic representation of the components that influence the condition of a species and reflects its chance of reproduction and survival. Envirograms have been used to describe the conditions of animals (Andrewartha and Birth 1984) but may also be applied to describe the condition of plant species.

CONSERVATION

Threats

There are several threats to the persistence of *Ipomopsis globularis*: motorized recreation, mining, exotic species invasion, effects of small population size, collection for horticultural trade, non-motorized

Table 4. List of species that have been documented one or more times occurring with *Ipomopsis globularis*.

Species name	Species name
Achillea lanulosa	*Kobresia myosuroides*
Acomastyllis rossii (=*Geum rossii*)	*Lidia biflora*
Amerosedum lanceolatum	*Lidia obtusiloba*
Anticlea elegans	*Lloydia serotina*
Arenaria sp.	*Minuartia obtusiloba*
Artemesia scopulorum	*Oxytropis splendens*
Artemisia arctica ssp. *saxicola*	*Oxytropis viscida*
Bistort bistortoides	*Packera cana*
Bistort vivipara	*Pedicularis groenlandica*
Calamagrostis purpurascens	*Pedicularis parryi*
Campanula uniflora	*Pedicularis scopulorum*
Carex elynoides	*Pentaphylloides floribunda*
Castilleja occidentalis	*Phlox condensata*
Chionophila jamesii	*Physaria* sp.
Claytonia sp.	*Poa cusickii* ssp. *epilis*
Crepis sp.	*Poa glauca*
Deschampsia cespitosa	*Poa rupicola*
Draba sp.	*Polemonium viscosum*
Dryas octopetala ssp. *hooderiana*	*Polygonum* sp.
Elymus trachycaulus	*Potentilla diversifolia*
Eremogone fenderli	*Rydbergia grandiflora*
Erigeron simplex	*Salix glauca*
Eriogonum flavum chloranthum	*Sedum* sp.
Eritrichium aretioides	*Silene acaulis*
Erysimum capitatum	*Stellaria* sp.
Festuca idahoensis	*Tetraneuris brevifolia*
Gastrolychnis apetala ssp. *uralensis*	*Trifolium dasyphyllum*
Helictotrichon mortonianum	*Trisetum spicatum*
Heterotheca pumila	*Tryphane rubella*
Hymenoxys acaulis	

Names provided are those used by the researchers who reported the associated species.

recreation, global climate change, and pollution. More complete information on the biology and ecology of this species may elucidate other threats. Assessment of threats to this species will be an important component of future inventory and monitoring work. Please see the sections below for specific treatments of these threats to habitat and individuals of *I. globularis*.

Motorized recreation

Motorized recreation (including off-highway vehicles, off-road vehicles, all-terrain vehicles, four-wheel drive vehicles, motorcycles, and snowmobiles) appears to pose the greatest threat to the quality and availability of habitat for *Ipomopsis globularis*. This use occurs throughout the entire global range of *I. globularis* and alters areas of natural habitat. The proliferation of roads and the associated disturbance from off-road vehicles likely encourage the spread of weeds into *I. globularis* habitat.

While the primary impact of motorized recreation on *Ipomopsis globularis* would be reduction of habitat, such activity also impacts individuals and occurrences directly and indirectly. Roads created by off-road vehicles could threaten occurrences of *I. globularis* directly by altering habitat and killing individuals, and indirectly by increasing erosion and providing dispersal corridors for exotic plant species. While it is likely that *I. globularis* can self-pollinate, it may also be a primarily outcrossing species, and roads could act as barriers to pollinators for *I. globularis* and prevent

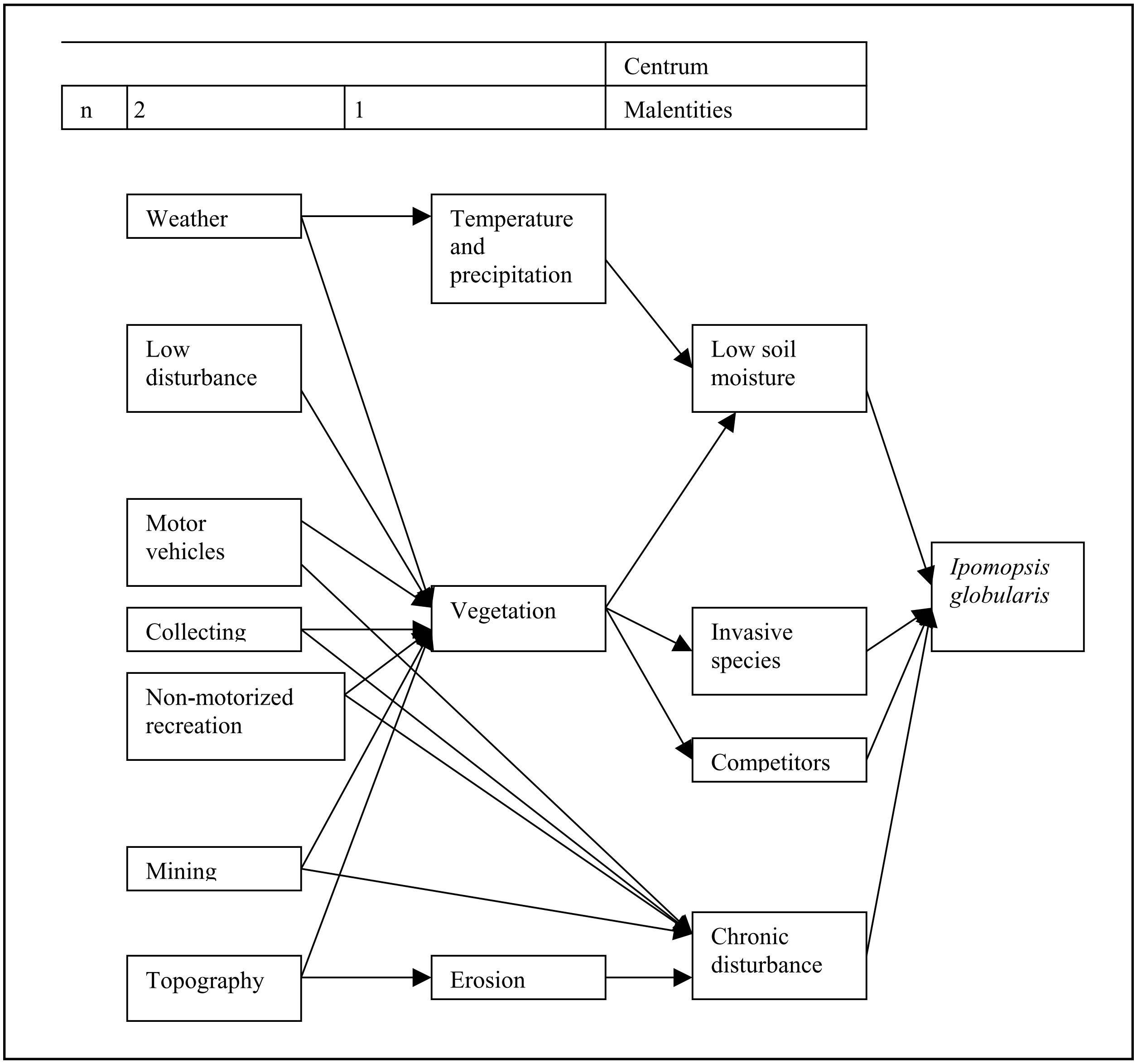

Figure 7. Envirogram outlining the malentities to *Ipomopsis globularis*.

effective gene flow by disrupting the trap lines of pollinators. Disturbed sites may also offer fewer species of pollinators for *I. globularis* than natural sites.

Motorized recreation has been observed at six out of the nine known occurrences: Hoosier Ridge (USDA Forest Service White River National Forest 2002, Coles personal communication 2003), Weston Pass, Mount Lincoln, Dolly Varden Gulch, Horseshoe Basin, and North Star Mountain (USDA Forest Service White River National Forest 2002, Colorado Natural Heritage Program 2003, Nichols personal communication 2003). Motorized vehicle use is rapidly increasing throughout the South Park Ranger District (Mayben personal communication 2003), and it is possibly occurring at other sites as well. Although Hoosier Ridge is closed to off-road vehicle use (Johnston personal communication 2003), motorcycle use was observed at this location in 1999 (Coles personal communication 2003). The only area that appears to be fairly secure in this regard is parts of the occurrence at Boreas Pass because of the remote location (Madsen personal communication 2003, Redner personal communication 2003).

Motorized recreation has increased dramatically in the Mosquito Range and adjacent areas, especially in the last two to three years (Nichols personal communication 2003). This is due in part to an increase in the local human population. Brekenridge, Fairplay, Alma, and Leadville, the towns in closest proximity to

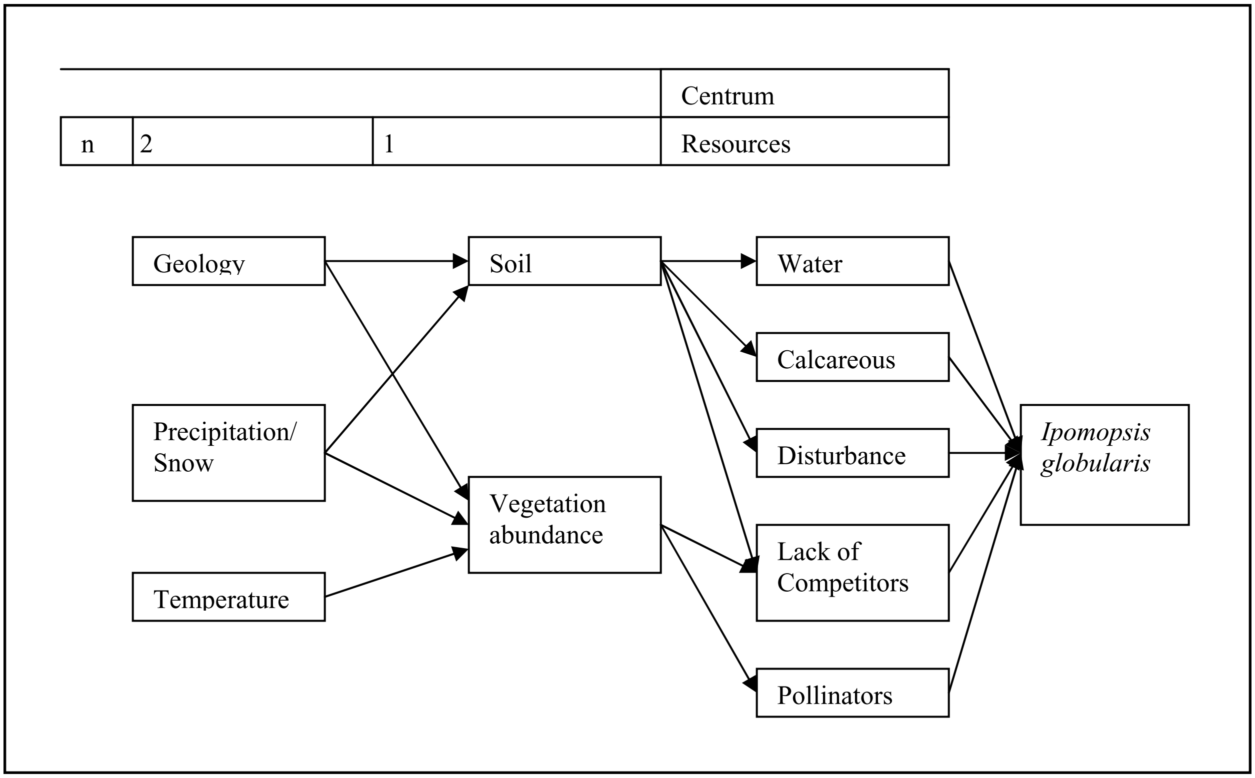

Figure 8. Envirogram outlining the resources of *Ipomopsis globularis*.

the occurrences of *Ipomopsis globularis*, are developing rapidly as popular tourist destinations and locations for second homes. These areas have grown substantially in the past 60 years (Colorado Division of Wildlife 2003). Fairplay to Hoosier Pass is the most rapidly growing part of Park County (Nichols personal communication 2003), and residential development is occurring at higher and higher elevations. Building permits have been issued above 11,000 feet (3,353 m) in both Park (Nichols personal communication 2003) and Summit (Redner personal communication 2003) counties. Areas that had previously been open to motorized recreation in the White River National Forest are now closed, and this may also be contributing to the increased use in the Pike-San Isabel National Forest. Additionally, the Pike-San Isabel National Forest is in close proximity to large metropolitan areas with human populations that enjoy motorized recreation, namely Denver and Colorado Springs. As one example, hunters are using four-wheel drive vehicles more frequently to access remote areas in national forests (Nichols personal communication 2003, Yeatts personal communication 2003).

Although the White River National Forest Land and Resource Management Plan calls for restricting motor vehicle use to established routes, tire tracks were observed on previously undisturbed tundra on Hoosier Ridge (Coles personal communication 2003). The Pike-San Isabel National Forest follows a 300 foot rule that applies to all National Forest System lands: it is permissible to travel 300 feet (91 m) off of an established route as long as there is not resource damage (Mayben personal communication 2003). However, it is extremely difficult for the USFS to enforce such a regulation (Johnston personal communication 2003, Mayben personal communication 2003), and tire tracks have been observed further than 300 feet from established routes in numerous locations in the Mosquito Range (Colorado Natural Heritage Program 2003, Nichols personal communication 2003).

Despite the clear increase in motorized recreation and the threats that these activities pose to natural habitats for *Ipomopsis globularis* and other native species, it is getting more and more difficult for the USFS to close roads in the Mosquito Range because of strong public interest in access to these areas. Park County Commissioners tend to advocate keeping roads open (personal communication Nichols 2003, personal communication Mayben 2003). Boreas Pass is the only occurrence that is not heavily influenced by mining claims and patents and other private lands. It is likely that the USFS would be unable to close roads leading to the remaining eight occurrences because it would block access to private lands and therefore violate the Alaska Native Lands Conservation Act (ANILCA) (personal communication Mayben 2003). Regardless, any road closure on national forest lands requires a roads analysis and specialist report including discussion of the impacts of the road as well as the social impacts of closing the road. In general, it is extremely difficult to justify closing roads (personal communication Mayben 2003). The specificity of the information regarding impacts to *I. globularis* is probably not adequate to justify closing any roads leading to the occurrences.

The threats posed by snowmobiles are somewhat different than those posed by summer motorized recreation. Snowmobiles compact and move snow, resulting in a change of the timing of snowmelt, which is an important factor for growth of alpine plants (Billings and Bliss 1959, Price and Waser 1998). Snowmobile use causes structural changes in the snow, changes in snow temperature gradients, water holding capacity, and melting rate (Neumann and Merriam 1972). Following snowmobile use, temperature gradients are less and low temperatures extend further down into the snow, which may be more stressful for organisms that live beneath the compacted snowfields. Under snowmobile trails the snow is denser and melts more slowly (Keddy et al. 1979). The compacted snow also creates a partial gas seal over the ground during snowmelt, which may effect decomposition and other ecological factors.

Researchers in Nova Scotia (Keddy et al. 1979) investigated the impacts from snowmobiles making one to 25 passes over an area. They found that the first pass caused the greatest increase in snow compaction (75 percent). Increased intensity (more passes over same spot) caused less damage than increased frequency. Keddy et al. (1979) conclude from their observations that it is preferable for snowmobiles to use trails than to diffuse use. They also found that areas covered with ice in the winter do not appear to be as damaged by snowmobile use, so it might help to divert snowmobile use to ice covered areas (Keddy et al. 1979). More research is needed to determine the impacts of motorized recreation, including snowmobile use, to *Ipomopsis globularis* in Region 2.

Mining

It is difficult to estimate the exact level of risk to *Ipomopsis globularis* posed by potential future mining. The Mosquito Range and adjacent areas have experienced extensive mining in the past (Pritchard 1992), and it is likely that occurrences of *I. globularis* were impacted by this historical use. However, at present, it is unlikely that any large mining operation would be interested in this area because the size of the deposits of gold and silver are relatively small (Jennings personal communication 2003). Nonetheless, small mining companies could be interested in mining the deposits in areas that support *I. globularis*. When USFS established the Hoosier Ridge RNA in 1991, mining interests challenged the designation (Ray 2001, Ladyman 2003), presumably because this was seen as a threat to their ability to mine the area in the future. The threat of mining in the future probably depends largely on the price of the local minerals and technological developments for extracting them. In any case, the impacts from even small-scale mining could be severe depending on the proximity to the occurrences and/or potential habitat for *I. globularis*. Mining activity, as well as associated roads, could cause serious levels of habitat fragmentation and destruction.

Exotic species invasions

No exotic species have been documented with *Ipomopsis globularis* (Colorado Natural Heritage Program 2003, Madsen personal communication 2003). However, several aggressive weeds have invaded areas of native plant habitat above timberline in Colorado, and these pose a serious potential threat to *I. globularis* and its habitat. To date, plants that have been reported above tree line in Colorado and are considered noxious weeds include yellow toadflax (*Linaria vulgaris*), spotted knapweed (*Centaurea bibersteinii*), scentless chamomile (*Matricaria perforata*), oxeye daisy (*Leucanthemum vulgare*), Shasta daisy (*L. maximum*), and Canada thistle (*Breaa arvense*) (Ray 2001, Lane personal communication 2003). Of these, oxeye daisy, scentless chamomile, and Shasta daisy have all been observed in Brekenridge; yellow toadflax has been observed in Alma, and scentless chamomile at Boreas Pass (Jennings personal communication 2003). Most likely, these noxious weeds come in to areas following disturbance (Elzinga personal communication 2003). Disturbance created by the abundance of roads in the Mosquito Range and adjacent areas makes this area more vulnerable to the spread of non-natives. The best strategy for protection of *I. globularis* is to prevent the introduction of these non-natives by carefully monitoring occurrences for such a change in species composition, and to implement a weed management plan without delay if noxious weeds are detected. Invasion of its habitat by non-native turf-forming grasses is cited as a significant threat to the federally listed *I. sancti-spiritus* (USDI Fish and Wildlife Service 2002).

Small population size

Ipomopsis globularis may be vulnerable because of its small population size, with estimates currently between 6,000 and 11,000 individuals. The prospect of natural catastrophes such as drought, disease outbreaks, ice storms, and avalanches, makes this species particularly vulnerable to extinction. As a narrowly restricted species, *I. globularis* may be more sensitive to environmental stochasticity. The degree to which it can survive bad years will depend largely on how long individual plants can persist, or remain dormant as seeds, which is not known for *I. globularis*. The minimum viable population size is also not known for *I. globularis*, but even small occurrences by the standards of the 50/500 rule of Soulé (1980) may still be viable and of conservation importance. For conservation planning purposes, the Colorado Natural Heritage Program considers occurrences of *I. globularis* containing 20 or more plants as viable, but this threshold will be revised when a minimum viable population size is determined (Colorado Natural Heritage Program 2003).

Collection for horticultural trade

Ipomopsis globularis is potentially threatened by collection for the horticultural trade because there is demand for showy aromatic species that do well in rock gardens. *Ipomopsis globularis* is listed as being available online through Rocky Mountain Rare Plants 2004-2005 Alpine Seed Catalog (http://www.rmrp.com). The plants are reported to be from Park County at 12,000 feet (3,658 m) elevation, and "surprisingly easy in cultivation." The description provided and the link to photographs indicate that they indeed have *I. globularis* for sale. Fifteen seeds are included in one order for a cost of $3.50. It is not known if Rocky Mountain Rare Plants is collecting seeds or whole plants, nor if they have a collecting permit for National Forest System lands. Most likely Rocky Mountain Rare Plants is collecting seeds rather than whole plants (Yeatts personal communication 2003). Unfortunately, even if *I. globularis* does not do well in rock gardens, if it is advertised that way it could sell and create enough demand to threaten the species.

A collecting permit is required by the USFS for collecting any species on National Forest System lands if the collecting is for commercial use. It is likely that such a permit for *Ipomopsis globularis* would not be issued (Madsen personal communication 2003). However, there is little to no enforcement of collecting restrictions on National Forest System lands, and, especially with the complex landownership patterns in the Mosquito Range and adjacent areas, it would be difficult for the USFS to prove that the plant materials were being collected from National Forest System lands rather than private lands (Mayben personal communication 2003).

There are no other known commercial uses for *Ipomopsis globularis*, and there are no reports of over-utilization of the species. Members of the Polemoniaceae are popular for gardening, but there are no indications that they are sought for use in the herb trade. *Ipomopsis globularis* is vulnerable to potential impacts from harvesting from the wild if for some reason it became sought after as a medicinal herb. Over-collection for scientific purposes, particularly in small populations, presents a small threat. Heavy collection for herbarium specimens has contributed to the imperilment of other species, such as the federally endangered *Potentilla robbinsiana* (NatureServe 2003). The proximity of *I. globularis* to popular hiking areas increases the likelihood that casual wildflower gathering could impact occurrences. Wildflower gathering is cited among the threats to *I. sancti-spiritus* (USDI Fish and Wildlife Service 2002).

Non-motorized recreation

Ipomopsis globularis is also threatened by non-motorized recreation, particularly hiking and mountain biking. The widespread access provided by existing roads, in combination with a rapidly developing local human population and tourist community, create a combination that could lead to increased impacts on occurrences of *I. globularis*. Although numerous roads provide easy access in much of the Mosquito Range and adjacent areas, routes to avoid resource damage are not well established. Non-motorized recreation activities could degrade the quality and availability of habitat for this species by trampling plants, introducing exotic plants, and causing erosion, which could impact micro-habitat conditions in terms of hydrology and soil compaction. If trampling is light (e.g., over just one year), then the recovery time may be relatively short (e.g., one year). Recovery from severe trampling over longer periods takes much longer. Alpine areas may be particularly vulnerable to this sort of land use. For example, Willard and Marr (1971) studied an alpine area that been trampled for 38 years. Four years of observation following the extensive trampling showed no improvement whatsoever. The authors estimate that tundra damaged for only a few seasons may require hundreds of years, possibly even a thousand years, to recover fully (Willard and Marr 1971). Trampling by recreation users has been shown to cause substantial declines in the numbers of plant species present and decreases in plant density and seed production (Colorado Native Plant Society 1997). Alpine plants can be particularly vulnerable, even to small alterations. For example, the removal of a rock providing shelter, a change in the course of a small rivulet of water, or the compaction of soil can destroy the microenvironment vital to a plant's survival (Colorado Native Plant Society 1997). At high elevations, small disturbances may result in severe consequences (Colorado Native Plant Society 1997).

Hikers use all of the areas that support *Ipomopsis globularis*, but Horseshoe Gulch, Boreas Pass, and Hoosier Ridge are particularly popular. The portion of the Boreas Pass occurrence that extends onto the western flank of Mount Silverheels does not appear to be used by hikers (Madsen personal communication 2003).

Global climate change

Anticipated increases in CO_2 and other "greenhouse" gases are predicted to warm the earth by several degrees Celsius (greater than 5 degrees Fahrenheit) during the 21st century (Price and Waser 1998, Wigley and Raper 1992), and this global climate change is likely to have wide-ranging effects. Projections based on current atmospheric CO_2 trends suggest that average temperatures will increase while precipitation will decrease in Colorado (Manabe and Wetherald 1986). These changes will significantly affect soil moisture, nutrient cycling, vapor pressure gradients, rates of plant growth, and timing of plant growth (Waser and Price 1998). Temperature increase could cause vegetation zones to climb 350 feet (100 m) in elevation for every degree Fahrenheit of warming (U.S. Environmental Protection Agency 1997). Because *Ipomopsis globularis* occurs between 10,500 and 13,800 feet (3,200 and 4,206 m) above sea level, and the highest peaks in the vicinity of the occurrences are between 13,000 feet (3,692 m) and just above 14,000 feet (4,267 m), an increase in just a few degrees could have serious implications for this species. Because the habitat for *I. globularis* is already xeric, lower soil moistures in the growing season induced by decreased precipitation could also have serious impacts.

At high elevations, global warming is likely to result in a longer snow free period, which will affect plant growth and reproduction. Spring snowmelt has been shown to be a very strong environmental cue to which many alpine plants respond when they begin initial springtime growth and flowering (Billings and Bliss 1959, Price and Waser 1998). Research by Price and Waser (1998) has shown that many plants respond to warming and earlier snowmelt with a phenological shift: they flower earlier, but not necessarily for a longer period of time. Over time, this shift may be seen in other aspects of the plant community and ecological relationships. For example, animal mutualists (pollinators, seed dispersers) and enemies (herbivores, seed predators) may, or may not, also shift (Price and Waser 1998). Further, community structure can shift, as well as how all species respond to the above interactions. For example, a shift in phenology may result in another plant species now competing for limited pollinator resources (Price and Waser 1998).

Other climate change models predict increased winter snowfall (e.g., Giorgi et al. 1998), which has other implications for *Ipomopsis globularis*. Increased snowfall could delay the onset of the growing season for *I. globularis* if persistent snow covers populations late into the spring, again causing potential problems with phonological shifts discussed above. An increase in snow depth, extent, and duration may also affect the carbon and nitrogen dynamics in the soil (Williams et al. 1998). For example, if snowfall increases in alpine areas, then there may be increased decomposition rates (Williams et al. 1998).

Pollution

Atmospheric nitrogen deposition (of both organic and inorganic forms) is increasing worldwide. A recent analysis of available information on atmospheric nitrogen deposition in the Rocky Mountains of Colorado and southern Wyoming (Burns 2003) shows that this region receives nitrogen deposition at a level that may have already caused changes in otherwise pristine systems. The increase in nitrogen deposition is resulting from agricultural uses, industrial uses, and burning fossil fuels (vehicles) east of the Rocky Mountains. Nitrogen deposition is generally greater east of the Continental Divide than west of the Divide in the Front Range, except in areas that are directly downwind of large power plants (Burns 2003). Westward movement of air from the Denver-Boulder-Fort Collins metropolitan area appears to be a strong contributor (Burns 2003). It is not known how specific occurrences of *Ipomopsis globularis* are responding to these changes.

Experimental nitrogen enrichment of alpine sites suggests that ecosystem processes are altered, resulting in species turnover (Bowman et al. 1993, Bliss and Gold 1999). Relatively low levels of nitrogen enrichment are advantageous to some species but deleterious to others, making it difficult to predict species- and community-level responses. Again, it is not known how *Ipomopsis globularis* would respond to these changes.

Acid precipitation may also present a problem for *Ipomopsis globularis*. Research conducted in the Rocky Mountains, Sierra Nevada, and Cascade Mountains shows that the areas that support *I. globularis* have relatively high concentrations of acidity, sulfate, nitrate, and calcium in the snowpack (Turk et al. 2001). Motorized recreational vehicles may also compromise the air quality in areas that support *I. globularis*.

Conservation Status of the Species in Region 2

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

Given the changes that have taken place within the occupied habitat of *Ipomopsis globularis* over the last 140 years, it can be assumed that in some places the distribution of this species has been diminished. However, movement of soil and anthropogenic disturbance might have spread this species to new locations, resulting in occasional small increases in its distribution. Because the pre-settlement population size of *I. globularis* is not known, it is difficult to assess the effects of historic mining infrastructure and management regimes on abundance. While prolonged or constant disturbance such as mining and heavy off-road vehicle use is likely to extirpate occurrences, periodic, light to moderate disturbance may be beneficial. With so many different landowners and land managers within its distribution, it is likely that management of some areas is not compatible with the persistence of *I. globularis* but that other areas are managed appropriately. While the net human impact on the distribution and abundance of *I. globularis* is difficult and complicated to assess, the cumulative impact of mining, motorized recreation, and habitat fragmentation is almost certainly resulting in a current decline of *I. globularis*. Further focused inventory and monitoring work would help to determine the current population trend of this species.

Do habitats vary in their capacity to support this species?

Habitats where *Ipomopsis globularis* is found appear to vary in their capacity to support it. Many apparently suitable sites do not support *I. globularis*; they may simply be unoccupied, or there may be some unknown feature that makes the sites unsuitable. This makes it difficult to assess a habitat's capacity to support this species. The nature of the disturbance regime of a given site may factor into its capacity to support *I. globularis*. However, much remains unknown about the nature of the disturbance regime to which *I. globularis* is adapted. Refinements of our understanding of the relationships between *I. globularis* and its habitat will be possible when more research is conducted on this topic.

Vulnerability due to life history and ecology

The overlap of the narrow endemism of *Ipomopsis globularis*, historical mining, and popular recreation areas in the Mosquito Range and adjacent areas is the primary source of its vulnerability and high degree of imperilment. Its narrow tolerance of edaphic conditions appears to limit it to soils of a very specific geologic stratum. Its high habitat specificity may leave it vulnerable to local extirpation.

As a narrowly restricted species, *Ipomopsis globularis* may be somewhat vulnerable to environmental stochasticity. The degree to which it can survive bad years will depend largely on how long individual plants can persist, or remain dormant as seeds.

Evidence of populations in Region 2 at risk

There is some evidence that all of the known occurrences of *Ipomopsis globularis* are facing some risk, and numerous botanists (O'Kane 1988, Abbott personal communication 2003, Bingham personal communication 2003, Hogan personal communication 2003, Jennings personal communication 2003, Lederer personal communication 2003, Redner personal communication 2003, Regier personal communication 2003, Yeatts personal communication 2003) are in agreement that because of its rarity and the precariousness of its occurrences, *I. globularis* warrants conservation attention.

Mining activity and an anticipated increase in motorized recreation have the potential to affect the entire global range of *Ipomopsis globularis*, and there are not provisions to ensure the long-term viability of this species. There is one small protected area that includes *I. globularis*, the Hoosier Ridge Research Natural Area. Landownership patterns in the Mosquito Range and adjacent areas are heavily influenced by the irregular patterns of mining property boundaries, making conservation action difficult.

Land and Resource Management Plans have been developed by the White River and Pike-San Isabel national forests. According to these plans, motorized recreation in areas inhabited by *Ipomopsis globularis* is limited to designated routes only (Johnston personal communication 2003, Mayben personal communication 2003). The Hoosier Ridge RNA is closed to motorized use completely (Johnston personal communication 2003). However, enforcement of this closure is difficult if not impossible (Johnston personal communication 2003, Mayben personal communication 2003).

The total population size of *Ipomopsis globularis* is somewhat small (an estimated 6,000 to 11,000 plants documented). While populations of this size are probably viable, the fragmentation of its habitat suggests that geneflow throughout the population may be obstructed, leading to smaller effective population sizes. Fragmentation may also impact the movement of pollinators. While *I. globularis* may be capable of self-fertilization, it is likely that heavy reliance on this means of reproduction will rapidly reduce the genetic diversity of the species.

Management of the Species in Region 2

Implications and potential conservation elements

The most current data available suggest that *Ipomopsis globularis* is a narrowly endemic species that is imperiled due to a small number of occurrences, high level of endemism, and threats to its habitat. Thus, the loss of an occurrence or a portion thereof is significant and will probably result in the loss of important components of the genetic diversity of the species. Conservation easements and management offer the best chance for the conservation of this species. Given its rarity, threats to its habitat, demonstrable impacts, and declining range and available habitat, management policies will have to take proactive steps to ensure that this species persists. Without strong proactive efforts to conserve it, *I. globularis* may warrant future federal listing as threatened or endangered. Safeguarding some of the highest quality occurrences may preclude the need for federal listing. Management policies that address motorized recreation, human and natural disturbance regimes, pollinator resources, noxious weeds, habitat fragmentation, and restoration of native plant communities would also protect *I. globularis*. Given (1994) offers much practical advice regarding restoration that will assist with the development of effective management and restoration policies.

Desired environmental conditions for *Ipomopsis globularis* include sufficiently large areas where the natural ecosystem processes on which the species depends can occur, permitting it to persist unimpeded by human activities and their secondary effects, such as introduction of noxious weeds. This includes a satisfactory degree of ecological connectivity between populations to provide corridors and other nectar resources for pollinators. From a functional standpoint, ecosystem processes on which *I. globularis* depends appear to remain intact to some extent. Whether this will remain true at the human population densities projected for the area is uncertain. Although *I. globularis* occurrences are apparently viable at present, the natural ecosystems and ecosystem processes have been altered, and the habitat is disturbed and fragmented. Further research on the ecology and distribution of *I. globularis* will help managers develop effective approaches to management and conservation. Given the extreme rarity and imperilment of this species, conserving the known occurrences is a high priority for biodiversity conservation.

It is likely that a thoughtful assessment of current management practices on lands occupied by *Ipomopsis globularis* would identify some opportunities for change that would be inexpensive and have minimal impacts on the livelihood and routines of local residents, managers, stewards, and recreationists while conferring substantial benefits to *I. globularis*.

Tools and practices

Species inventory

Species inventory work is among the highest priorities for research on *Ipomopsis globularis*. Collecting baseline information and developing a detailed map of the known distribution and abundance will provide a starting point from which population trend can be assessed. Although there have been several concerted efforts to locate other *I. globularis* occurrences, no new occurrences have been identified since 1995 (Colorado Natural Heritage Program 2003). However, further searching could yield other yet undiscovered occurrences. Species inventories are simple, relatively inexpensive, and effective, and they are necessary for developing an understanding of the target species sufficient for developing a monitoring program. Contracting experts on this species to search for more occurrences and update historic records would contribute greatly to our knowledge of it. In particular, more current information is needed on four of the nine occurrences that have not been observed for nearly 20 years (Mount Lincoln, Cooper Creek, Sheep Mountain, and Horseshoe Gulch).

Although it is somewhat inconspicuous in the vegetative stage, at other stages *Ipomopsis globularis* is relatively conspicuous and showy for an alpine species. It tends to grow in open habitats and is not difficult to distinguish from other members of *Ipomopsis*. As a result, field crews could be quickly taught to recognize this species in the field. Surveying for *I. globularis* is complicated by the need to obtain permission to enter private land throughout its known range. Search efforts can also be more difficult in dry years when fewer plants produce flowers.

Areas with the highest likelihood of new occurrences are those with the appropriate geologic substrate within the range of the known occurrences. Many areas within the known range of *Ipomopsis globularis* remain to be searched because of the difficulties in accessing remote areas. There may be other occurrences on limestone outcrops many miles away from the Mosquito Range, particularly if the species was once more widespread. The Collegiate Peaks and Holy Cross Wilderness Areas, as well as the alpine areas along the Continental Divide from Boreas Pass north to Loveland Pass are all worthy of further inventory work.

Habitat inventory

The Colorado Natural Heritage Program routinely uses aerial photography, topographic maps, soil maps, and geology maps to refine search areas when conducting inventories of large areas. This approach has been highly effective in Colorado and elsewhere. It is most effective for species for which there is basic knowledge of substrate and habitat specificity from which distribution patterns and potential search areas can be deduced.

Searches for *Ipomopsis globularis* could be aided by modeling habitat based on the physiognomy of known occurrences. The intersection of topography, geologic substrate, and vegetation could be used to generate a map of a probabilistic surface showing the likelihood of the presence of *I. globularis* in given locations. This would be a valuable tool for guiding and focusing future searches. Dr. Tom Stohlgren's group at the Natural Resource Ecology Laboratory at Colorado State University has used these techniques to model weed invasion probabilities in native ecosystems (Stohlgren et al. 2003), and they will be using such techniques to model potential rare plant habitat in the near future (Stohlgren personal communication 2002). Generating such a map for *I. globularis* is contingent on the refinement of the definition of its suitable habitat.

Population monitoring

A monitoring program for *Ipomopsis globularis* would begin by targeting the known occurrences; other occurrences could be added to the program as they are discovered. The best time for inventory and monitoring of this species is from mid-July to late August when flowering is at its peak. Multiple sample sites with different levels of anthropogenic disturbance could be selected within the large occurrences at Weston Pass, Hoosier Ridge, and Boreas Pass. Monitoring sites under a variety of land management scenarios would help to identify appropriate management practices for *I. globularis* and to understand its population dynamics and structure.

A monitoring program that addresses recruitment, seed production, seed and plant longevity, population variability, and pollinators would generate data useful to managers and the scientific community. The most sensitive measure of population change would be gleaned from recruitment success. Monitoring interactions with pollinators could be effectively done by expanding on the methods employed by Spackman et al. (2001b). Suitable methods for monitoring pollinators are also discussed in Kearns and Inouye (1993). Measuring seed production would require a visit later in the summer after fruit matures. It will be important to define *a priori* the changes that the sampling regime intends to detect, and the management actions that will follow from the results (Schemske et al. 1994, Elzinga et al. 1998).

Because of a potentially high annual variability in reproductive effort, resampling of monitoring plots would be necessary every year to gain insight into the population dynamics of *Ipomopsis globularis*. Johnston (personal communication 2002) has identified a broadly applicable method employing the use of randomly arrayed systematic sampling units. Each sampling unit consists of a transect with randomly placed 1m^2 quadrats. The quadrats are evenly spaced, but the placement of the first quadrat on the transect is selected randomly. After they are established, the quadrats would become permanent. Within each quadrat, plants would be marked and tracked using an aluminum tag or other field marker. Recruitment within each plot is quantified by counting seedlings. To reduce the chance of missing seedlings, a quadrat frame subdivided with tight string would help observers search each quadrat systematically. Elzinga et al. (1998) offers additional suggestions regarding this method.

A stratified random design might also be employed to establish the sampling units, particularly at locations where it is difficult to lay a transect due to the ruggedness of the site. Permanent plots could be selected within a habitat unit by randomly choosing X and Y Universal Transverse Mercator (UTM) coordinates. Then, the plots could be located using highly accurate Global Positioning System (GPS) units. Once established and marked, a recreation grade GPS could be used to relocate the plots. If subsequent power analysis indicates that the sample size is inadequate, it is easy to add more quadrats in this sample design. Disadvantages to this method include the difficulty in using GPS in very steep terrain.

Several methods of monumentation are identified in Elzinga et al. (1998) depending on the site physiography and frequency of human visitation to the site. Monumentation is an important consideration that will reap long-term benefits if done properly at the outset of the monitoring program.

Estimating cover and/or abundance of associated species within the plots described above could permit the investigation of interspecific relationships through ordination or other statistical techniques. In very sparsely vegetated plots, this can be difficult, but it can be done accurately using appropriate cover classes or subdivided quadrat frames. Understanding environmental constraints on *Ipomopsis globularis* would facilitate the management of this species. Gathering data on edaphic characteristics (moisture, texture, and soil chemistry, particularly pH, if possible) from the permanent plots described above would permit the canonical analysis of species-environment relationships. These data would facilitate hypothesis generation for further studies of the ecology of this species. Comparing lysimetry data between occupied and unoccupied habitat could help to refine the definition of potential habitat if soil chemistry controls the distribution of *I. globularis*.

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

At present, the priorities lie in gathering data on distribution and population sizes for *Ipomopsis globularis*. Gathering population data can be done rapidly and requires only a small amount of additional time and effort (Elzinga et al. 1998). Thus, presence/absence monitoring is not a priority for *I. globularis*.

To address the metapopulation structure of *Ipomopsis globularis*, one approach might be to select highly suitable but unoccupied sites and attempt to observe colonization events. Selecting monitoring sites from different anthropogenic disturbance regimes offered above would offer data from which a metapopulation structure for *I. globularis* could be investigated. Observations of local extinctions would also add to our understanding of the metapopulation structure of *I. globularis*. Even for plant species, in which metapopulation dynamics can be successfully inferred from regional extinction and colonization data, focusing efforts on monitoring of individual populations is more likely to provide an accurate assessment of the species (Harrison and Ray 2002).

Habitat monitoring

Habitat monitoring would be particularly beneficial to *Ipomopsis globularis*. For sites that are occupied by *I. globularis*, habitat monitoring needs to be conducted concurrently with population monitoring. Documenting habitat attributes, disturbance regime, and associated species during all population monitoring efforts would greatly augment our present understanding of its habitat requirements and management needs. This could be incorporated into the field forms used for the quantitative sampling regimen described above. If carefully selected environmental variables are quantified during monitoring activities, they would help to explain observations of population change. Habitat monitoring of known occurrences will alert managers of new impacts such as weed infestations and damage from human disturbance. Making special note of signs of degradation from recreational uses may help managers prevent serious degradation proactively by implementing changes in the management regime. Change in environmental variables might not cause observable demographic repercussions for several years, so resampling the chosen variables may help to identify underlying causes of population trends. Evidence of current land use practices and management is also important to document while monitoring populations. Each potential threat discussed in the Threats section of this document could be monitored for direct impacts on the plants and for indirect impacts through alteration of habitat.

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

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

Beneficial management actions

The establishment of areas that would be managed for the conservation of *Ipomopsis globularis* is perhaps the best conservation strategy for this species. As the human population increases in the area, occurrences of *I. globularis* could be lost and its habitat will become increasingly fragmented. Conservation easements, fee purchase, and other land trust activities would be useful conservation tools to protect occurrences on private land. Although it appears that *I. globularis* does not occur on any existing conservation easements, there remain many opportunities for the counties or other entities to purchase the lands and mineral (subsurface) rights to parcels that support occurrences of *I. globularis*. Purchasing conservation easements even on small properties may confer significant benefits to the conservation of *I. globularis*. Land exchanges that bring occurrences on private land into federal ownership, particularly the USFS, would also be a useful conservation tool. However, this can be an extremely difficult prospect in the Mosquito Range and adjacent areas where there are so many private landowners. A 20-acre area of interest to the South Park Ranger District (Pike-San Isabel National Forest) was found to have over 200 landowners, with many names listed for each single parcel (personal communication Mayben personal communication 2003). Generally, land exchanges with the USFS are possible only for lands within the proclaimed boundary of the national forest.

Management practices that reduce the impacts from recreation uses to occurrences of *Ipomopsis globularis* are likely to contribute greatly to the achievement of conservation goals for this species. Research is needed to identify disturbance regimes that are compatible with *I. globularis*. Given our current limited knowledge based solely on observations, exclusion of motorized recreation (and enforcement) within all known occurrences, at least from June through September when the plant is growing and reproducing, and when the snow cover is typically shallow, is most likely to be compatible with the persistence of *I. globularis*. Another approach that might be considered on a site-by-site basis is the use of exclosures. Maschinski et al. (1997) found the use of exclosures to be effective in protecting the endangered *Astragalus cremnophylax* var. *cremnophylax* (sentry milkvetch) from trampling.

To date, weeds have not been documented within any of the known occurrences of *Ipomopsis globularis*, but management strategies that work to prevent infestations are likely to confer great benefits. If weeds are found, then weed control efforts have the potential to negatively impact *I. globularis*. Avoiding the use of herbicides for weed control within occurrences of *I. globularis* is likely to be highly beneficial. In occurrences of the federally listed *I. sancti-spiritus*, hand pulling of weeds in occurrences on road cuts is identified as the preferred method for weed control (USDI Fish and Wildlife Service 2002).

Other roadside activities could be modified to benefit *Ipomopsis globularis* at Weston Pass. Installation and maintenance of utilities in rights-of-way could impact could impact a large portion of the occurrence, but careful attention to avoiding *I. globularis* would greatly reduce impacts. Awareness of the species during future projects will help to ensure its viability. The Colorado Natural Heritage Program can provide accurate data on the distribution of this species to assist with avoiding impacts to occurrences. Surveys of areas in question by someone who is familiar with *I. globularis* would be necessary in certain situations.

Historical mining disturbances and current recreational use have decreased the amount of natural habitat in the area while increasing the distance each pollinator needs to travel to reach nectar resources. Appropriate management of natural vegetation in the vicinity of occurrences of *Ipomopsis globularis* is likely to benefit pollinators and may improve the likelihood of persistence for currently unknown occurrences. Managing for large pollinators, which can travel farther than small pollinators, might benefit *I. globularis*.

Further inventory and monitoring efforts would be highly beneficial to *Ipomopsis globularis*. Identifying high quality occurrences, in which the size, condition, and the landscape context are excellent, will help managers to prioritize conservation efforts. Much suitable habitat within the range of *I. globularis* remains to be searched.

Seed banking

No seeds or genetic material are currently in storage for *Ipomopsis globularis* at the National Center for Genetic Resource Preservation (Miller personal communication 2003). It is not among the National Collection of Endangered Plants maintained by the Center for Plant Conservation (Center for Plant Conservation 2002). Collection of seeds for long-term storage will be useful if future restoration work is necessary.

Information Needs

Distribution

Further species inventory work specifically targeting *Ipomopsis globularis* is a high research priority. Until there is a complete picture of its distribution and population size, it will not be possible to accurately assess the conservation needs and priorities for this species. Often, when a species thought to be rare is actively sought and inventoried, it is found that the species is not as rare as previously believed. Because *I. globularis* has already been actively sought in several studies, this scenario is less likely. However, recent floristic inventory work by Barry Johnston (personal communication 2003) has been lucrative at least in terms of expanding the boundaries of the known occurrences, suggesting that other occurrences might await discovery. Places to focus future search efforts include the Mosquito Range, the Holy Cross and Collegiate Peaks Wilderness Areas, and alpine areas along the Continental Divide north of Boreas Pass to Loveland Pass although parts of this area might not have suitable habitat (personal communication Jennings 2003).

Life cycle, habitat, and population trend

While information on the life cycle of *Ipomopsis globularis* can be inferred to some extent from the very well-studied *I. aggregata*, specific research on *I. globularis* is needed to understand its population ecology. A more thorough investigation of its lifespan and autecology is needed.

The habitat for *Ipomopsis globularis* has been described, but the nature of its natural habitat and natural disturbance regime is poorly understood. An explanation for the extremely limited range of *I. globularis* is wanting. Calcareous outcrops can be found in alpine areas in many other parts of Colorado, but the particular environmental variables to which *I. globularis* responds are unknown. Hypotheses regarding the role of pH, soil texture, dispersal ability, disturbance, community ecology, and historic versus contemporary habitat availability as causes of rarity for *I. globularis* need to be tested. Understanding its habitat and being able to identify suitable habitat is particularly important for the conservation and management of *I. globularis*. Autecological research is needed to help refine our definition of appropriate habitat and to facilitate effective habitat monitoring and conservation stewardship of this species.

The population trend of *Ipomopsis globularis* is not known and may be difficult to quantify. However, understanding the population biology of *I. globularis* is important for appropriate stewardship and management of this species.

Response to change

Rates of reproduction and establishment and the effects of environmental variation on these parameters have not been investigated in *Ipomopsis globularis*, making the effects of various management options difficult to assess during project planning. Understanding the specific responses of *I. globularis* to disturbance is important for determining appropriate management practices, but they are not clear and need further investigation.

Change in the amount of mining disturbance and recreational use in the habitat of *Ipomopsis globularis* could decrease the availability and diversity of pollinators. In her studies of *I. polyantha*, Collins (1995) noted that large-bodied species have greater nutrient reserves, enabling them to travel farther to pollinator resources. Thus, a shift towards larger pollinators might be expected if the area becomes more fragmented and if populations of *I. globularis* become more insular. Pollinators capable of residing in disturbed habitats are also likely to be favored. Research on the effects of anthropogenic disturbance to pollinators is warranted for *I. globularis*.

Metapopulation dynamics

Research on the population ecology of *Ipomopsis globularis* has not been done to determine the importance of metapopulation structure and dynamics to its long-term persistence at local or regional scales. Migration, extinction, and colonization rates are unknown for *I. globularis*. Baseline population dynamics and viability must first be assessed. Given the complex patchwork of varying disturbance and management regimes within the known range of *I. globularis*, it is probably constantly being extirpated at some sites while colonizing others.

Demography

Only the broadest generalizations can be made at present regarding the demography of *Ipomopsis globularis*. Population size has not been assessed for occurrences of *I. globularis*. Growth and survival rates are also unknown, and the rate of reproduction is poorly understood. Our knowledge of the distribution of the species is also incomplete. Therefore, much work is needed in the field before local and range-wide persistence can be assessed with demographic modeling techniques. Short-term demographic studies often provide misleading guidance for conservation purposes, so complementary information, such as historical data and experimental manipulations, needs to be included whenever possible (Lindborg and Ehrlén 2002). However, the value of demographic data for conservation planning and species management cannot be overstated.

Population trend monitoring methods

Known occurrences of *Ipomopsis globularis* have not been monitored, but methods are available to begin a monitoring program. Lesica (1987) described a technique for monitoring populations of non-rhizomatous perennial plant species that would apply to *I. globularis*. Selection of monitoring sites from a variety of land use scenarios will be necessary to monitor trend at the population level.

Restoration methods

There have been no known attempts to restore habitat or occurrences of *Ipomopsis globularis*. Therefore, there is no applied research from which to draw in developing a potential restoration program. It is likely that *I. globularis* may be readily propagated in a greenhouse environment, but it may be difficult to transfer plants successfully into a natural or quasi-natural (restored) setting. Rocky Mountain Rare Plants 2004-2005 Alpine Seed Catalog (http://www.rmrp.com) reports that *I. globularis* plants are "surprisingly easy in cultivation." Restoration work is probably a low priority at this time.

Research priorities for Region 2

Further species inventory work is needed to identify all occurrences of *Ipomopsis globularis*. Focusing on expanding the boundaries of known occurrences and identifying new occurrences in the Mosquito Range and adjacent areas are important steps for developing a complete understanding of the distribution of *I. globularis*. Targeted search efforts at phenologically appropriate times (July to early August) in suitable habitat will help to confirm the distribution and abundance of *I. globularis* and may identify other opportunities for its conservation. The identification of large, healthy occurrences on properties where landowners are interested in establishing conservation easements is needed so that conservation action on behalf of *I. globularis* can begin. Identifying robust occurrences in natural settings is important for setting conservation targets and priorities. Collecting detailed notes on associated species, habitat, geology, soil, and other natural history observations at all locations would be extremely useful information.

Reaching a better understanding of the influence of human activities on individuals and habitat of *Ipomopsis globularis* would provide substantial practical benefits for land managers and planners. Documenting and monitoring impacts from all potential threats to *I. globularis* would help managers act to mitigate these threats. Identifying life history and phenological stages when *I. globularis* is less sensitive to recreational impacts would help greatly by informing the development of management practices that are compatible with *I. globularis*.

The role of disturbance in the autecology of *Ipomopsis globularis* remains poorly understood. An understanding of the specific tolerances of *I. globularis* to different human and natural disturbance regimes would assist with developing conservation strategies and management plans by determining the types of disturbance most likely to negatively impact it.

Demographic studies are needed for *Ipomopsis globularis*. Demographic data may be more useful for assessing status and developing recovery efforts than for genetic information (Schemske et al. 1994). Determining the critical life history stages of *I. globularis* would allow managers to focus efforts on implementing management protocols that benefit those stages. A monitoring program that determines effective population sizes and investigates the growth, survival, and reproduction of individuals within populations will have considerable practical value and would help to determine the conservation status of *I. globularis*.

Information gleaned from studies of the physiological and community ecology of *Ipomopsis globularis* would be valuable in the event that a population needs to be restored, and it will help to determine the biotic and abiotic factors that contribute to its survival. Understanding the plant-environment relationship for *I. globularis* would be insightful in understanding the coping strategies employed by this species, and it would help to model its potential distribution.

Additional research and data resources

The manuscript of Porter et al. (2003) was provided by Dr. J. Mark Porter. This paper is not yet published (Wilken personal communication 2004). Further revisions will occur before publication, which may require changes to this assessment (most likely the Classification and description section).

Definitions

50/500 rule – A generalized rule stating that isolated populations need a genetically effective population of about 50 individuals for short-term persistence, and a genetically effective population of about 500 for long-term survival (Soulé 1980).

Actinomorphic – Flowers that are radially symmetrical (Harris and Harris 1999).

Capitate – Headlike; collected into a short, dense cluster (Weber and Wittmann 2001).

Cladistic analyses – Phylogenenic systematics.

Fragmentation – Process by which habitats are increasingly subdivided into smaller units, resulting in their increased insularity as well as losses of total habitat area (Fiedler and Jain 1992).

Iteroparous – Does not die following reproduction.

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

Pinnately dissected leaves – Having divisions in the form of a feather, i.e. with one main axis having later offshoots (Weber and Wittmann 2001).

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

Salverform – Referring to a narrow, tubular corolla that opens out to form a very open, dish-like apex (Weber and Wittmann 2001).

Scree – Accumulation of rocky debris lying on a slope or at the base of a hill (Spackman et al. 1997b).

Semelparous – Reproduces and then dies.

Talus – Sloping mass of coarse rock fragments accumulated at the foot of a cliff or slope (Spackman et al. 1997b).

Tundra – A treeless area between the icecap and the tree line of Arctic regions, having a permanently frozen subsoil and supporting low-growing vegetation such as lichens, mosses, and stunted shrubs (Pickett 2000).

Xenogamy – Fertilization involving pollen and ovules from different flowers on genetically distinct plants. Synonymous with outcrossing (Allaby 1998).

Imperilment Ranks used by Natural Heritage Programs, Natural Heritage Inventories, Natural Diversity Databases, and NatureServe.

Global imperilment (G) ranks are based on the range-wide status of a species. State-province imperilment (S) ranks are based on the status of a species in an individual state or province. State-province and Global ranks are denoted, respectively, with an "S" or a "G" followed by a character. **These ranks should not be interpreted as legal designations.**	
G/S1	Critically imperiled globally/state-province because of rarity (5 or fewer occurrences in the world/state; or very few remaining individuals), or because of some factor of its biology making it especially vulnerable to extinction.
G/S2	Imperiled globally/state-province because of rarity (6 to 20 occurrences), or because of other factors demonstrably making it very vulnerable to extinction throughout its range.
G/S3	Vulnerable through its range or found locally in a restricted range (21 to 100 occurrences).
G/S4	Apparently secure globally/state-province, though it might be quite rare in parts of its range, especially at the periphery.
G/S5	Demonstrably secure globally, though it may be quite rare in parts of its range, especially at the periphery.
GX	Presumed extinct.
G#?	Indicates uncertainty about an assigned global rank.
G/SU	Unable to assign rank due to lack of available information.
GQ	Indicates uncertainty about taxonomic status.
G/SH	Historically known, but not verified for an extended period, usually.
G#T#	Trinomial rank (T) is used for subspecies or varieties. These taxa are ranked on the same criteria as G1-G5.
S#B	Refers to the breeding season imperilment of elements that are not permanent residents.
S#N	Refers to the non-breeding season imperilment of elements that are not permanent residents. Where no consistent location can be discerned for migrants or non-breeding populations, a rank of SZN is used.
SZ	Migrant whose occurrences are too irregular, transitory, and/or dispersed to be reliable identified, mapped, and protected.
SA	Accidental in the state or province.
SR	Reported to occur in the state or province, but unverified.
S?	Unranked. Some evidence that the species may be imperiled, but awaiting formal rarity ranking.
Notes: Where two numbers appear in a G or S rank (e.g., S2S3), the actual rank of the element falls between the two numbers.	

References

Abbott, R. 2003. Personal communication with Colorado Natural Heritage Program Botanist regarding *Ipomopsis globularis*.

Alarcon, R. and D.R. Campbell. 2000. Absence of conspecific pollen advantage in the dynamics of an *Ipomopsis* (Polemoniaceae) hybrid zone. American Journal of Botany 87:819-824.

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

Anderson, J. 1988. Status report for *Ipomopsis polyantha* var. *polyantha*. Unpublished report produced for the U.S. Fish and Wildlife Service. Grand Junction, CO.

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.

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

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

Bethlenfalvay, G.J. and S. Dakessian. 1984. Grazing effects on mycorrhizal colonization and floristic composition of the vegetation on a semiarid range in northern Nevada. Journal of Range Management 37:312-316.

Billings, W.D. and L.C. Bliss. An alpine snowbank environment and its effects on vegetation, plant development, and productivity. Ecology 40(3):388-397.

Bingham, R. 2003. Personal communication with Western State College (Gunnison, CO) Ph.D. Botanist regarding *Ipomopsis globularis*.

Bliss, L.C. and W.G. Gold. 1999. Vascular plant reproduction, establishment, and growth and the effects of cryptogamic crusts within a polar desert ecosystem, Devon Island, NWT, Canada. Canadian Journal of Botany 77(5):623-636.

Bowman, W.D., T.A. Theodose, J.C. Schardt, and R.T. Conant. 1993. Constraints of nutrient availability on primary production in alpine communities. Ecology 74:2085-2098.

Brand, A. 1907. Polemoniaceae. *In*: A. Engler, editor. Das Pflanzenreich. 4(250):1-203.

Bray, W. L. 1898. On the relation of the flora of the Lower Sonoran Zone in North America to the flora of the arid zones of Chili and Argentine. Botanical Gazette 26: 121-127.

Burns, D.A. 2003. Atmospheric nitrogen deposition in the Rocky Mountains of Colorado and southern Wyoming—a review and new analysis of past study results. Atmospheric Environment 37:921-932.

Campbell, D.R., N. Crawford, A.K. Brody, and T.A. Forbis. 2002a. Resistance to pre-dispersal seed predators in a natural hybrid zone. Oecologia 131:436-443.

Campbell, D.R., N.M. Waser, and G.T. Pederson. 2002b. Predicting patterns of mating and potential hybridization from pollinator behavior. American Naturalist 159:438-450.

Campbell, D.R. and N.M. Waser. 2001. Genotype-by-environment interaction and the fitness of plant hybrids in the wild. Evolution 55:669-676.

Campbell, D. R., N.M. Waser, and E.J. Melendez- Ackerman. 1997. Analyzing pollinator-mediated selection in a plant hybrid zone: hummingbird visitation patterns on three spatial scales. American Naturalist 149:295-315.

Campbell, D.R., N.M. Waser, and P.G. Wolf. 1998. Pollen transfer by natural hybrids and parental species in an *Ipomopsis* hybrid zone. Evolution 52:1602-1611.

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

Center for Plant Conservation. 2002. National collection of endangered plants. Accessed via the World Wide Web at http://www.mobot.org/CPC/NC_Choice.html.

Chronic, H. 1980. Roadside Geology of Colorado. Mountain Press Publishing Co., Missoula, MT.

Chumley, T.W. 1998. A floristic inventory of the east slope, central Colorado. M.S. Thesis. University of Wyoming, Laramie, WY.

Coles, J. 2003. Personal communication with Colorado botanist regarding *Ipomopsis globularis*.

Collins, C. 1995. The natural history and reproductive biology of the pagosa gilia, *Ipomopsis polyantha* (Rydberg) V. Grant var. *polyantha* (Polemoniaceae). M.A. Thesis. California State University, Fullerton, CA.

Colorado Division of Wildlife. 2003. Natural diversity information source accessed via the World Wide Web at http://ndis.nrel.colostate.edu.

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

Colorado Natural Heritage Program. 2003. Biological and conservation data (BCD) system. Colorado Natural Heritage Program, Fort Collins, CO.

Colorado Natural Heritage Program Site Committee. 2001. Recommendations for development and standardization of potential conservation areas and network of conservation areas. Colorado Natural Heritage Program, Fort Collins, CO.

Cronquist, A., A.H. Holmgren, N.H. Holmgren, J.L. Reveal, and P.K. Holmgren. 1984. Intermountain Flora- Vascular Plants of the Intermountain West, U.S.A. Volume Four- Subclass Asteridae (except Asteraceae). The New York Botanical Garden, Bronx, NY.

Dorn, R. 2003. Redrawing the Phlox Family tree. Castilleja- A Publication of the Wyoming Native Plant Society 22: 3.

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

Elzinga, S. 2003. Personal communication with Eagle County Weed and Pest Coordinator regarding weed species above treeline in Colorado.

Elzinga, C.L., D.W. Salzer, and J.W. Willoughby. 1998. Measuring and monitoring plant populations. Bureau of Land Management Technical Reference 1730-1. Bureau of Land Management National Business Center, Denver, CO.

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

Fiedler, P.L. and S.K. Jain. 1992. Conservation Biology: The Theory and Practice of Nature Conservation, Preservation and Management. Chapman and Hall, Inc, London Foutz, D.R. 1994. Geology of Colorado Illustrated. Foutz, Grand Junction, CO.

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

Given, D.R. 1994. Principles and practice of plant conservation. Timber Press, Portland, OR.

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

Grant, V. 1956. A Synopsis of *Ipomopsis*. El Aliso 3:351-362.

Grant, V. 1959. Natural History of the Phlox Family. Martinus Nijhoff, The Hague, Netherlands.

Grant, V. 1992. Systematics and phylogeny of the *Ipomopsis aggregata* Group (Polemoniaceae) - Traditional and molecular approaches. Systematic Botany 17:683-691.

Grant, V. and K.A. Grant. 1965. Flower Pollination in the Phlox Family. Columbia University Press, New York, NY.

Grant, V. and D.H. Wilken. 1986. Taxonomy of the *Ipomopsis aggregata* group (Polemoniaceae). Botanical Gazette 147:359-371.

Grant, V. and D.H. Wilken. 1988. Natural hybridization between *Ipomopsis aggregata* and *Ipomopsis tenuituba* (Polemoniaceae). Botanical Gazette 149:213-221.

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

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

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

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

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

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

Harrison, S. and C. Ray. 2002. Plant population viability and metapopulation-level processes. *In*: S.R. Beissinger and D.R. McCullough, editors. Population Viability Analysis. The University of Chicago Press, Chicago, IL.

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

Hogan, T. 2003. Personal communication with Assistant Curator of the University of Colorado Herbarium regarding *Ipomopsis globularis*.

Irwin, R.E., A.K. Brody, and N.M. Waser. 2001. The impact of floral larceny on individuals, populations, and communities. Oecologia 129:161-168.

Jennings, W.F. 2003. Personal communication with private consultant regarding distribution and threats to *Ipomopsis globularis* and weed species above timberline in Colorado.

Johnston, B.C. 2002a. Species Evaluation for *Ipomopsis globularis* for the R2 Sensitive Species List. September 30, 2002. Available online at: http://www.fs.fed.us/r2/projects/scp/evalrationale/evaluations/dicots/ipomopsisglobularis.pdf.

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

Johnston, B.C. 2003. Personal communication with USDA Forest Service Botanist regarding populations of *Ipomopsis globularis* on the Dillon Ranger District of the White River National Forest.

Johnston, B.C., J.S. Peterson, and W. Harmon. 1981. Status Report for *Ipomopsis globularis* (Brand) W.A. Weber. Unpublished report prepared for the U.S. Fish and Wildlife Service.

Juenger, T. and J. Bergelson. 1997. Pollen and resource limitation of compensation to herbivory in scarlet gilia, *Ipomopsis aggregata*. Ecology 78:1684-1695.

Juenger, T. and J. Bergelson. 2000. The evolution of compensation to herbivory in scarlet gilia, *Ipomopsis aggregata*: Herbivore-imposed natural selection and the quantitative genetics of tolerance. Evolution 54:764-777.

Kartesz, J.T. 1999. A synonymized checklist and atlas with biological attributes for the vascular flora of the United States, Canada, and Greenland. First Edition. *In*: J.T. Kartesz and C.A. Meacham. Synthesis of the North American Flora [computer program]. Version 1.0. North Carolina Botanical Garden, Chapel Hill, NC.

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

Keddy, P. 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 3(5):409-415.

Ladyman, J.A.R. 2003. *Astragalus molybendus* Barneby (Leadville milkvetch): A Technical Conservation Assessment. Prepared for the USDA Forest Service, Rocky Mountain Region, Species Conservation Project.

Lane, E. 2003. Personal communication with Colorado Department of Agriculture Weed Coordinator regarding weed species above timberline in Colorado.

Laspilitas.com. 1995. Roots. In: Manual of California Native Plants. Accessed on November 20, 2002 on the World Wide Web at http://www.laspilitas.com/plants/adv/advroots.htm.

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

Lederer, N. 2003. Personal communication with Assistant Curator of the University of Colorado Herbarium regarding the distribution of *Ipomopsis globularis*.

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

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

Madsen, B. 2003. Personal communication with Pike San Isabel National Forest Botanist regarding *Ipomopsis globularis*.

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

Maschinski, J. 1996. Seed germination and pollination requirements of Holy Ghost Ipomopsis (*Ipomopsis sancti-spiritus*). Pages 167-170 *in* J. Maschinski, H.D. Hammond, and L. Holter, technical editors. Southwestern Rare and Endangered Plants: Proceedings of the Second Conference; 1995 September 11-14; Flagstaff, AZ. General Technical Report RM-GTR-283. USDA Forest Service, Rocky Mountain Research Station, Fort Collins, CO.

Maschinski, J. 2001. Extinction risk of *Ipomopsis sancti-spiritus* in Holy Ghost Canyon with and without management intervention. Southwestern Rare and Endangered Plant Conference: Proceedings of the Third Conference; 2000 September 25-28; Flagstaff, AZ. RMRS-P-23. USDA Forest Service, Rocky Mountain Research Station, Fort Collins, CO.

Maschinski, J., R. Frye, and S. Rutman. 1997. Demography and population viability of an endangered pant species before and after protection from trampling. Conservation Biology 11:4.

Mayben, S. 2003. Personal communication with District Ranger of the South Park Ranger District, Pike San Isabel National Forest regarding management of areas that support *Ipomopsis globularis*.

Melendez-Ackerman, E. and D.R. Campbell. 1998. Adaptive significance of flower color and inter-trait correlations in an *Ipomopsis* hybrid zone. Evolution 52:1293-1303.

Michaux, A. 1803. *Ipomopsis*. Flora Boreali-Americana, ed 1:141.

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

NatureServe. 2003. NatureServe Explorer: an online encyclopedia of life [web application]. March 8, 2003.

New York Botanical Garden. 2003. Image of holotype specimen for *Ipomopsis globularis*. Accessed via the World Wide Web at http://scisun.nybg.org:8890/searchdb/owa/wwwcatalog.detail_list?this_id=3310402.

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

Nichols, G. 2003. Personal communication with Park County planner regarding human land uses in the Mosquito Range.

O'Kane, S.L. 1988. Colorado's rare flora. Great Basin Naturalist 48:434-484.

Orthner, A.R. 1999. Flora of the Buffalo Peaks Wilderness Area and vicinity, Mosquito Range, Colorado. M.S. Thesis, Museum and Field Studies Program, University of Colorado, Boulder, CO.

Paige, K.N. 1992. Overcompensation in response to mammalian herbivory - From mutualistic to antagonistic interactions. Ecology 73:2076-2085.

Paige, K. N. 1999. Regrowth following ungulate herbivory in *Ipomopsis aggregata*: Geographic evidence for overcompensation. Oecologia 118:316-323.

Paige, K.N., B. Williams, and T. Hickox. 2001. Overcompensation through the paternal component of fitness in *Ipomopsis arizonica*. Oecologia 128:72-76.

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

Patterson, B. 2002. The modernization of the Polemoniaceae: or, how I learned to stop worrying and love DNA. Presentation to the California Native Plant Society. San Francisco State University. Accessed via the World Wide Web at: http://online.sfsu.edu/~patters/Polemons/Media/cnpstitle.jpg.

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

Pickett, J, P., editor. 2000. The American Heritage Dictionary of the English Language: Fourth Edition. Houghton Mifflin Boston, MA. Online: http://dictionary.reference.com/search?q=tundra.

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

Porter, J.M. and L. Johnson. 2001. Age and diversification and their implications for historical biogeography of Polemoniaceae. Botanical Society of America Annual Meeting Abstracts - Systematics section.

Porter, J.M. and L.A. Johnson. 1998. Phylogenetic relationships of Polemoniaceae: inferences from mitochondrial *nad1h* intron sequences. Aliso 17:157-188.

Porter, J.M. and L.A. Johnson. 2000. A phylogenetic classification of Polemoniaceae. Aliso 19:55-91.

Porter, J.M. 2002. Personal communication with expert on the Polemoniaceae regarding *Gilia* (*Aliciella*) *sedifolia*.

Porter, J.M. 2003. Personal communication with expert on the Polemoniaceae regarding *Ipomopsis globularis*.

Porter, J.M., L.A. Johnson, and D. Wilken. 2003. Phylogenetics and systematics of *Ipomopsis* (Polemoniaceae) I: Phylogenetic estimates using chloroplast and nuclear DNA sequences. Manuscript to be published in Aliso. 62 pp.

Price, M.V. and N.M. Waser. 1998. Effects of experimental warming on plant reproductive phenology in a subalpine meadow. Ecology 79(4):1261-1271.

Pritchard, S.F. 1992. Roadside Summit the Human Landscape. Summit Historical Society, Summit County, Colorado.

Ray, J. 2001. Leadville milkvetch (*Astragalus molybdenus* Barneby) species status review. Unpublished report prepared by the Center for Native Ecosystems, Boulder, CO.

Redner, N. 2003. Personal communication with USDA Forest Service, Dillon Ranger District Botanist regarding *Ipomopsis globularis*.

Regier, K.F. 2003. Personal communication with M.S. Botanist, University of Colorado, Denver, regarding *Ipomopsis globularis*.

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

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

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

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

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

Spackman, S., D. Culver, and J. Sanderson. 2001a. Park County Inventory of Critical Biological Resources. Unpublished report prepared for Park County by the Colorado Natural Heritage Program, Fort Collins, CO.

Spackman, S.C., G. Doyle, and D.G. Anderson. 2001b. Visiting insect diversity and visitation rates for two globally-imperiled plant species in Colorado's Mosquito Range. Unpublished report prepared for the Native Plant Conservation Alliance, National Fish and Wildlife Foundation by the Colorado Natural Heritage Program, Fort Collins, CO.

Spackman, S., K. Fayette, D. Culver, K. Murrell, and M. Sherman. 1997a. Summit County Conservation Inventory Volume 1: A Natural Heritage Assessment. Unpublished report prepared for Summit County Open Space and Trails and Planning Departments by the Colorado Natural Heritage Program, Fort Collins, CO.

Spackman, S., B. Jennings, J.C. Dawson, M. Minton, A. Kratz, and C. Spurrier. 1997b. 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.

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

Stern, K.R. 1994. Introductory Plant Biology. Wm. C. Brown Publishers, Dubuque, IA.

Stohlgren, T. 2002. Personal communication regarding upcoming research projects involving rare plant and noxious weed distribution and habitat modeling.

Stohlgren, T.J., D.T. Barnett, and J.T. Kartesz. 2003. The rich get richer: patterns of plant invasions in the United States. Frontiers in Ecology and the Environment 1:11-14.

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

Turk, J.T., H.E. Taylor, G.P. Ingersoll, K.A. Tonnessen, D.W. Clow, M.A. Mast, D.H. Campbell, and J.M. Melack. 2001. Major-ion chemistry of the Rocky Mountain snowpack, USA. Atmospheric Environment 35:3957-3966.

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

USDA Forest Service Region 2. 2002. What is a sensitive species? USDA Forest Service, Rocky Mountain Region. Accessed via the World Wide Web at: http://www.fs.fed.us/r2/nebraska/gpng/sensitive.html.

USDA Forest Service White River National Forest. 2002. USDA Forest Service, Rocky Mountain Region, White River National Forest, Final environmental impact statement to accompany the land and resource management plant-2002 revision. Provided in CD format by the USFS. USDA Forest Service, White River National Forest, Glenwood Springs, CO.

USDA Natural Resource Conservation Service. 2003. The PLANTS Database, Version 3.5 (http://plants.usda.gov). National Plant Data Center, Baton Rouge, LA 70874-4490.

USDI Fish and Wildlife Service. 1999. List of endangered and threatened plants. Federal Register Section 17.12:38-55.

USDI Fish and Wildlife Service. 2002. Holy Ghost Ipomopsis (*Ipomopsis sancti-spiritus*) Recovery Plan. U.S. Fish and Wildlife Service, Albuquerque, NM.

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.

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

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

Waser, N.M. and M.V. Price. 1989. Optimal Outcrossing in *Ipomopsis aggregata* - Seed Set and Offspring Fitness. Evolution 43:1097-1109.

Weber, W.A. 1966. Additions to the Flora of Colorado IV. University of Colorado Studies, Series in Biology No. 23. University of Colorado Press, Boulder, CO.

Weber, W.A. and R.L. Wittmann. 1992. Catalog of the Colorado Flora. University Press of Colorado, Niwot, CO.

Weber, W.A. and R.C. Wittmann. 2001. Colorado Flora: Eastern Slope. University Press of Colorado, Niwot, CO.

Western Regional Climate Center. 2003. Monthly Climate Summary for Climax, Colorado. Accessed via the World Wide Web at http://www.wrcc.dri.edu.

Wheeler, J. 1991. Seed and seedling ecology of *Eriastrum densifolium* ssp. *sanctorum*, and endangered floodplain endemic. M.A. Thesis. California State University, Fullerton, CA.

Wigley, T.M.L. and Raper, S.C.B. 1992. Implications for climate and sea level of revised IPCC emissions scenarios. Nature 357:293-300.

Wilken, D. 1995. Letter to Christine Collins regarding *Ipomopsis polyantha* dated August 25, 1995.

Wilken, D. 2004. Personal communication with Vice-President for Conservation, Education, and Research at the Santa Barbara Botanic Garden regarding the genus *Ipomposis*.

Wilken, D. and R.L. Hartman. 1991. A revision of the *Ipomopsis spicata* complex (Polemoniaceae). Systematic Botany 16(1):143-161.

Willard, B.E. and J.W. Marr. 1971. Recovery of alpine tundra under protection after damage by human activities in the Rocky Mountains of Colorado. Biological Conservation 3 (3):181-190.

Williams, M.W, P.D. Brooks, and T. Seasteadt. 1998. Nitrogen and carbon soil dynamics in response to climate change in a high elevation ecosystem in the Rocky Mountains, USA. Arctic and Alpine Research 30 (1):26-30.

Wolf, P.G., D.R. Campbell, N.M. Waser, S.D. Sipes, T.R. Toler, and J.K. Archibald. 2001. Tests of pre- and post-pollination barriers to hybridization between sympatric species of *Ipomopsis* (Polemoniaceae). American Journal of Botany 88:213-219.

Wolf, P.G., R.A. Murray, and S.D. Sipes. 1997. Species-independent, geographical structuring of chloroplast DNA haplotypes in a montane herb *Ipomopsis* (Polemoniaceae). Molecular Ecology 6:283-291.

Wolf, P.G. and P.S. Soltis. 1992. Estimates of gene flow among populations, geographic races, and species in the *Ipomopsis aggregata* complex. Genetics 130:639-647.

Wolf, P.G., P.S. Soltis, and D.E. Soltis. 1993. Phylogenetic significance of chloroplast DNA restriction site variation in the *Ipomopsis aggregata* complex and related species (Polemoniaceae). Systematic Botany 18:652-662.

Yeatts, L. 2003. Personal communication with Rock Garden Society Member, Photographer and Botanist regarding *Ipomopsis globularis*.

Zomlefer, W. 1994. Guide to Flowering Plant Families. University of North Carolina Press, Chapel Hill, NC.