Visiting insect diversity and visitation rates for two globally-imperiled plant species in Colorado's Mosquito Range

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Abstract

Ipomopsis globularis (Globe gilia), and *Saussurea weberi* (Weber's saussurea) are globally imperiled plant species known only from geographically restricted areas in alpine habitats of the Rocky Mountains. These species were observed in the Mosquito Range of Colorado to determine the diversity of insect visitors (potential pollinators) and approximate insect visitation rates. *Ipomopsis globularis* was visited primarily by fly and ant species; and in general, the insects visited at a rate of about 0.83 visits/open corolla/30 minutes. *Saussurea weberi* was visited primarily by flies, and also by bees, supporting the research of Abbott (1998). *S. weberi* was observed to have an insect visitation rate of about 0.14 visits/open corolla/30 minutes. Rare, geographically restricted species are particularly susceptible to human disturbances that would reduce the frequency and/or diversity of potential pollinator visits. Management plans for these plant species should consider the ecology of associated insect visitors, which may play an important role in their pollination ecology. Further information is needed before thorough conservation strategies can be developed.

Introduction

The purpose of this study was to identify insect visitors (potential pollinators) and insect visitation rates for two globally imperiled plant species, *Ipomopsis globularis* (Brand) W.A. Weber (Globe gilia) and *Saussurea weberi* Hulten (Weber's saussurea), so that management of these species could take insect relationships into account. *Ipomopsis globularis* is known only from the Mosquito Range of central Colorado (Figure 1). *Saussurea weberi* is only known from very geographically restricted areas in SW Montana (one location in the Anaconda Range), west central Wyoming (in the Wind River Range) and central Colorado (in the Mosquito Range). Our research took place in the Mosquito Range of Colorado during the summer of 2000.

The Mosquito Range has an unusually high degree of plant endemism, supporting fifteen globally imperiled plant species, three of which are endemic to this range. The Mosquitos also support seventeen state-imperiled plant species, many of which are disjunct from the northern United States and Canada (Colorado Natural Heritage Program 2001, Table 1). The level of protection, management, and research focused on the Mosquito Range is much less than its global significance warrents. With five of Colorado's popular 14,000-foot peaks, potential threats of recreational overuse of the range are amplified by its close proximity to Denver and the rapidly growing Front Range. Considerable resource damage is occurring in the Mosquito Range with increasing recreational uses, especially hiking, mountain biking, and off-road vehicle use. Erosion and vegetation loss have escalated, especially in the past 10 years, and threaten the ecological integrity of this area. In addition, this area has a history of extensive mining, which has fragmented and degraded the alpine systems, and unexplored mining claims are pervasive. Although the current level of mining is not extensive, increases in mining activity could result in species extirpation or extinction.

Appropriate management practices are difficult to determine because so little is known about the biology of the imperiled plant species. In particular, the reproductive biology of the plants is not understood, nor how these species are pollinated. Since viability is a key factor in the selection of conservation priorities and management strategies, an understanding of primary ecological and biological requirements is necessary.

Only one other study has investigated the pollinators for any of the globally imperiled plants in the Mosquito Range. Abbott (1998) investigated pollinator relationships for *Saussurea weberi* and reported bees as the primary pollinator of this species. Abbott made a very strong contribution to our knowledge of this species by showing that *Bombus frigidus* and *Bombus sylvicola* were the primary visitors to *Saussurea weberi* at Horseshoe Cirque in the Mosquito Range, and that these bee species carry pollen and effectively cross pollinate *S. weberi*. Research on the pollination ecology of *Ipomopsis globularis* had not been conducted prior to the present study.

Study area

The Mosquito Range of Colorado is a relatively small mountain range, approximately 20 miles long and 5 miles wide. Despite its small area, the Range includes lands managed by three Ranger Districts of two National Forests, the Pike and the San Isabel. The Range also includes numerous private inholdings, and falls into three Colorado counties: Summit, Park, and Lake. The Mosquito Range is in central Colorado, and in the center of the southern Rocky Mountain Ecoregion (Bailey 1994).

The unusual ecological characteristics of the Mosquito Range make it home to plants that are found nowhere else in the world. The rare and endemic plants are found primarily on soils derived from limestone, dolomite, or other carbonate rock substrates (Naumann 1988, Spackman *et al*. 1997). Limestone bedrock in a high elevation setting is relatively rare in the Rocky Mountains. Table 1 presents a list of all of the rare and endemic plant species known from the Mosquito Range.

Given the rich floral diversity and the high level of threats, the Mosquito Range is identified by the Colorado Rare Plant Technical Committee as one of the top ten areas of the state needing conservation action. The committee represents forty-three public and private entities.

We chose four specific sites in the Mosquito Range for this study: one at the northern end of the Range (Boreas Pass), one at the southern end (Weston Pass), and two in the center of the Range (North Star Mountain and Horseshoe Cirque). Figure 1 presents a map of the Mosquito Range and the four sites monitored for insect visitation. We selected the specific study sites subjectively, based primarily on the following criteria: distribution within the Mosquito Range, site accessibility, and density of flowers.

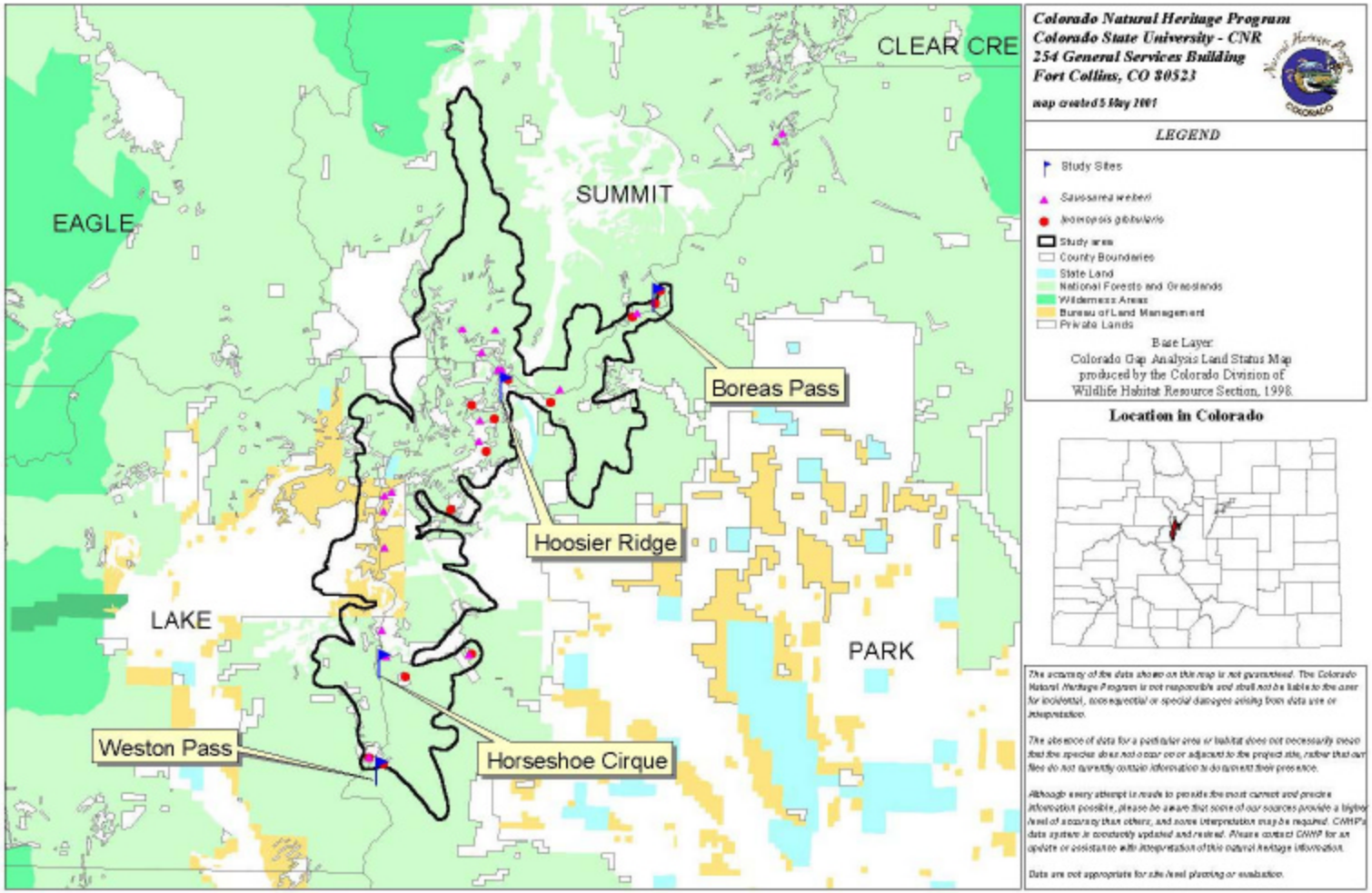

Figure 1. The Mosquito Range of Colorado, including the Tenmile Range, and Boreas Pass to Weston Pass. This map also shows the four sites for the insect diversity and visitation rate study, the full global distribution for Ipomopsis globularis, and the full statewide distribution for Saussurea weberi.

Species descriptions

Ipomopis globularis (globe gilia), known only from the Mosquito Range of Colorado, is a showy, alpine member of the Polemoniaceae. This species stands about 10-20 cm tall and supports a globose inflorescence with fragrant white to pale purple flowers. This species is found above treeline in gravelly, calcareous soils. *Ipomopsis globularis* is considered to be imperiled throughout its range (G2) by the Natural Heritage Network (Association for Biodiversity Information 2001), and is included on the National Forest Service list of sensitive species for Region 2. Figure 1 shows the full global distribution of this species. Figures 2 and 3 present photographs of *Ipomopsis globularis* and its habitat in the Mosquito Range.

Figure 2. *Ipomopsis globularis*

Figure 3. *Ipomopsis globularis*

Saussurea weberi (Weber's saussurea) is a purple flowered member of the Asteraceae. The plants stand about 8-20 cm tall and support an inflorescence of purple disk flowers with purple stamens and long plumose pappus bristles. Ray flowers are absent. Abbott (1998) found this species to be an obligate outcrosser, and noted that the flowers have a subtle skunky-sweet fragrance. *Saussurea weberi* is found above treeline in soils derived from limestone or dolomite within a limited distribution in W Montana, NW Wyoming, and C Colorado (Montana Natural Heritage Program 2001, Wyoming Natural Diversity Database 2001, Colorado Natural Heritage Program 2001). It is the only member of the genus *Saussurea* found in Colorado (Weber and Wittmann 1996). *Saussurea weberi* is considered to be imperiled throughout its range (G2G3) by the Natural Heritage Network (Association for Biodiversity Information 2001); however, it is not included on the U.S. Forest Service sensitive species list. Figure 1 shows the full distribution of this species in Colorado. Figures 4 and 5 present photographs of *Saussurea weberi* and its habitat in the Mosquito Range.

Figure 4. *Saussurea weberi*

Figure 5. *Saussurea weberi*

Methods

Rare Plant Inventory and Assessments

A team of Colorado Natural Heritage Program and Colorado Native Plant Society botanists searched alpine areas of the Mosquito Range during the short flowering period to map and document the location and condition of distinct populations of *Ipomopsis globularis* and *Saussurea weberi*. We gathered data on other globally and state-imperiled plant species that are also known from this area as time permitted.

Field surveys took place in July and August of 2000, and were conducted by hiking through each inventory area, inspecting typical habitat as well as unusual edaphic or topographic features (e.g., rock outcrops, moist depressions, etc.).

During the field surveys, as we found new locations for any of the plant species of concern (Table 1), we recorded habitat information including precise location, size of area, associated species, substrate, slope, aspect, percent vegetation cover, and levels of natural and human disturbance. We recorded population information including approximate number of individuals, approximate density of individuals, evidence of reproductive success, and evidence of natural or human induced threats.

We entered all data into the Biological Conservation Database with the Colorado Natural Heritage Program at Colorado State University.

Table 1. Plants of concern known from the Mosquito Range of Colorado. Species in bold are endemic to the Mosquito Range. Species ranked G1-3 are globally imperiled. Species ranked G5 or G4 and S1 or S2 are found in the Mosquito Range in populations that are disjunct from the primary part of the species range. Explanation of ranks and status are included in Appendix 3. Species are listed in approximate order of imperilment.

Scientific Name	Common Name	Global Rank	State Rank	Federal Status
Draba weberi	**Weber's draba**	**G1**	**S1**	
Eutrema penlandii	**Penland alpine fen mustard**	**G1G2**	**S1S2**	
Botrychium pallidum	Pale moonwort	G2	S2	FS
Ipomopsis globularis	**Globe gilia**	**G2**	**S2**	
Draba exunguiculata	Clawless draba	G2	S2	
Botrychium echo	Reflected moonwort	G2	S2	FS
Draba grayana	Gray's Peak whitlow-grass	G2	S2	
Physaria alpina	Avery Peak twinpod	G2	S2	
Ptilagrostis porteri	Porter feathergrass	G2	S2	FS
Machaeranthera coloradoensis	Colorado tansy-aster	G2?	S2	FS
Astragalus molybdenus	Molybdenum milk-vetch	G3	S2	FS
Saussurea weberi	Weber's saw-wort	G3	S2	BLM
Draba streptobrachia	Colorado divide whitlow-grass	G3	S3	
Aquilegia saximontana	Rocky Mountain columbine	G3	S3	
Draba porsildii	Porsild's whitlow-grass	G3G4	S1	
Scirpus rollandii	Rolland bulrush	G3Q	S2	FS
Braya humilis	Low braya	G4	S2	
Parnassia kotzebuei	Kotzebue's grass-of-parnassus	G4	S2	

Draba borealis	Boreal whitlow-grass	G4	S2	
Draba fladnizensis	White arctic whitlow-grass	G4	S2S3	
Ranunculus karelinii	Ice cold buttercup	G4G5	S2	
Eriophorum altaicum var. *neogaeum*	Altai cotton-grass	G4T?	S3	FS
Salix lanata ssp *calcicola*	Lanate willow	G4T4	S1	FS
Draba lonchocarpa var. *lonchocarpa*	Lance-pod whitlowgrass	G4T4	S2	
Draba incerta	Yellowstone whitlow-grass	G5	S1	
Oxytropis parryi	Parry's crazy-weed	G5	S1	
Crepis nana	Dwarf alpine hawksbeard	G5	S2	
Draba oligosperma	Few-seeded whitlow-grass	G5	S2	
Phippsia algida	Ice grass	G5	S2	
Botrychium lunaria	Moonwort grape-fern	G5	S2S3	
Papaver radicatum ssp. *kluanense*	Alpine poppy	G5T3?	S3	
Armeria maritima ssp. *sibirica*	Sea pink	G5T5	S1	FS

Measuring visiting insect diversity

Following the methods of McMullen (1998) we conducted a visiting insect diversity study to identify insect visitors that may be responsible for pollinating the plants. For each plant species, we spent approximately one hour observing and collecting the insects that visited the flowers. These one-hour collection periods were repeated as weather permitted, twice each day, once in the morning and once in the afternoon, spaced as much as possible throughout the flowering period. A visit was defined as physical contact with any part of an open flower. Insects that visited the flowers were collected with a standard insect net and killed in a cyanide jar. During each collection period the following information was recorded: date, time of day, specific location, air temperature, approximate wind speed, and percent cloud cover. Voucher specimens of insect visitors were identified by Drs. Boris Kondratieff, Paul Opler, and Howard Evans, and were deposited at the Colorado State University C.P. Gillette Museum of Arthropod Diversity. Insect nomenclature follows Poole and Gentili (1996).

Measuring insect visitation rates

To determine insect visitation rates, we spent 30 minutes counting the number of insect visits to a group of flowers. Each observer watched one or more plants and noted the total number of open corollas observed. The number of open corollas observed by one observer ranged widely, from 20-385 corollas, depending on the size, distribution, and phenological stage of the plants. We gathered the information to calculate: # visits/ # of open corollas/ 30-minute period. This was repeated as weather permitted, three times each day, at regular intervals spaced throughout the day as much as possible throughout the flowering period. During each observation period the following information was recorded: date, time of day, specific location, air temperature, approximate wind speed, and percent cloud cover. No insects were collected during these observation periods.

Due to harsh alpine conditions and accessibility, our pollination study was primarily limited to daytime pollinators. We conducted one 30-minute after-dark observation/collection on *Ipomopsis globularis* at North Star Mountain.

Figure 6. Volunteer collecting visiting insects

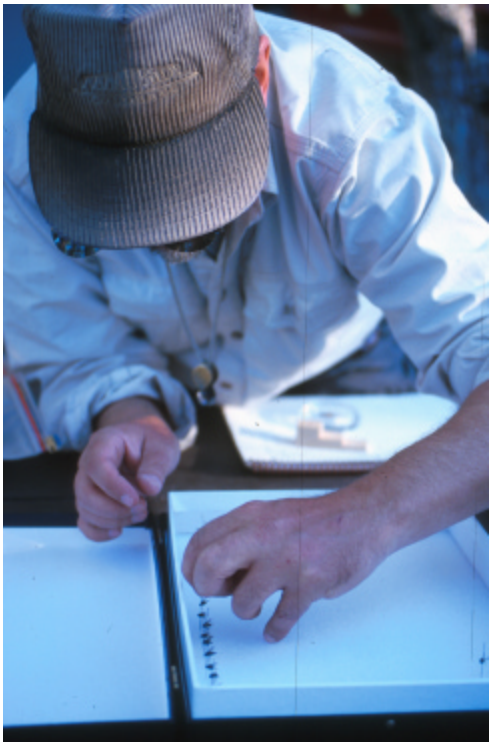

Figure 7. Volunteer pinning insect specimens

Results

Rare plant assessments

Overall, the population size, condition, and landscape context have not changed significantly in any of the occurrences visited in this study relative to information available from previous years (Colorado Natural Heritage Program 2000). All occurrences appeared to support robust, healthy plants, and showed a mix of size classes. We were concerned, however, about the level of habitat fragmentation and habitat degradation found within and adjacent to the occurrences resulting from various recreational uses, especially off-road vehicle use and historical mining activities.

During the course of our research, ten other rare plant records were created or updated for specific locations of *Physaria alpina* Rollins, *Eutrema penlandii* Rollins, *Askellia nana* (Richardson) Weber, *Draba crassa* Rydberg, *Draba weberi* Price & Rollins, *Ptilagrostis porteri* (Rydberg) Weber, *Eriophorum altaicum* var. *neogaeum* Raymond, and *Salix lanata* ssp. *calcicola* (Wiegand) Hulten.

Insect diversity and visitation rates

Ipomopsis globularis

We spent a total of 21.5 hours collecting insects that visited *Ipomopsis globularis* at three study sites, Weston Pass, North Star Mountain, and Boreas Pass, and collected a total of 81 insects (Table 2). Of the 81 collected, well over half (52) were flies (50 of which were *Thricops villicrura* Coquillet), and nearly a quarter (19) were ants (all *Formica neorufibaris gelida* Wheeler.) Similar insect visitor assemblages were found at each location. *Thricops villicrura* and *Formica neorufibaris gelida* were the dominant visitors at all three sites. Other visiting taxa to *Ipomopsis globularis* included several hemipteran species, a wasp species (*Agathis* sp.), and a moth species (*Lasionycta impingens* Walker.) We collected one moth individual during the after-dark observation period. Although not collected, we observed a species of *Bombus* visiting *Ipomopsis globularis* at the North Star Mountain site.

We collected a total of 13 insects (9 species) at the Weston Pass site that were observed in the alpine study areas but were not observed visiting *Ipomopsis globularis* (Table 3). Although we did not collect insects that were not visiting the rare plants at the other two sites, a similar suite of insects was observed at all of the sites. The collection of *Entomoscelis americana* Brown was the second collection of this species for the Colorado State University C.P. Gillette Museum of Arthropod Diversity.

Table 2. Insects collected during visitation to *Ipomopsis globularis* at three sites in the Mosquito Range of Colorado. Numbers indicate the total number of individuals collected. Research on *Ipomopis globularis* was not conducted at Horseshoe Cirque.

Taxon	Weston Pass	North Star	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 *Lygaeus kalmii* Stal	2		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	

Table 3. List of insects observed that did not visit *Ipomopsis globularis* during the observation periods (collected at the Weston Pass site).

Order: Coleoptera (beetles)
Family: Chrysomelidae
Entomoscelis americana Brown
Family: Carabidae
Carabus taedatus Fabricus

Order: Diptera (flies)
Family: Tephritidae
Paroxyna variabilis (Doane)

Order: Homoptera (leafhoppers)
Family: Cicadellidae

Order: Hymenoptera (bees, wasps, ants)
Family: Apidae
Bombus melanopyge Nylander
Bombus sylvicola Kirby

Family: Braconidae
Agathis sp.

Order: Lepidoptera (butterflies and moths)
Family: Papilionidae
Parnassius smintheos
Family: Pterophoridae
Paraplatyptilia xylopsamma Meyrick
Family: Satyridae
Erebia callias Edwards

Order: Orthoptera (grasshoppers and crickets)
Family: Acrididae

We made a total of 21 30-minute visitation rate observations for *Ipomopsis globularis*. These observations showed that *Ipomopsis globularis* appears to be visited primarily by flies, at an average rate of 0.5 fly visits/open corolla/30 minutes (0-1.85 fly visits/open corolla/30 minutes, n=21), and by ants, at an average rate of 0.3 ant visits/open corolla/30 minutes (0-2.62 ant visits/open corolla/30 minutes, n=21) (Figure 8). All other insects combined visited at an average rate of 0.02 visits/open corolla/30 minutes (0-0.19 visits/open corolla/30 minutes, n=21). The total average visitation rate for all of the insects that visited *Ipomopsis globularis*, including flies and ants, was 0.83 visits/open corolla/30 minutes.

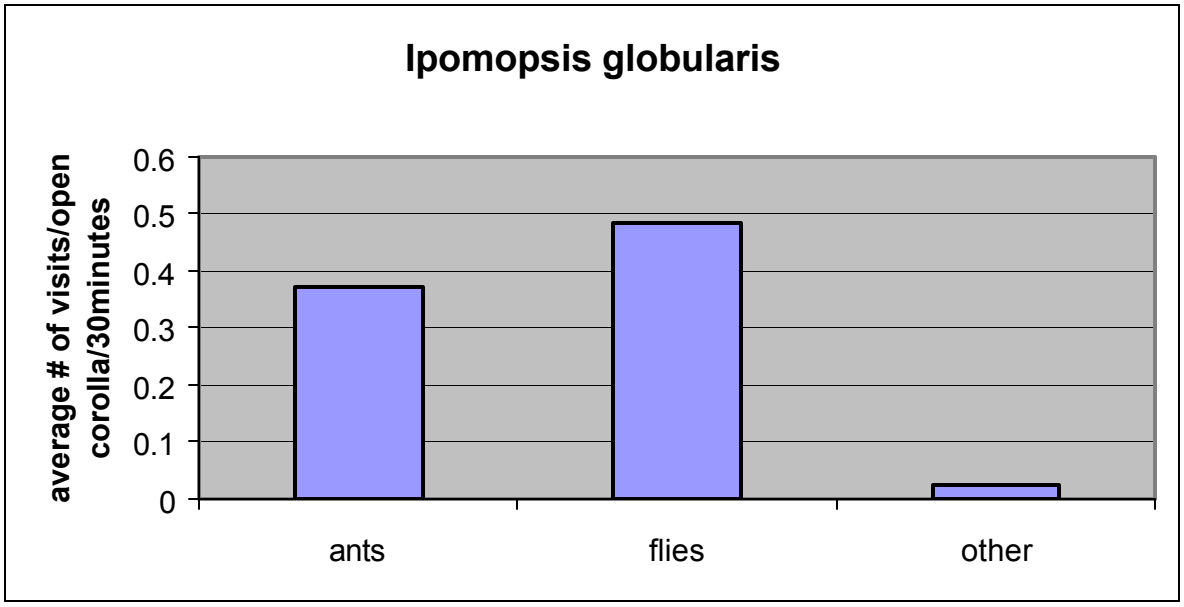

Figure 8. Average number of ant, fly, and other insect visits per open *Ipomopsis globularis* corolla during 30 minute observation periods at three study sites in Colorado's Mosquito Range: Weston Pass, North Star Mountain, and Boreas Pass. The total number of 30 minute observations was 21. Fly visits varied from 0-1.85 visits/open corolla/30 minutes. Ant visits varied from 0-2.6 visits, and other insects varied from 0-0.19 visits.

Observations of insect visitor behavior showed ants probing the flowers with their heads and also completely entering the flowers of *Ipomopsis globularis*. The ants would literally disappear inside of the flowers and they were observed to stay inside individual flowers for up to ten minutes. Flies spent long periods of time (up to 15 minutes) at one inflorescence moving from one flower to the next. Flies on *Ipomopsis globularis* were observed to put their mouth parts and legs into the flowers.

Saussurea weberi

We spent a total of 13 hours collecting insects that visited *Saussurea weberi* at two study sites, Horseshoe Cirque and North Star Mountain (Table 4), and collected a total of 69 insects. Of the 69 collected, over 75% (53) were flies (order Diptera). At least six Diptera species were represented from three different families, but the most common of the Diptera collected were *Thricops villicrura* Coquillet and *Pegoplata* species. The next most commonly collected insect visitors to *Saussurea weberi* were bees (11 individuals representing four species of *Bombus*). Although fairly common, bees represented only about 16% of the insects collected. Other visiting taxa included five individuals from the genus *Lygus* in the family Miridae (Hemiptera). Insect visitor assemblages at the two different locations were closely comparable given that more time was spent collecting at North Star Mountain (9 hours) than Horseshoe Cirque (4 hours).

We made a total of 17 30-minute visitation rate observations for *Saussurea weberi*. These observations showed that *Saussurea weberi* appears to be visited primarily by flies, at an average rate of 0.08 fly visits/open corolla/30 minutes (0-0.52 fly visits/open corolla/30 minutes, n=17) (Figure 9). Bees visited this species at an average rate of 0.015 visits/open corolla/30 minutes (0-0.22 bee visits/open corolla/30 minutes, n=17), and all other insects combined visited at an average rate of 0.047 visits (0-0.50 visits/open corolla/30 minutes. The total average visitation rate for all of the insects that visited *Saussurea weberi*, including flies and bees, was 0.14 visits/open corolla/30 minutes.

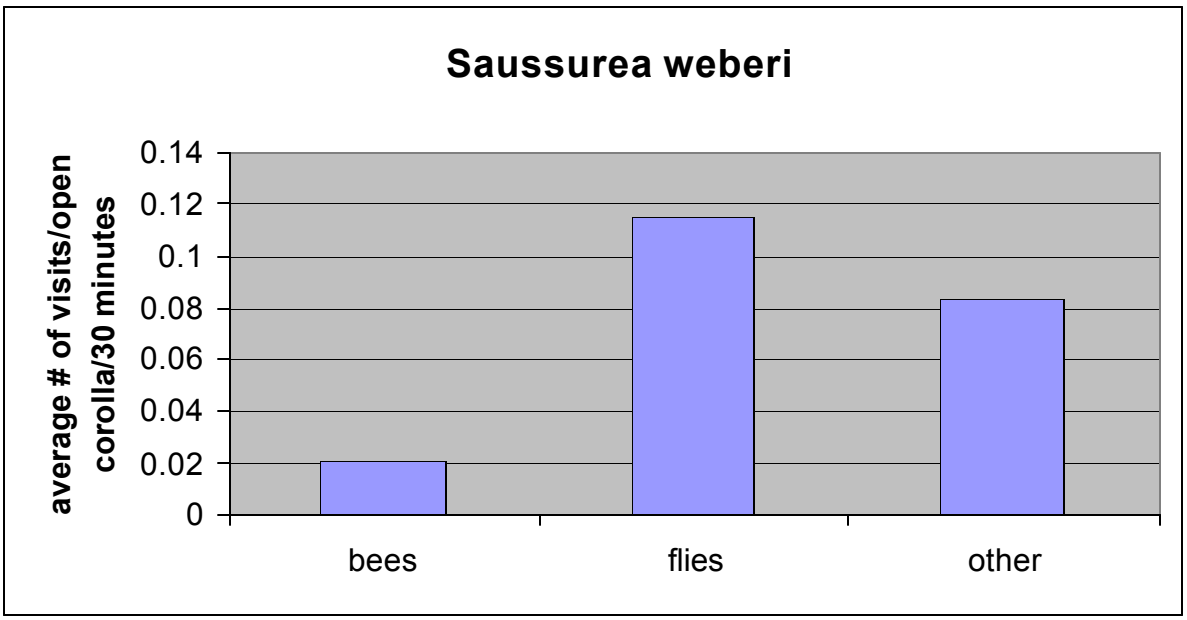

Figure 9. Average number of bee, fly, and other insect visits per open *Saussurea weberi* corolla during 30 minute observation periods at two study sites in Colorado's Mosquito Range: Horseshoe Cirque and North Star Mountain. The total number of 30 minute observations was 17. Bee visits varied from 0-0.22 visits/open corolla/30 minutes. Fly visits varied from 0-0.52 visits, and other insects varied from 0-0.5 visits.

Observations of visitor behavior showed that flies spent long periods of time (up to 7 minutes) at one inflorescence moving from one flower to the next. Pollen was not observed on any of the insects except for the species of *Bombus*, and it is not certain that the pollen observed was from *Saussurea weberi.* Pollen analysis on the *Bombus* collected was beyond the scope of this study.

Table 4. Insects collected during visitation to *Saussurea weberi* at two sites in the Mosquito Range of Colorado. Numbers indicate the total number of individuals collected.

Taxon	Horseshoe Cirque	North Star
Order: Diptera (flies)		
Family Anthomiidae		
Pegoplata spp.	2	17
Genus and species not determined	1	4
Family: Dolichopodidae		
Mesorhaga sp.		1
Family: Empididae		
Rhamphomyia spp.		2
Family: Muscidae		
Thricops villicrura Coquillett	4	20
Genus and species not determined		2
Order: Hemiptera (true bugs)		
Family: Miridae		
Lygus sp.	2	3
Order: Hymenoptera (bees, wasps, ants)		
Family: Apidae		
Bombus flavifrons Cresson		1
Bombus frigidus Sm.		6
Bombus melanopyges Nylander		1
Bombus sylvicola Kirby	2	1

Discussion

Although specific pollinators cannot be definitively determined with the results of this study, our results suggest important plant-insect relationships. *Ipomposis globularis* was primarily visited by flies and ants, and *Saussurea weberi* was visited primarily by flies and bees. Although all of the insects collected are potential pollen carriers, flies and bees are the most likely pollinators because they have been shown to be effective pollinators in numerous studies in the past (F◈gri and van der Pijl 1979), and they were the most common visitors to the rare plants.

Pollination by ants is possible, though it is very rare and unlikely (Hickman 1974, F◈gri and van der Pijl 1979, Beattie *et al*. 1984). Ant pollination is unlikely for several reasons: ants naturally secrete antibiotics that inhibit pollen function (Beattie *et al*. 1984), pollen is less likely to adhere to the ants' smooth body parts, and pollen carrying capacity is further reduced by frequent grooming (Peakall *et al*. 1991).

Insect visitors could also have a detrimental effect on the plants. Abbott (1998) reported predation upon fruit and seeds of *Saussurea weberi* by larval stages (maggots) of two species of *Botanophila* (flies). This genus was not noted in the present study. Ants and other insects could be seed predators, and/or nectar theives (F◈gri and van der Pijl 1979, Westoby *et al*. 1991). Ants were noted in this study to completely enter the flowers of *Ipomopsis globularis.* It is likely that this resulted in some benefit to the ants, by providing shelter from wind and rain; but any benefit or detriment to the plants is uncertain.

All of the ants collected during this study were *Formica neorufibaris gelida.* This is the most cold-tolerant ant subspecies of Colorado, and is known commonly from a high latitudinal and altitudinal range across the North American continent (Gregg 1963). *Formica neorufibaris gelida* was observed in this study to form colonies in gravelly soils within the habitat of *Ipomopsis globularis.* This ant subspecies is also known to use a number of other substrates such as clay, loam, rocks, wood, and decaying logs.

Flies were found to be common visitors to both *Ipomopsis globularis* and *Saussurea weberi*, and were observed spending long periods of time at the flowers, potentially effecting pollination. Although flies are known to be effective pollinators, they are also thought to be irregular and unreliable pollinators because they do not gather food to feed their young, and generally utilize many different sources of food (F◈gri and van der Pijl 1979). Flies were particularly common visitors to *Ipomopsis globularis*. The flowers of this species are light purple to purplish brown just after the peak of anthesis, and have a slightly skunky, sweet fragrance. Although the specific chemical compounds creating the floral scent is not known, F◈gri and van der Pijl (1979) note that flies are attracted to flowers with purplish brown hues when the flowers have a decaying protein odor.

Although bees were not found to visit *Saussurea weberi* at a very high rate (0.015 bee visits/open corolla/30 minutes), it is remarkable that four species of *Bombus* were observed visiting the flowers (Table 4). Because most species of *Bombus* in Colorado are ground nesters (Byron 1980) it is not surprising that a high level of species richness would be found in alpine areas where open areas of bare ground are abundant. Abbott (1998) also identified *Bombus* as an important associate of *Saussurea weberi.* During his two-year study at Horseshoe Cirque in the Mosquito Range, Abbott noted just two species of *Bombus*, *B. frigidus* and *B. sylvicola*.

For plant species that require insect interaction for pollination, insect visitation rates are important because the visitation rate affects the overall likelihood of effective pollination (Kearns and Inouye 1993). For insects, the visitation rate is important to their overall success in terms of energy intake and expenditure.

An appropriate insect visitation rate is not known for either of the plant species studied. Without additional information about how much pollen is being carried by the insect visitors and whether or not they are truly affecting pollination, we can only speculate about the overall rate of insect visitation that would be adequate to support the long term viability of the plant species. During our research we observed that the plant populations for both species appeared to include a healthy mix of size classes. It therefore seems that the current visitation rates for *Ipomopsis globularis* (total of 0.83 visits/open corolla/30 minutes) and *Saussurea weberi* (total of 0.14 visits/open corolla/30 minutes) are high enough to assure effective pollination of these species. Further research is warranted to increase our confidence that this is the case. We hope that the results of this study provide effective baseline data from which this question can be more fully evaluated in the future. If the insect visitation rates falls over time, this may be a preliminary indication that the reproductive system of the plant species is being compromised. It should be noted however, that visitation rates can quickly respond to subtle

changes such as microclimate (Kearns and Inouye 1993), which may not be problematic to the plant-insect relationship.

Numerous insects were identified in the rare plant habitat that were not visiting the rare plants (Table 3). This suggests that the rare plants are attracting certain members of the local insect fauna, and not others.

It is likely that most, if not all, of the insects observed are common species to the region. Because there has not been much collecting at high elevations in Colorado, the insects are not well known, but are not necessarily rare (pers. comm. Kondratieff 2001).

For the most part, the specific plant locations were found to be weed free. *Matricria perforata* (Wild camomile) was noted along the road at the North Star Mountain site in very low percent cover. Weeds could present a problem not only by competing with the rare plants for space, sunlight, soil moisture, etc., but also by competing with the rare plant for pollinators (Simonson *et al.* 2001), which could result in the rare plants receiving inadequate pollination.

Management Implications

Information about insect visitors to *Ipomopsis globularis* and *Saussurea weberi* contributes to important regional conservation planning efforts. Rare, geographically restricted species are particularly susceptible to human disturbances that would reduce the frequency and/or diversity of potential pollinator visits. Management plans for these plant species should consider the ecology of associated insect visitors, which may play an important role in their pollination ecology. For example, species of *Bombus* may nest in abandoned rodent burrows (Byron 1980). Recreational uses such as hiking, mountain biking, and off-road vehicle use, as well as mining and grazing, may cause these burrows to collapse. As another example, because insects are likely to rely on more than just one plant species through their lifecycle, attention must be paid to the full ecosystem in which the rare plants and associated insects are found.

Pollinator abundance and diversity are known to decline as a result of habitat fragmentation (Rathcke and Jules 1993, Buchmann and Nabhan 1996). When patch size becomes too small, pollinators may go elsewhere for suitable resources. As patches become too isolated, gene flow may be reduced and result in problems associated with inbreeding depression (Buchmann and Nabhan 1996). Researchers warn that it is the ecological interactions that could become extinct before the species within the relationship are lost. In fact, most models predict a 50-400 year time lag before habitat fragmentation results in extirpations or extinctions (Buchmann and Nabhan 1996). The potential consequences of pollinator declines need to be considered in regional conservation strategies for *Ipomopsis globularis* and *Saussurea weberi*. While the Mosquito Range has experienced and continues to experience a great deal of habitat fragmentation, there are significant portions of the range that are intact and could benefit from long-term protection strategies.

During this study we observed new off-road vehicle tracks carving paths through the habitat of *Ipomopsis gloularis* and *Saussurea weberi*. We contacted land managers with the US Forest Service about this resource management issue.

Recommendations for further research and conservation actions

Additional research is warranted to better understand the biology and ecology of these rare plants. Further elucidation of the reproductive ecology and plant-insect relationships of *Ipomopsis globularis* and *Saussurea weberi* could be gained with species-specific studies on pollen flow, nutritional content of nectar and seeds, seed set and seedling recruitment success, impacts of seed predation, and the possibility of ant pollination. We recommend expanding this research to additional study sites to better understand the species throughout their ranges to gain a broader perspective on each species as a whole. Also, research should be expanded over time, as there may be annual variation to insect visitors as a result of varying annual and seasonal weather patterns. Nocturnal studies could provide important information about after-dark insect visitors. A monitoring program designed to detect changes in the plant populations, insect populations, and plant-insect relationships would benefit our ability to protect these species and their alpine ecosystems.

Further inventory is necessary to gain a more complete picture of the full distribution of *Ipomopsis globularis* and *Saussurea weberi*. Habitat inaccessibility and lack of funding has prohibited a thorough search to date. Site-specific threats to the species should be noted along with other population and habitat data.

Currently, the only solid protection afforded *Ipomopsis globularis* and *Saussurea weberi* is the 1025-acre Hoosier Ridge Research Natural Area. Protection efforts for these species, as well as the numerous other imperiled species in the Mosquito Range, is complicated by the complexity of land ownership and land management patterns, including lands managed by three Ranger Districts of two National Forests, numerous private inholdings, and three Colorado counties. Nonetheless, the US Forest Service is responsible for management of the vast majority of the ecosystem that supports these imperiled species, and we hope that the results of this study will directly contribute to the development of a multi-forest Threatened, Endangered, and Sensitive (TES) Plant strategy. Further, we hope that the information collected through this research will be used to examine issues related to recreation management, land allocations, restoration, and conservation planning for all of the imperiled species and ecological systems of the Mosquito Range.

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Appendix 1- The Natural Heritage Network and Methodology

Colorado is well known for its rich diversity of geography, wildlife, plants, and plant communities. However, like many other states, it is experiencing a loss of much of its flora and fauna. This decline in biodiversity is a global trend resulting from human population growth, land development, and subsequent habitat loss. Globally, the loss in species diversity has become so rapid and severe that Wilson (1988) has compared the phenomenon to the great natural catastrophes at the end of the Paleozoic and Mesozoic eras.

The need to address this loss in biodiversity has been recognized for decades in the scientific community. However, many conservation efforts made in this country were not based upon preserving biodiversity; instead, they primarily focused on preserving game animals, striking scenery, and locally favorite open spaces. To address the absence of a methodical, scientifically-based approach to preserving biodiversity, Dr. Robert Jenkins, in association with The Nature Conservancy, developed the Natural Heritage Methodology in 1978.

Recognizing that rare and imperiled species are more likely to become extinct than common ones, the Natural Heritage Methodology ranks species according to their rarity or degree of imperilment. The ranking system is scientifically based upon the number of known locations of the species as well as its biology and known threats. By ranking the relative rareness or imperilment of a species, the quality of its populations, and the importance of associated Potential Conservation Areas, the methodology can facilitate the prioritization of conservation efforts so the most rare and imperiled species may be preserved first. As the scientific community began to realize that plant communities are equally important as individual species, this methodology has also been applied to ranking and preserving rare plant communities, as well as the best examples of common communities.

The Natural Heritage Methodology is used by Natural Heritage Programs throughout North, Central, and South America, forming an international database network. Natural Heritage Network data centers are located in each of the 50 U.S. states, five provinces of Canada, and 13 countries in South and Central America and the Caribbean. This network enables scientists to monitor the status of species from a state, national, and global perspective. It also enables conservationists and natural resource managers to make informed, objective decisions in prioritizing and focusing conservation efforts.

What is Biological Diversity?

Protecting biological diversity has become an important management issue for many natural resource professionals. Biological diversity at its most basic level includes the full range of species on Earth, from species such as bacteria, and protists, through multicellular kingdoms of plants, animals, and fungi. At finer levels of organization, biological diversity includes the genetic variation within species, both among geographically separated populations and among individuals within a single population. On a wider scale, diversity includes variations in the biological communities in which species live, the ecosystems in which communities exist, and the interactions between these levels. All levels are necessary for the continued survival of species and plant communities, and all are important for the well-being of humans. It stands to reason that biological diversity should be of concern to all people.

The biological diversity of an area can be described at four levels:

1. **Genetic Diversity** -- the genetic variation within a population and among populations of a plant or animal species. The genetic makeup of a species is variable between populations within its geographic range. Loss of a population results in a loss of genetic diversity for that species and a reduction of total biological diversity for the region. This unique genetic information cannot be reclaimed.

2. **Species Diversity** -- the total number and abundance of plant and animal species and subspecies in an area.

3. **Community Diversity** -- the variety of plant communities within an area that represent the range of species relationships and inter-dependence. These communities may be diagnostic or even restricted to an area. It is within commu nities that all life dwells.

4. **Landscape Diversity** -- the type, condition, pattern, and connectedness of natural communities. A landscape consisting of a mosaic of natural communities may contain one multifaceted ecosystem, such as a wetland ecosystem. A landscape also may contain several distinct ecosystems, such as a riparian corridor meandering through shortgrass prairie. Fragmentation of landscapes, loss of connections and migratory corridors, and loss of natural communities all result in a loss of biological diversity for a region. Humans and the results of their activities are integral parts of most landscapes.

The conservation of biological diversity must include all levels of diversity: genetic, species, community, and landscape. Each level is dependent on the other levels and inextricably linked. In addition, and all too often omitted, humans are also linked to all levels of this hierarchy. We at the Colorado Natural Heritage Program believe that a healthy natural environment and human environment go hand in hand, and that recognition of the most imperiled elements is an important step in comprehensive conservation planning.

Appendix 2- Colorado's Natural Heritage Program

To place this document in context, it is useful to understand the history and functions of the Colorado Natural Heritage Program (CNHP).

CNHP is the state's primary comprehensive biological diversity data center, gathering information and field observations to help develop state-wide conservation priorities. After operating in Colorado for 14 years, the Program was relocated from the State Division of Parks and Outdoor Recreation to the University of Colorado Museum in 1992, and more recently to the College of Natural Resources at Colorado State University.

The multi-disciplinary team of scientists and information managers at CNHP gathers comprehensive information on the rare, threatened, and endangered species and significant plant communities of Colorado. Life history, status, and locational data are incorporated into a continually updated data system. Sources include published and unpublished literature, museum and herbaria labels, and field surveys conducted by knowledgeable naturalists, experts, agency personnel, and our own staff of botanists, ecologists, and zoologists. Information management staff carefully plot the data on 1:24,000 scale U.S.G.S. maps and enter it into the Biological and Conservation Data System. This locational information is incorporated into a GIS system (Arcview and Arcinfo). The Element Occurrence database can be accessed from a variety of angles, including taxonomic group, global and state rarity rank, federal and state legal status, source, observation date, county, quadrangle map, watershed, management area, township, range, and section, precision, and conservation unit.

CNHP is part of an international network of conservation data centers that use the Biological and Conservation Data System developed by The Nature Conservancy. CNHP has effective relationships with several state and federal agencies, including the Colorado Natural Areas Program, Colorado Department of Natural Resources and the Colorado Division of Wildlife, the U.S. Environmental Protection Agency, and the U.S. Forest Service. Numerous local governments and private entities also work closely with CNHP. Use of the data by many different individuals and organizations, including Great Outdoors Colorado, encourages a proactive approach to development and conservation thereby reducing the potential for conflict. Information collected by the Natural Heritage Programs around the globe provides a means to protect species before the need for legal endangerment status arises.

Concentrating on site-specific data for each element of natural diversity enables us to evaluate the significance of each location to the conservation of natural biological diversity in Colorado and in the nation. By using species imperilment ranks and quality ratings for each location, priorities can be established for the protection of the most sensitive or imperiled potential conservation areas. A continually updated locational database and priority-setting system such as that maintained by CNHP provides an effective, proactive land-planning tool.

Appendix 3- The Natural Heritage Ranking System

Information is gathered by CNHP on Colorado's plants, animals, and plant communities. Each of these species and plant communities is considered an **element of natural diversity**, or simply an **element**. Each element is assigned a rank that indicates its relative degree of imperilment on a five-point scale (e.g., 1 = extremely rare/imperiled, 5 = abundant/secure). The primary criterion for ranking elements is the number of occurrences, i.e., the number of known distinct localities or populations. This factor is weighted more heavily because an element found in one place is more imperiled than something found in twenty-one places. Also of importance are the size of the geographic range, the number of individuals, trends in both population and distribution, identifiable threats, and the number of already protected occurrences.

Element imperilment ranks are assigned both in terms of the element's degree of imperilment within Colorado (its State or S-rank) and the element's imperilment over its entire range (its Global or G-rank). Taken together, these two ranks give an instant picture of the degree of imperilment of an element. For example, the lynx, which is thought to be secure in northern North America but is known from less than 5 current locations in Colorado, is ranked G5S1. The Rocky Mountain Columbine which is known only from Colorado, from about 30 locations, is ranked a G3S3. Further, a tiger beetle that is only known from one location in the world at the Great Sand Dunes National Monument is ranked G1S1. CNHP actively collects, maps, and electronically processes specific occurrence information for plants considered extremely imperiled to vulnerable (S1 - S3). Those with a ranking of S3S4 are "watchlisted," meaning that specific occurrence data are collected and periodically analyzed to determine whether more active tracking is warranted. A complete description of each of the Natural Heritage ranks is provided in the following table.

Definition of Colorado Natural Heritage Imperilment Ranks

Global imperilment ranks are based on the range-wide status of a species. State imperilment ranks are based on the status of a species in an individual state. State 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 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 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, 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.
SR Reported to occur in the state, but unverified.
S? Unranked. Some evidence that species may be imperiled, but awaiting formal rarity ranking.

Notes: Where two numbers appear in a state or global rank (e.g., S2S3), the actual rank of the element falls between the two numbers.

Element Occurrence Ranking

Actual locations of elements, whether they be single organisms, populations, or plant communities, are referred to as **element occurrences**. The element occurrence is considered the most fundamental unit of conservation interest and is at the heart of the Natural Heritage Methodology. In order to prioritize element occurrences for a given species, an element occurrence rank (EO-Rank) is assigned according to their ecological quality whenever sufficient information is available. This ranking system is designed to indicate which occurrences are the healthiest and ecologically the most viable, thus focusing conservation efforts where they will be most successful. The EO-Rank is based on 3 factors:

> **Size** – a quantitative measure of the area and/or abundance of an occurrence such as area of occupancy, population abundance, population density, or population fluctuation.
> **Condition** – an integrated measure of the quality of biotic and abiotic factors, structures, and processes within the occurrence, and the degree to which they affect the continued existence of the occurrence. Components may include reproduction and health, development/maturity for communities, ecological processes, species composition and structure, and abiotic, physical or chemical factors.
> **Landscape Context –** an integrated measure of the quality of biotic and abiotic factors, and processes surrounding the occurrence, and the degree to which they affect the continued existence of the occurrence. Components may include landscape structure and extent, genetic connectivity, and condition of the surrounding landscape.

Each of these factors is rated on a scale of A through D, with A representing an excellent grade and D representing a poor grade. These grades are then averaged to determine an appropriate EO-Rank for the occurrence. If there is insufficient information available to rank an element occurrence, an EO-Rank of E is assigned. Possible EO-Ranks and their appropriate definitions are as follows:

A	The occurrence is relatively large, pristine, defensible, and viable.
B	The occurrence is small but in good condition, or large but removed from its natural condition and/or not viable and defensible.
C	The occurrence is small, in poor condition, and possibly of questionable viability.
D	The occurrence does not merit conservation efforts because it is too degraded or not viable.
H	Historically known, but not verified for an extended period of time.
X	Extirpated.
E	Extant. The occurrence does not contain enough information to rank using the above ranks.
F	The occurrence was not relocated; failed to find.