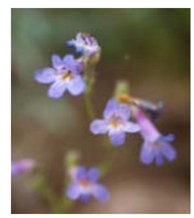
Visiting insect diversity and visitation rates for seven globally-imperiled plant species in Colorado's middle Arkansas Valley









by
Susan C. Spackman Panjabi
Colorado Natural Heritage Program
College of Natural Resources, Colorado State University
Ft. Collins, Colorado

prepared for
Native Plant Conservation Alliance
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Colorado State University
Knowledge to Go Places

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Abstract

Eriogonum brandegei (Brandegee wild buckwheat), *Nuttallia chrysantha* (golden blazing star), *Nuttallia densa* (Arkansas Canyon stickleaf), *Oenothera harringtonii* (Arkansas Valley evening primrose), *Oonopsis puebloensis* (Pueblo goldenweed), *Oxybaphus rotundifolius* (round leaf four-o'clock), and *Penstemon degeneri* (Degener penstemon) are globally imperiled plant species known only from geographically restricted areas in the middle Arkansas Valley of Colorado. These species were observed to determine the diversity of insect visitors (potential pollinators) and approximate insect visitation rates. *Eriogonum brandegei* was visited primarily by bees, flies, and ants, and the insects visited at a rate of 2.0 visits/inflorescence/30 minutes. *Nuttallia chrysantha* was visited primarily by bees and flies, and the insects visited at a rate of 6.0 visits/open corolla/30 minutes. *Nuttallia densa* was visited primarily by bees and flies, and the insects visited at a rate of 5.7 visits/open corolla/30 minutes. *Oenothera harringtonii* was visited primarily by bees and sphinx moths, and the insects visited at a rate of 0.89 visits/open corolla/30 minutes. *Oonopsis puebloensis* was visited primarily by flies, bees, and butterflies, and the insects visited at a rate of 7.54 visits/ inflorescence /30 minutes. *Oxybaphus rotundifolius* was visited primarily by flies and bees, and the insects visited at a rate of 1.39 visits/open corolla/30 minutes. *Penstemon degeneri* was visited primarily by flies, bees and wasps, and the insects visited at a rate of 0.6 visits/open corolla/30 minutes. A total of 55 insect taxa were identified as visitors to the rare plants. None of the insects are rare, nor are they specialists. Rare, geographically restricted plant 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 primary purpose of this study was to identify insect visitors (potential pollinators) and insect visitation rates for seven globally imperiled plant species, *Eriogonum brandegei* Rydb. (Brandegee wild buckwheat), *Nuttallia chrysantha* (Engelmann *ex* Brandegee) Greene (Golden blazing star), *Nuttallia densa* (Greene) Greene (Arkansas Canyon stickleaf), *Oenothera harringtonii* W.L. Wagner *et al.* in W.L. Wagner (Arkansas Valley evening primrose), *Oonopsis puebloensis* G. Brown *in ed*. (Pueblo goldenweed), *Oxybaphus rotundifolius* (Greene) Standley (Round-leaf four-o'clock), and *Penstemon degeneri* Crosswhite (Degener beardtongue) so that management of these species could take insect relationships into account. These species are known only from the middle Arkansas Valley of southeastern Colorado (Figure 1). Another objective was to update information about the distribution and status of the rare plant species. Field research took place during the summers of 2001 and 2003. The summer of 2002 brought such severe drought to Colorado that many of the study species did not produce flowers.

The middle Arkansas Valley of Colorado has an unusually high degree of plant endemism, supporting about 20 globally imperiled plant species, 12 of which are endemic to this area. The middle Arkansas Valley also supports about 30 state-imperiled plant species, many of which are disjunct from other parts of their ranges (Colorado Natural Heritage Program 2004, Table 1). Much of these species' ranges overlap with areas experiencing rapid population growth;

consequently, habitat for these plants is rapidly being fragmented or destroyed as a result of residential, industrial, and recreational developments (Spackman and Floyd 1996, The Nature Conservancy 2001). An extremely high proportion of the species' locations are on private lands (see Figure 1). Much of the private land is extensively platted and dissected by roads. Fremont and Pueblo counties are among the fastest growing counties in the United States, and low-density development is proceeding rapidly throughout the Arkansas Valley. Many of the known populations are found in highway right-of-ways where they are at risk from weed invasion, road maintenance and widening, mowing, and pesticide use (Grunau and Lavender 2002). Military activities at Fort Carson and the construction of Pueblo Reservoir have also compromised some populations. In addition, this area has and is experiencing extensive mining, which has further fragmented and degraded the habitat systems. Increases in mining and military activities, water development projects, residential and recreational developments could result in species extirpation or extinction. Because of the combination of rare plants and development activities, the middle Arkansas Valley is a primary focus of conservation concern in Colorado (The Nature Conservancy 2001, Kelso et al. 2003, Colorado Natural Heritage Program 2004).

Table 1. Plants of concern known from the middle Arkansas Valley of Colorado. Species in bold are endemic or nearly endemic to this area. Species ranked G1-3 are globally imperiled. Species ranked S1 or S2 are state imperiled. Explanation of ranks are included in Appendix 3. Nomenclature follows Weber and Wittmann (2001), synonyms following USDA NRCS (2004) are provided.

Scientific name	**Synonym**	**Common name**	**Global Rank**	**State Rank**
Agastache foeniculum		Lavender Hyssop	G4G5	S1
Aletes lithophilus	*Neoparrya lithophila*	Rock-loving Neoparrya	G3	S3
Ambrosia linearis		Plains Ragweed	G3	S3
Amorpha nana	*Amorpha nana*	Dwarf Wild Indigo	G5	S2S3
Aquilegia chrysantha var. *rydbergii*		Golden Columbine	G4T1Q	S1
Asclepias uncialis sensu stricto	*Asclepias uncialis* ssp. *uncialis*	Dwarf Milkweed	G3?T2T3	S2S3
Asplenium platyneuron		Ebony Spleenwort	G5	S1
Bolophyta tetraneuris	***Parthenium tetraneuris***	**Barneby's Fever-few**	**G3**	**S3**
Carex concinna		Low Northern Sedge	G4G5	S1
Carex crawei		Crawe Sedge	G5	S1
Carex leptalea		Bristle-stalk Sedge	G5	S1
Carex oreocharis		A Sedge	G3	S1
Carex peckii		Peck Sedge	G4G5	S1
Cheilanthes eatonii		Eaton's Lip Fern	G5?	S2
Cheilanthes standleyi	*Notholaena standleyi*	Standley's Cloak Fern	G4	S1
Cheilanthes wootonii		Wooton's Lip Fern	G5	S1
Chenopodium cycloides		Sandhill Goosefoot	G3	S1
Commelina dianthifolia		Birdbill Day-flower	G5	S1?
Cypripedium calceolus ssp. *parviflorum*	*Cypripedium parviflorum*	American Yellow Lady's-slipper	G5	S2

Scientific name	Synonym	Common name	Global Rank	State Rank
Delphinium ramosum var. *alpestre*	*Delphinium alpestre*	Colorado Larkspur	G2	S2
Echinocereus reichenbachii var. *perbellus*		Lace Hedgehog Cactus	G5	S1
Epipactis gigantea		Helleborine	G3	S2
Eriogonum brandegei	***Eriogonum brandegeei***	**Brandegee Wild Buckwheat**	**G1G2**	**S1S2**
Festuca campestris		Big Rough Fescue	G4?	SH
Frasera coloradensis		**Colorado Green Gentian**	**G3**	**S3**
Grindelia inornata		**Colorado Gumweed**	**G2?**	**S2?**
Heuchera richardsonii		Richardson Alum-root	G5	S1
Hypoxis hirsuta		Yellow Stargrass	G5	SH
Isoetes setacea ssp. *muricata*	*Isoetes echinospora* ssp. *muricata*	Spiny-spored Quillwort	G5?T5?	S2
Juncus brachycephalus	*Juncus brachycephalus*	Small-headed Rush	G5	S1
Lesquerella calcicola		**Rocky Mountain Bladderpod**	**G2**	**S2**
Liatris ligulistylis		Gay-feather	G5?	S1S2
Nuttallia chrysantha	***Mentzelia chrysantha***	**Golden Blazing Star**	**G2**	**S1S2**
Nuttallia densa	***Mentzelia densa***	**Arkansas Canyon Stickleaf**	**G2**	**S2**
Oenothera harringtonii		**Arkansas Valley Evening Primrose**	**G2**	**S2**
Oonopsis foliosa* var. *monocephala		**Single-head Goldenweed**	**G2G3**	**S2**
Oonopsis puebloensis		**Pueblo Goldenweed**	**G2**	**S1S2**
Oxybaphus rotundifolius	***Mirabilis rotundifolia***	**Round-leaf Four-o'clock**	**G2**	**S2**
Pellaea atropurpurea		Purple Cliff-brake	G5	S2S3
Pellaea suksdorfiana	*Pellaea glabella* ssp. *simplex*	Smooth Cliff-brake	G5T4?	S2
Pellaea wrightiana		Wright's Cliff-brake	G5	S2
Penstemon degeneri		**Degener Beardtongue**	**G2**	**S2**
Potentilla ambigens		Southern Rocky Mountain Cinquefoil	G3	S1S2
Ribes americanum		American Currant	G5	S2
Sarcostemma crispum		Twinevine	G4G5	S1
Unamia alba	*Solidago ptarmicoides*	Prairie Goldenrod	G5	S2S3
Viola pedatifida		Prairie Violet	G5	S2
Woodsia neomexicana		New Mexico Cliff Fern	G4?	S2

Appropriate conservation and 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, and little is known about how these species are pollinated. Since population 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 middle Arkansas Valley of Colorado. Kelso and her colleagues (2003) investigated insect relationships for *Oxybaphus rotundifolius* and reported a diverse array of visitors, most frequently syrphid flies and halictid bees, and documented six insect taxa carrying pollen of *O. rotundifolius*. They also determined that *O. rotundifolius* is capable of producing seeds without insect facilitation. Research on the pollination ecology of the other six plant species had not been conducted prior to the present study.

Study area

The middle Arkansas Valley of Colorado, from Buena Vista to the state line, is roughly 200 miles long and 150 miles wide (Figure 1). The area falls into eight Colorado counties: Chafee, Fremont, Custer, Pueblo, El Paso, Huerfano, Otero, and Las Animas, and includes lands managed by the Bureau of Land Management, the U.S. Forest Service, Colorado State Parks, Colorado Division of Wildlife, U.S. Department of Defense, and numerous private landowners. The middle Arkansas Valley is in southeastern Colorado, and includes portions of the Great Plains and the Southern Rocky Mountain Ecoregions (Bailey 1994).

The highest concentration of rare plant species in the Arkansas Valley of Colorado is between Canon City and Pueblo. This area is of particular conservation concern because of the high level of botanical endemism (pers. comm. Kelso 2004, The Nature Conservancy 2001). The rare plants in the middle Arkansas Valley are also distributed further upstream from Canon City, and also in the Purgatoire drainage in the southern part of the watershed.

The climate of the middle Arkansas River Valley is arid, with low humidity, low annual precipitation, and hot summer temperatures. Prevailing weather patterns place this area in the rainshadow of the Sangre de Cristo and Mosquito Ranges. Temperature and precipitation data is available from the Arkansas River Valley at Canon City (1948 to 2002) and Pueblo Reservoir (1975-2002) (Western Regional Climate Center 2003). In typical years, July and August are the wettest months of the year at Canon City and at Pueblo Reservoir. These months have averaged approximately 2 inches of rain at each location from monsoonal afternoon thundershowers. These months are also the hottest of the year, with maximum daily temperatures often exceeding 100ºF. Total average annual precipitation at Canon City and Pueblo Reservoir is almost identical (12.75 inches and 12.79 inches respectively), but quite a bit more of it falls as snow in Canon City (36.1 inches) than at Pueblo Reservoir (20.7 inches).

We chose 12 specific sites in the middle Arkansas Valley for this study: McIntyre Hills, Cotopaxi, Southeast of Garden Park, Droney Gulch, and Royal Gorge in Fremont County, Pueblo West, Pueblo Reservoir North, Juniper Road, Juniper Breaks, Walker Ranch and Pueblo Wildlife Area in Pueblo County, and Pryor in Huerfano County (Figure 2). We selected the specific study sites subjectively, based primarily on the following criteria: distribution within the known range of the study species, site accessibility, and density of flowers.

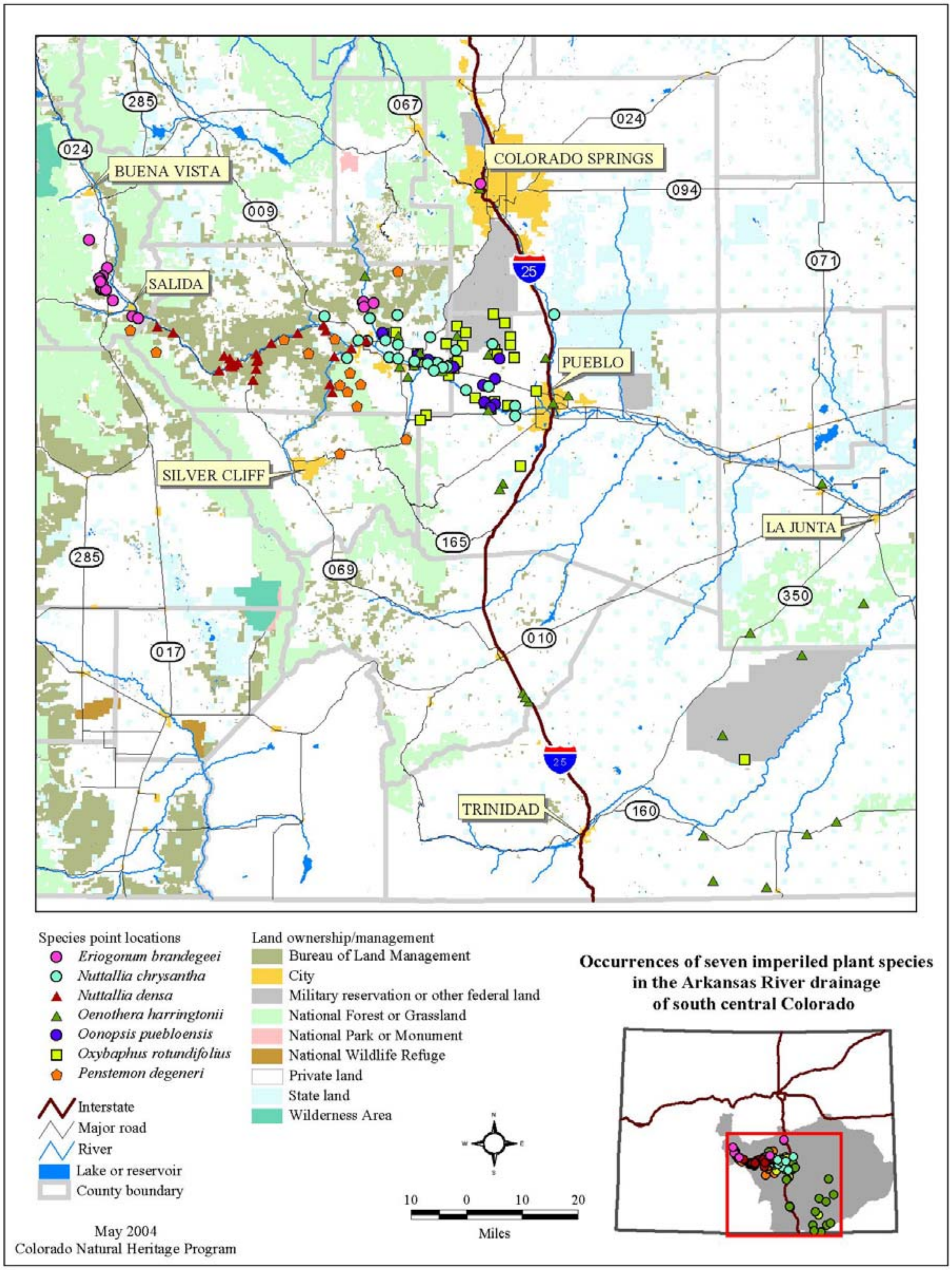

Figure 1. Middle Arkansas Valley of southeastern Colorado. The rare plant locations in Colorado Springs (for *Eriogonum brandegei* and *Oenothera harringtonii*) are based on herbarium specimen labels, and are probably not correct.

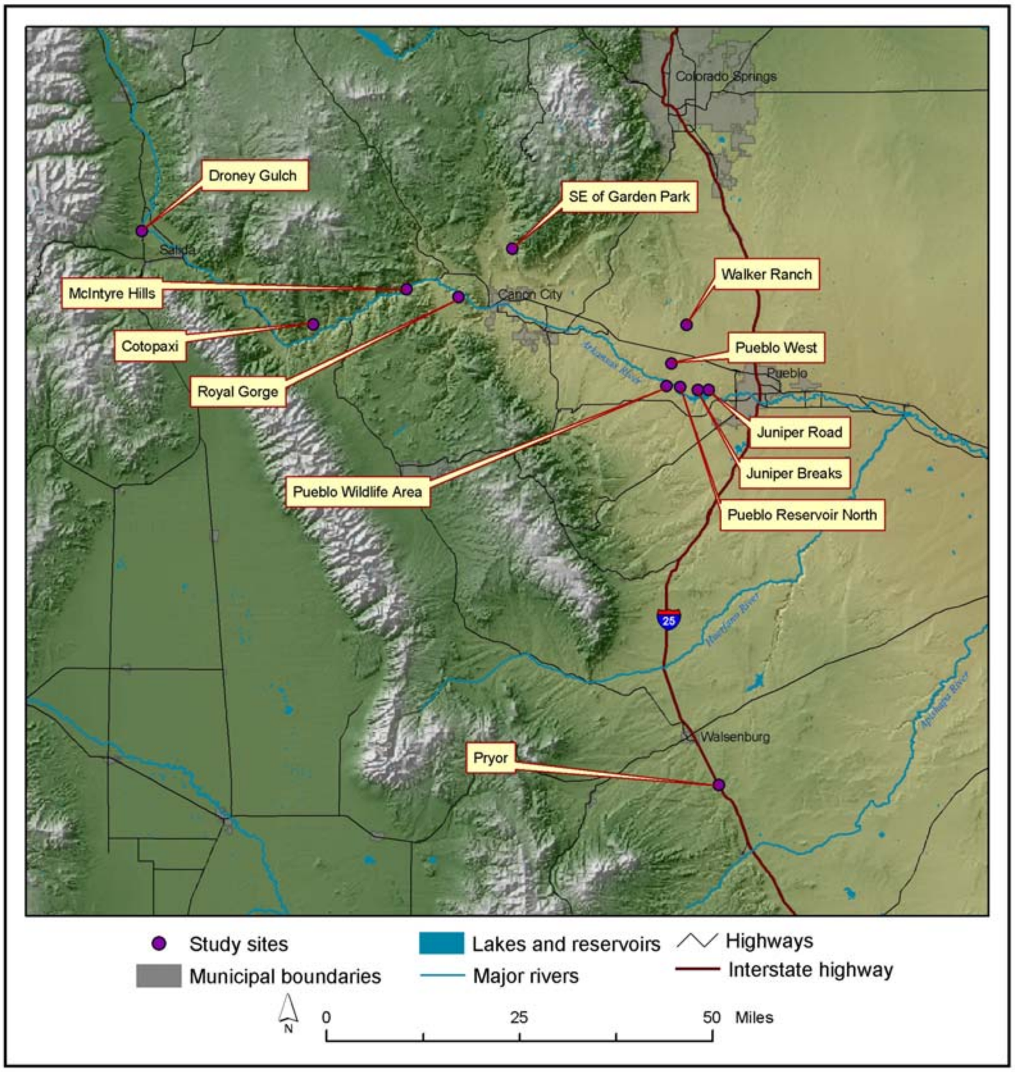

Figure 2. Twelve sites in the Middle Arkansas Valley that were monitored for insect visitation in 2001 and 2003.

Species descriptions

Eriogonum brandegei (Brandegee wild buckwheat), known only from Fremont and Chaffee counties in south central Colorado, is a distinct member of the Polygonaceae (Buckwheat family). Plants stand about 10-25 cm tall and support globose inflorescences of white flowers that are 3-3.5 mm long, with slightly exserted stamens. This species is found in deposits of fine particle soils derived from the Dry Union or Morrison formations, within open sagebrush or pinyon-juniper stands (Spackman et al. 1997, Colorado Natural Heritage Program 2004). *Eriognonum brandegei* is considered to be imperiled throughout its range (G2) by the Natural Heritage Network (Colorado Natural Heritage Program 2004, NatureServe 2004), and is included on the U.S. Forest Service Region 2 and Colorado Bureau of Land Management lists of sensitive species. *Eriognonum brandegei* is known from about 1,100 acres within an elevation range of 5700-7600 feet (Colorado Natural Heritage Program 2004). Figure 3 shows the full global distribution of this species. Figures 4 and 5 present photographs of *E. brandegei* and its habitat in the middle Arkansas Valley of Colorado.

The flowers of species in the Polygonaceae are generally insect pollinated, often by bees and flies (Zomlefer 1994). Most perennial members of the genus *Eriogonum* reproduce both vegetatively and sexually, but the relative importance of these modes of reproduction varies considerably within the genus (pers. comm. Reveal 2002). There is no specific information on pollinators for *E. brandegei*. Most *Eriogonum* species throughout the Rockies, Sierra Nevada, and Cascades are visited by a broad range of generalist pollinators, with no clear examples of specialization (pers. comm. Reveal 2002; Tepedino 2002). *Eriogonum* species offer a small amount of nectar at the base of the filaments and ovaries. This reward and pollen attracts bees, flies, and ants.

Nuttallia chrysantha *=Mentzelia chrysantha* (Golden blazing star) is a yellow-flowered member of the Loasaceae (Stickleaf family). The plants stand about 20-75 cm tall and support bright yellow flowers with 10 petals, 15-20 mm long. The flowers of *N. chrysantha* open at about 6 pm and remain open until about 9 pm. *Nuttallia chrysantha* is found on barren slopes in soils derived from limestone, shale, or clay within a limited distribution in Fremont and Pueblo counties, Colorado (Spackman et al. 1997, Colorado Natural Heritage Program 2004). *Nuttallia chrysantha* is considered to be imperiled throughout its range (G2) by the Natural Heritage Network (Colorado Natural Heritage Program 2004, NatureServe 2004). *Nuttallia chrysantha* is found on a small area of land managed by the Bureau of Land Management (BLM), and is included on the BLM Colorado State Sensitive Species List. This species is also found at Pueblo State Park and on private lands. *Nuttallia chrysantha* is known from about 900 acres within an elevation range of about 4700-6500 feet (Colorado Natural Heritage Program 2004). Figure 6 shows the full global distribution of this species. Figures 7 and 8 present photographs of *N. chrysantha* and its habitat in the middle Arkansas Valley.

The pollination ecology of *Nuttallia chrysantha* has not been investigated. Species in the genus *Mentzelia* (*Nuttallia)* are predominantly outcrossing and self-incompatible (Thompson and Prigge 1984). Lack of seed set under greenhouse conditions has shown that *Nuttallia nuda*, a very close relative of *N. chrysantha*, is an obligate outcrosser (Brown and Kaul 1981). However, other studies have observed some degree of self-compatibility or facultative autogamy in the genus (e.g., Brown 1971, Thompson and Prigge 1984, Little 1985). Most species of *Mentzelia (Nuttallia)* exhibit adaptations that encourage outcrossing (Brown 1971). Potential pollinators include bees, bumble bees, wasps, butterflies, syrphids, flies, and ants (Thompson 1963, Brown and Kaul 1981, Keeler 1981, Little 1985, Christy 1995). Brown (1971) made preliminary observations of visitations by honeybees and sphinx moths on *Nuttallia decapetala*.

Nuttallia densa =*Mentzelia densa* (Arkansas Canyon stickleaf) is another yellow-flowered member of the Loasaceae (Stickleaf family), with more of a shrubby growth form, and smaller flowers than *N. chrysantha*. *Nuttallia densa* plants stand up to 30 cm tall and support bright yellow flowers with petals that are 8-15 mm long. The flowers of this species also remain closed until about 6 pm. *Nuttallia densa* is found in rocky areas within pinyon-juniper, sagebrush, or mountain mahogany communities, in soils derived from Precambrian granodiorite and gneiss within a 30 square mile distribution in Fremont County, Colorado (Coles 1990, Colorado Natural Heritage Program 2004). *Nuttallia densa* is considered to be imperiled throughout its range (G2) by the Natural Heritage Network (Colorado Natural Heritage Program 2004, NatureServe 2004). This species is found primarily on private lands, and is not included on the U.S. Forest Service or Bureau of Land Management sensitive species lists. *Nuttallia densa* is known from about 300 acres within a elevation range of about 5800-7200 feet. Figure 9 shows the full global distribution of this species. Figures 10 and 11 present photographs of *N. densa* and its habitat in the middle Arkansas Valley.

The pollination ecology of *Nuttallia densa* has not been investigated. In a 1990 status report, Coles speculates that because the flowers of *Nuttallia densa* are only open in the late afternoon and early evening, moths, bumblebees, and bats are potential pollinators (Coles 1990).

Oenothera harringtonii (Arkansas Valley evening primrose) is a robust, fragrant, white-flowered member of the Onagraceae (Evening primrose family). Plants stand 15-40 cm tall and support large white flowers with petals that are 2-2.6 cm long. This species is found in grassland communities, in fine textured soils within a limited distribution in El Paso, Fremont, Huerfano, Las Animas, Pueblo and Otero counties, Colorado (Spackman et al. 1997, Colorado Natural Heritage Program 2004). *Oenothera harringtonii* is considered to be imperiled throughout its range (G2) by the Natural Heritage Network (Colorado Natural Heritage Program 2004, NatureServe 2004). This species is found primarily on private lands, and has been documented at the Comanche National Grassland. It is included on the U.S. Forest Service Sensitive Species list for Region 2. This species is known from an elevation range of about 4700-6100 feet (Colorado Natural Heritage Program 2004). Figure 12 shows the full global distribution of this species, and Figures 13 and 14 present photographs of *O. harringtonii* and its habitat in the middle Arkansas Valley.

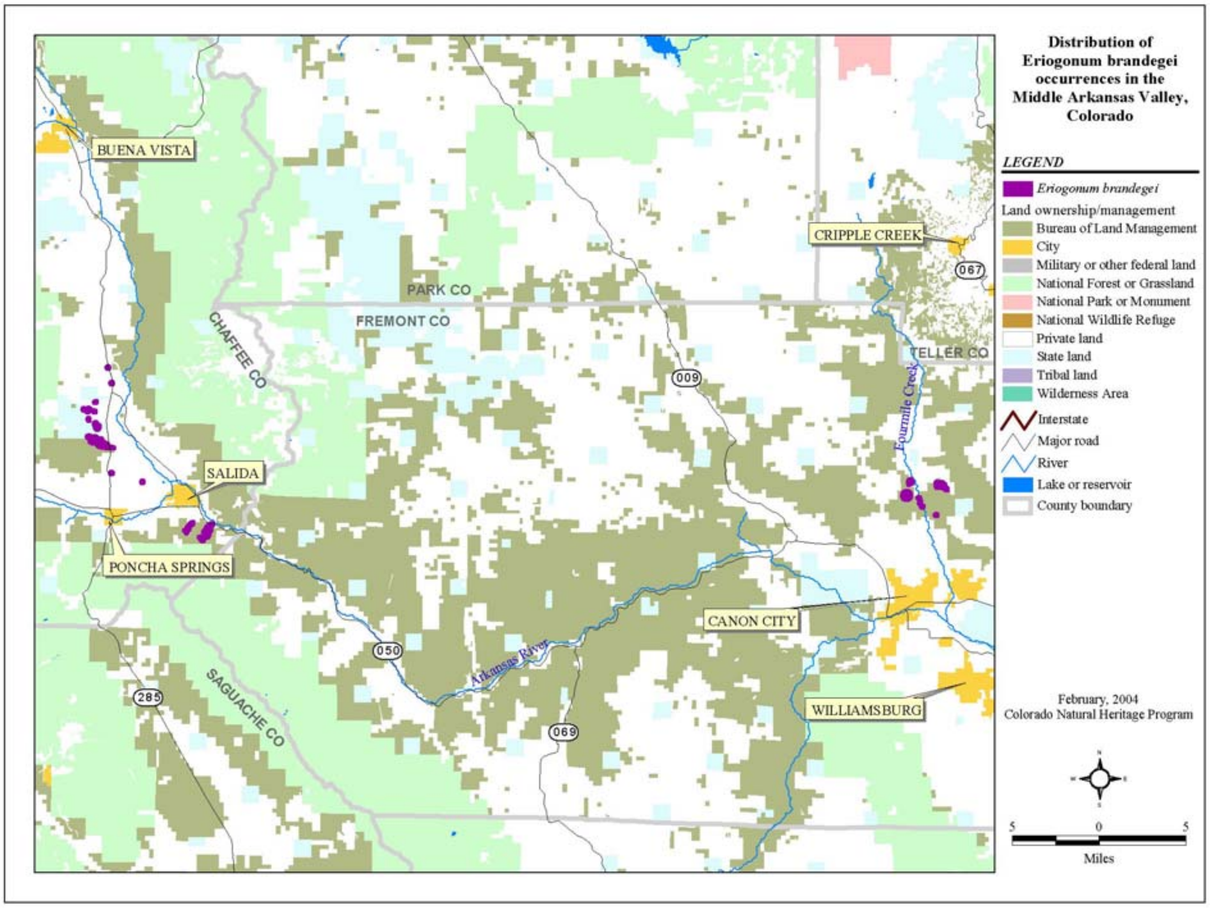

Figure 3. Global distribution of *Eriognoum brandegei*

Figure 4. *Eriogonum brandegei*

Figure 5. *Eriognonum brandegei* habitat

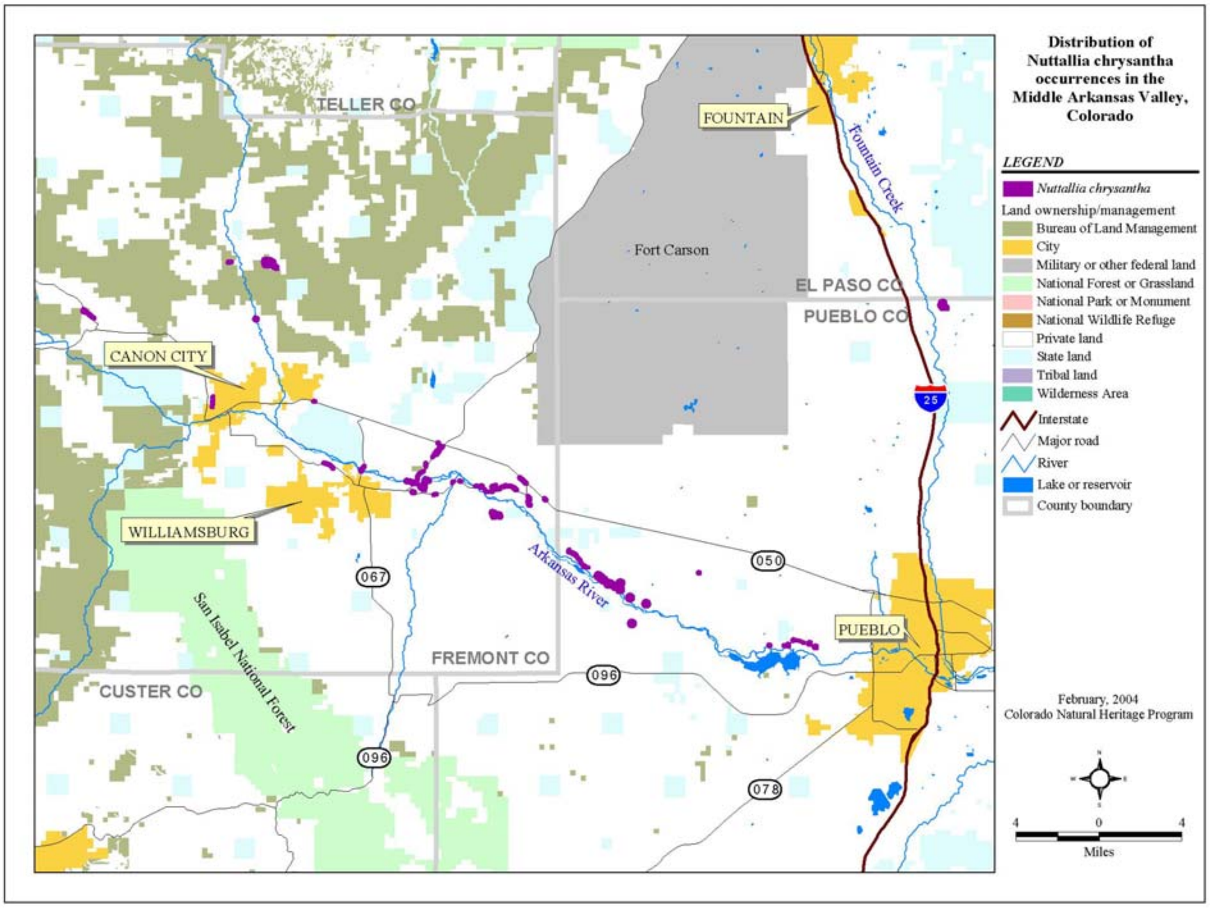

Figure 6. Global distribution of *Nuttallia chrysantha*

Figure 7. *Nuttallia chrysantha*

Figure 8. *Nuttallia chrysantha* habitat

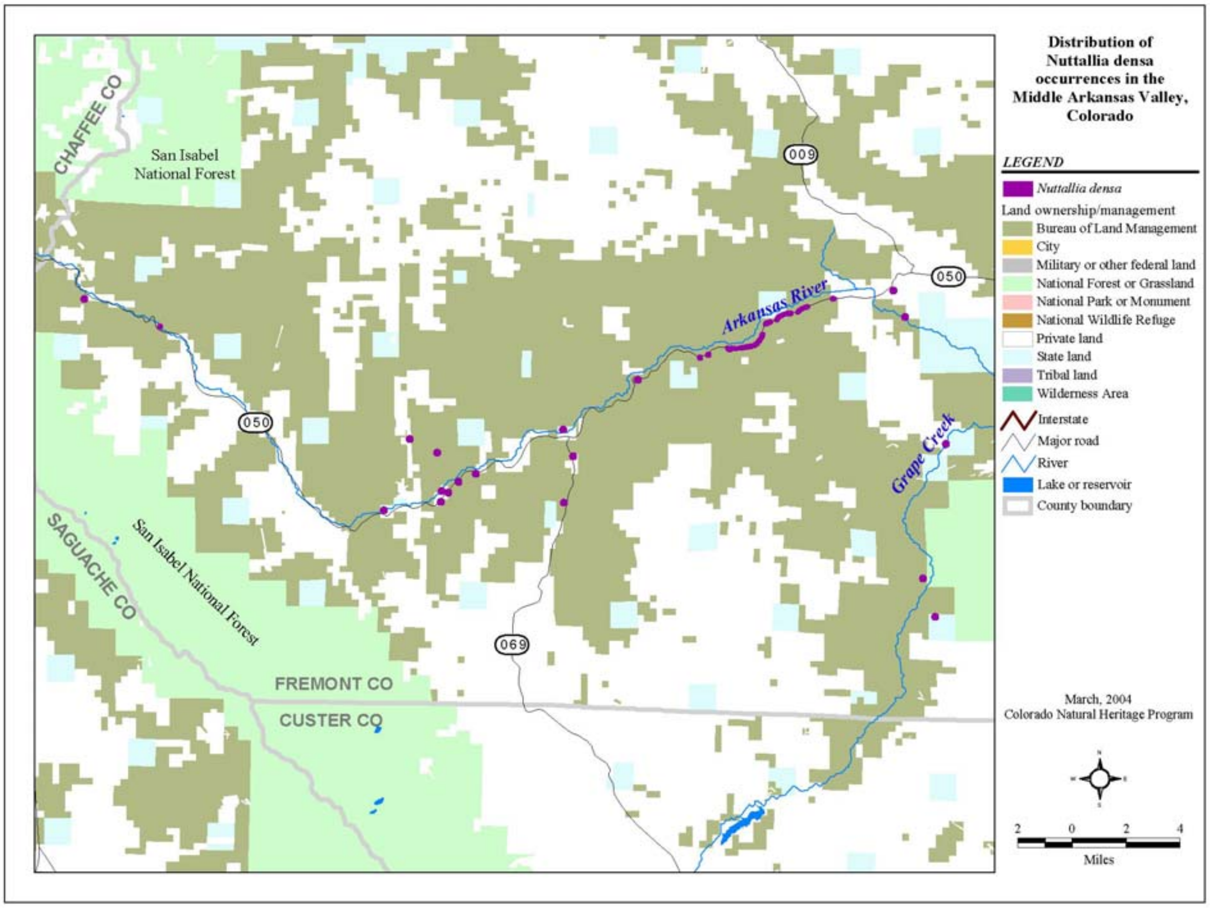

Figure 9. Global distribution of *Nuttallia densa*

Figure 10. *Nuttallia densa*

Figure 11. *Nuttallia densa* habitat

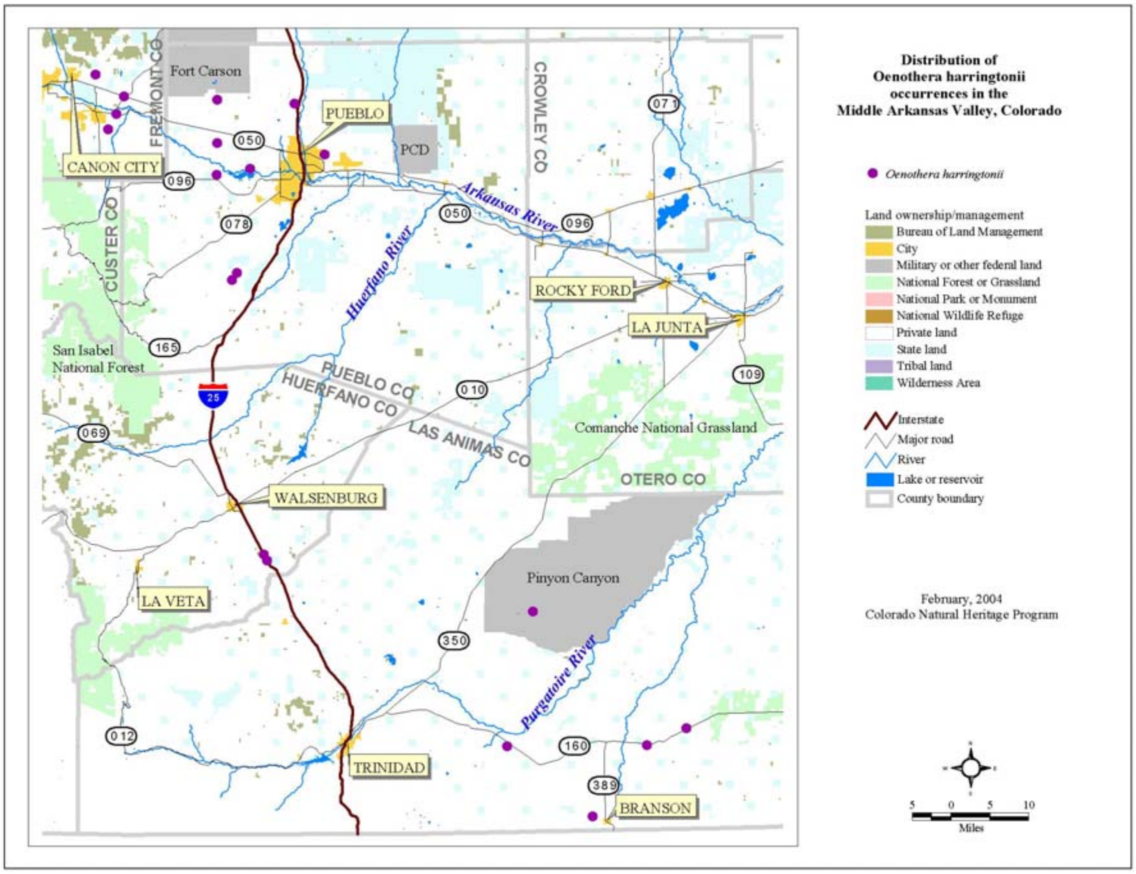

Figure 12. Global distribution of *Oenothera harringtonii*

Figure 13. *Oenothera harringtonii*

Figure 14. *Oenothera harringtonii* habitat

Although research has not been conducted on the reproductive ecology of *Oenothera harringtonii*, pollination biology of the genus *Oenothera* has been studied rather extensively (Linsley et al. 1963, Gregory 1963 and 1964, Stockhouse 1973, Raven 1979). *Oenothera harringtonii* is likely self-incompatible and an obligate outcrosser, based on the floral biology of many of its cogeners. Numerous species have been identified as important pollinators in this genus, especially hawkmoths (Gregory 1963, Raven 1979, Stockhouse 1973, pers. comm. Raguso 2002) and bees (Raven 1979, Linsley et al. 1963).

Oonopsis puebloensis (Pueblo goldenweed) is a yellow-flowered member of the Asteraceae (Sunflower family). The plants stand about 15-30 cm tall and support an inflorescence of bright yellow ray and disk flowers. *Oonopsis puebloensis* is found in barren shale outcrops in sparse shrublands or pinyon-juniper woodlands, in soils derived from the Smoky Hill Member of the Niobrara Formation (Spackman et al. 1997). This species was discovered in 1982, and is only known from a limited distribution in Fremont and Pueblo counties, Colorado (Colorado Natural Heritage Program 2004). *Oonopsis puebloensis* is considered to be imperiled throughout its range (G2) by the Natural Heritage Network (Colorado Natural Heritage Program 2004, NatureServe 2004). This species is found primarily on private lands, and is not included on the U.S. Forest Service or Bureau of Land Management sensitive species lists. It has been documented on about 400 acres within an elevation range of about 4800-5500 feet (Colorado Natural Heritage Program 2004). Figure 15 shows the full global distribution of this species. Figures 16 and 17 present photographs of *O. puebloensis* and its habitat in the middle Arkansas Valley.

The reproductive ecology of *Oonopsis puebloensis* has not been studied. Species in the Asteraceae are usually capable of self-pollination, but also rely on insects for some outcrossing. Species in this family are known to be pollinated by butterflies, moths, flies, and bees (Zomlefer 1994). A few species are solely wind pollinated (Zomlefer 1994). The numerous flowers found on each inflorescence of many species, such as *O. puebloensis*, allow insects to visit many flowers in a short amount of time without traveling far. The relatively large heads of bright yellow flowers found on *O. puebloensis* may be an adaptation for insect pollination.

Oxybaphus rotundifolius = *Mirabilis rotundifolia* (Round-leaf four-o'clock), known only from Las Animas, Fremont, and Pueblo counties in southeastern Colorado, is a showy member of the Nyctaginaceae (Four-O'Clock family). Plants stand about 2-3 dm tall and support bright magenta flowers with petals that are about 1 cm long, and have five exserted stamens. The flowers of *O. routundifolius* open before dawn, and generally close by mid-morning. This species is found on barren chalk outcrops of the Smoky Hill Member of the Niobrara Formation in sparse shrublands or woodlands (Spackman et al. 1997). *Oxybaphus rotundifolius* is considered to be imperiled throughout its range (G2) by the Natural Heritage Network (Colorado Natural Heritage Program 2004, NatureServe 2004). This species is found primarily on private lands and is not listed on the U.S. Forest Service or Bureau of Land Management lists of sensitive plant species. *Oxybaphus rotundifolius* has been documented on about 3400 acres within an elevation range of about 4800-5600 feet (Colorado Natural Heritage Program 2004). Figure 18 shows the distribution of this species in the middle Arkansas Valley. It is also known from a disjunct location in Las Animas County. Figures 19 and 20 present photographs of *O. rotundifolius* and its habitat in the middle Arkansas Valley of Colorado.

Oxybaphus rotundifolius is known to use a variety of pollinators, but is also capable of self-pollination when insects are excluded (Kelso et al. 2003). Kelso and her colleagues (2003) observed that *O. rotundifolius* was visited by a diverse array of insects including two fly (Diptera) species (*Syrphus* sp. and *Hydrophoria* sp.), eight bee (Hymenoptera) species (*Bombus nevadensis*, two *Anthophora* species, two *Dialictus* species, three species from the family Halictinae), and one true bug (Hemiptera) species (*Lygaeus kalmii*). Hawkmoths are common pollinators of other species in the Nyctaginaceae, but have not been documented visiting the flowers of *O. rotundifolius* (pers. comm. Kelso 2004).

Penstemon degeneri (Degener beardtongue) is a blue to blue-violet flowered member of the Scrophulariaceae (Snapdragon family). Plants stand 25-40 cm tall and support gradually inflated, tube-shaped flowers that are 1.4-2 cm long. This species is found in pinyon-juniper and grassland communities, in soils derived from igneous bedrock within a limited distribution in Fremont and Custer counties, Colorado (Spackman et al. 1997, Colorado Natural Heritage Program 2004). *Penstemon degeneri* is considered to be imperiled throughout its range (G2) by the Natural Heritage Network (Colorado Natural Heritage Program 2004, NatureServe 2004). This species is included on the sensitive species list for Region 2 of the U.S. Forest Service and the Colorado Bureau of Land Management. *Penstemon degeneri* has been documented on about 600 acres within an elevation range of about 6000-9500 feet (Colorado Natural Heritage Program 2004). Figure 21 shows the full global distribution of this species, and Figures 22 and 23 present photographs of *P. degeneri* and its habitat in the middle Arkansas Valley.

The reproductive ecology of *Penstemon degeneri* has not been studied. The floral biology of species in the genus *Penstemon* suggests that insect pollination may be an important reproductive strategy. Insects (and hummingbirds) are attracted to brightly colored *Penstemon* flowers and to the nectar that is secreted by a disc around the base of the ovary (Zomlefer 1994). The corolla throat of species in this genus often has darker spots or lines that serve as nectar guides, and the lower lip of the corolla may serve as a landing platform (Zomlefer 1994).

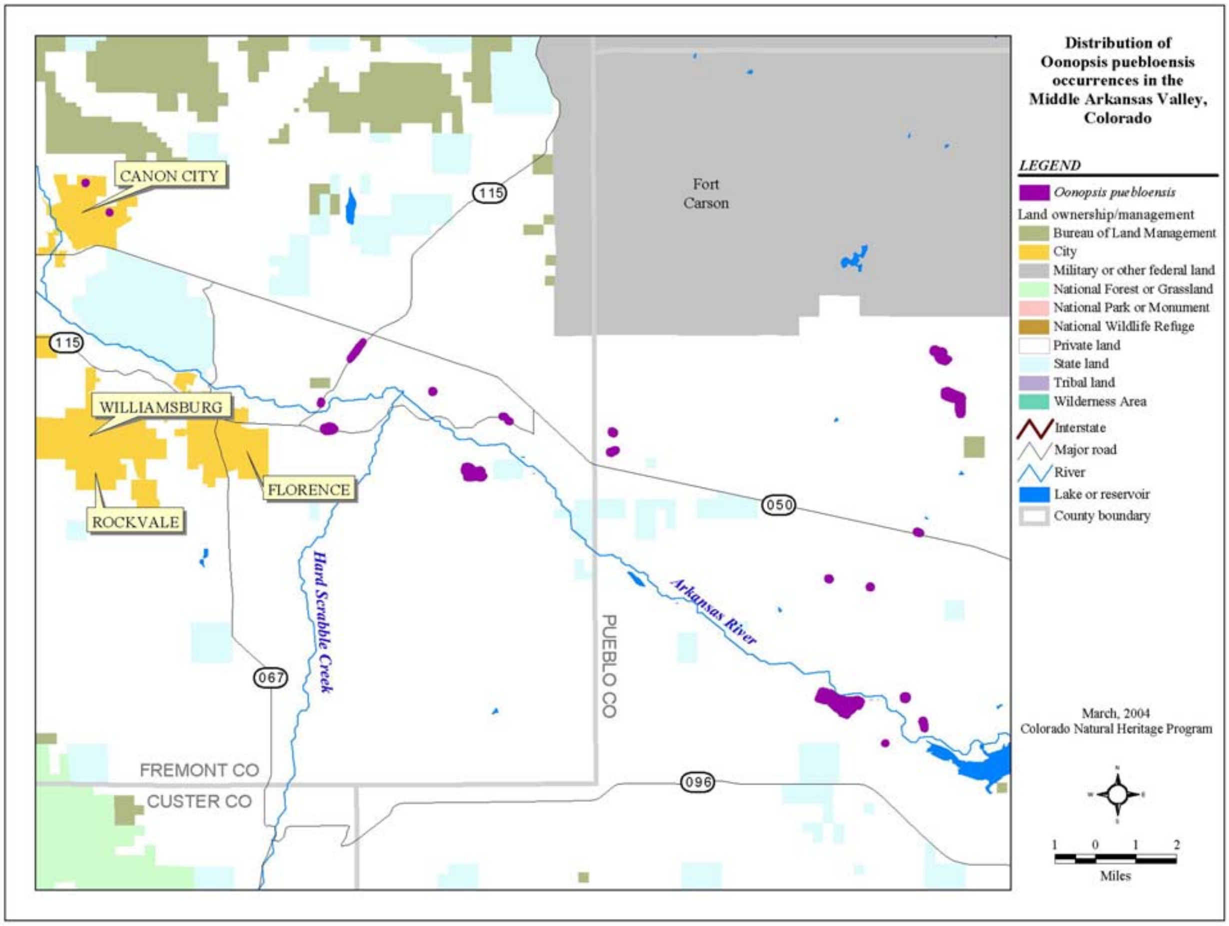

Figure 15. Global distribution of *Oonopsis puebloensis*.

Figure 16. *Oonopsis puebloensis*

Figure 17. *Oonopsis puebloensis* habitat

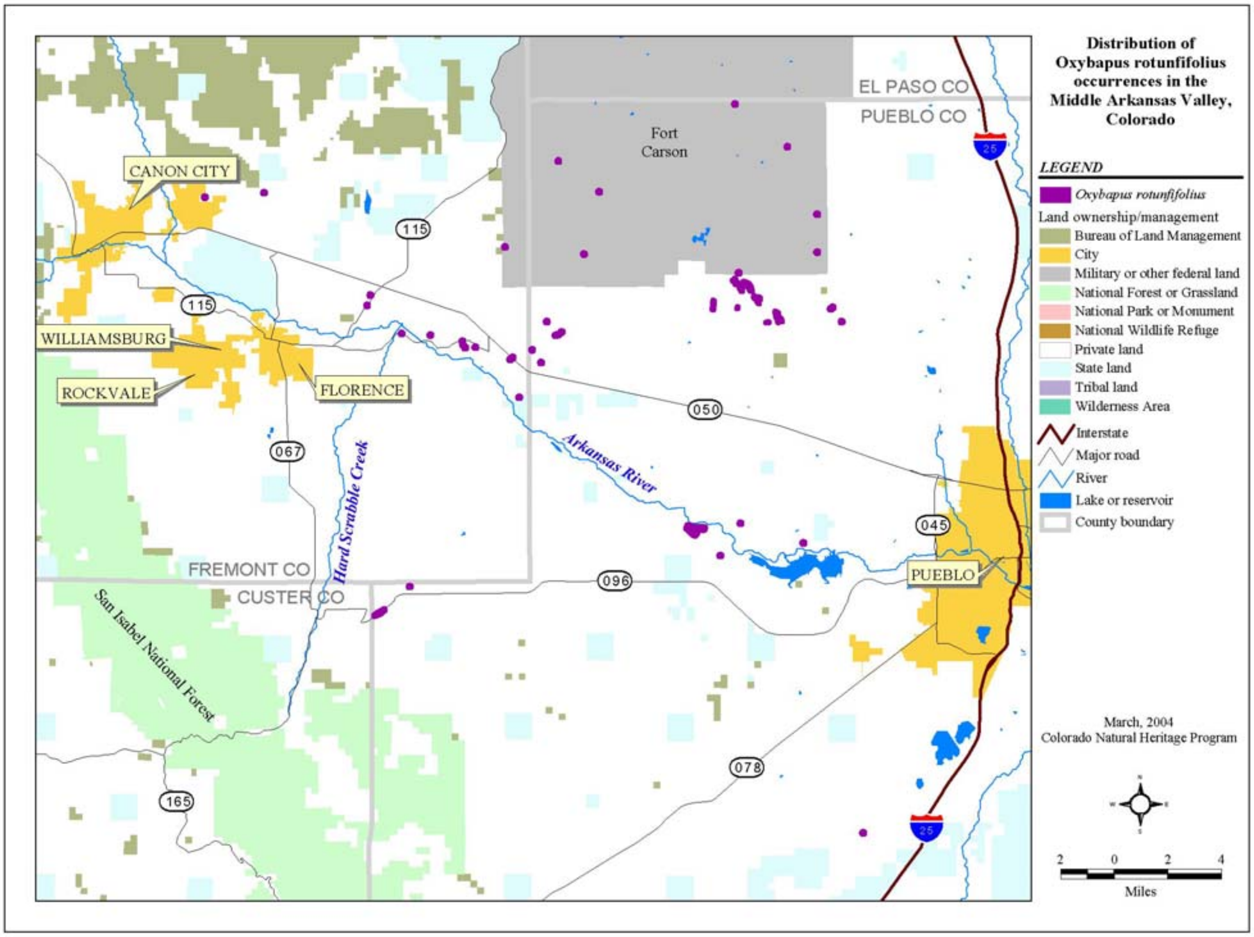

Figure 18. Distribution of *Oxybaphus rotundifolius* in Pueblo and Fremont counties. There is also an occurrence in Las Animas County.

Figure 19. *Oxybaphus rotundifolius*

Figure 20. *Oxybaphus rotundifolius* habitat

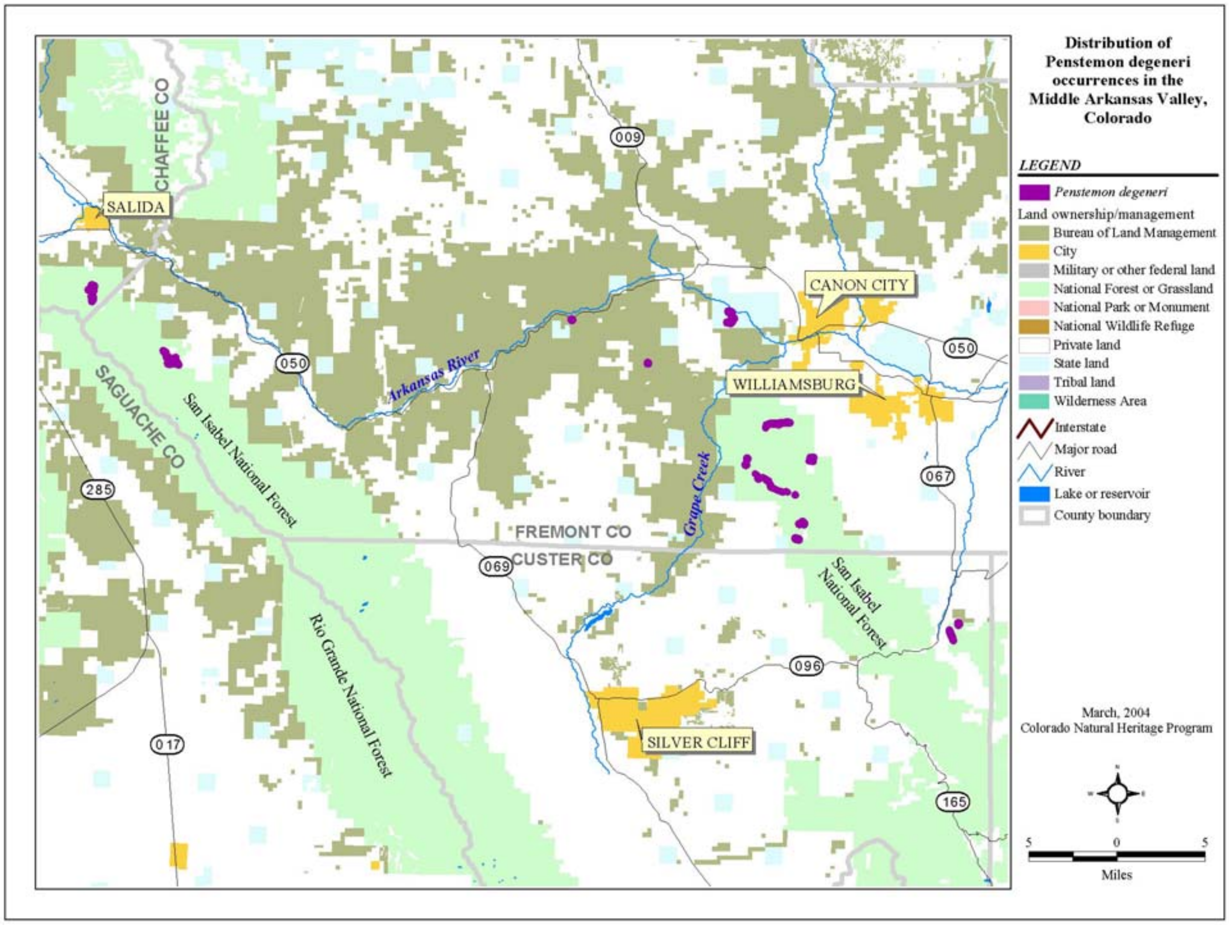

Figure 21. Global distribution of *Penstemon degeneri*

Figure 22. *Penstemon degeneri*

Figure 23. *Penstemon degeneri* habitat

Methods

Rare plant inventory and assessments

A team of Colorado Natural Heritage Program and Colorado Native Plant Society botanists searched appropriate habitats in the middle Arkansas Valley at phonologically appropriate times to map and document the location and condition of distinct populations of *Eriogonum brandegei* (Brandegee wild buckwheat), *Nuttallia chrysantha* (Golden blazing star), *Nuttallia densa* (Arkansas Canyon stickleaf), *Oonopsis puebloensis* (Pueblo goldenweed), *Oenothera harringtonii* (Arkansas Valley evening primrose), *Oxybaphus rotundifolius* (Round leaf four-o'clock), and *Penstemon degeneri* (Degener penstemon). 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 June and July of 2001, and June and July of 2003 (2002 was skipped because of the severe drought in this area), and were conducted by hiking through inventory areas, inspecting typical habitat as well as unusual edaphic or topographic features (e.g., rock outcrops, moist depressions, etc.). Private landowners were contacted to obtain permission to search areas that were located on private lands.

During the field surveys, as new locations for any of the plant species of concern were found (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.

Specimen label information was also gathered from local herbaria, including Rocky Mountain, University of Colorado, Colorado State University, and Colorado College herbaria. All data were entered into the Biological Conservation Database with the Colorado Natural Heritage Program at Colorado State University.

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 30 minutes observing and collecting the insects that visited the flowers. These 30-minute 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. However, since the flowers of the two species of *Nuttallia* are only open after about 6 pm, we observed and collected insects from these species once per day in the evening. Similarly, *Oxybaphus rotundifolius* flowers often close by mid-morning, so observations and collections were made in the morning hours. 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. Figures 24 and 25 show Colorado Natural Heritage Program botanists and volunteers collecting and curating insect specimens. 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, Howard Evans, and Sara Simonson, 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 recorded the total number of open corollas or inflorescences observed. Total number of inflorescences were recorded for *Eriogonum brandegei* and *Oonopsis puebloensis*, and the total number of open corollas were recorded for the other five plants. The number of flowers observed by one observer ranged widely, from 1 to 75 corollas or inflorescences, depending on the size, distribution, and phenological stage of the plants. We gathered the information to calculate: # visits/ # of open corollas or inflorescences/ 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, with the observations of the two species of *Nuttallia* conducted in the evening, and the observations of *Oxybaphus rotundifolius* limited to the morning hours. Figure 26 shows a Colorado Natural Heritage Program botanist conducting a visitation rate observation. 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.

Figure 24. Colorado Natural Heritage Program botanist collecting visiting insects.

Figure 25. Colorado Natural Heritage Program volunteers pinning insect specimens.

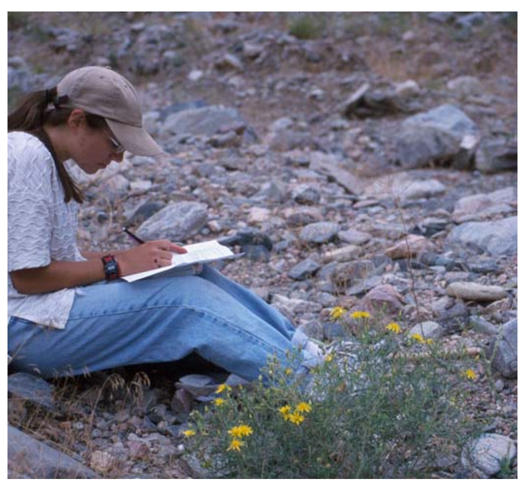

Figure 26. Colorado Natural Heritage Program volunteer conducting a visitation rate observation.

Results

Rare plant assessments

Rare plant records were created or updated for two locations of *Eriogonum brandegei* (Brandegee wild buckwheat), 14 locations of *Nuttallia chrysantha* (Golden blazing star), 3 locations of *Nuttallia densa* (Arkansas Canyon stickleaf), five locations of *Oonopsis puebloensis* (Pueblo goldenweed), 14 locations of *Oenothera harringtonii* (Arkansas Valley evening primrose), eight locations of *Oxybaphus rotundifolius* (Round-leaf four-o'clock), and 10 locations of *Penstemon degeneri* (Degener beardtongue). Figures 1, 3, 6, 9, 12, 15, 18, and 21 present the full known distribution for all of the rare plant species, including these new records. We were concerned about the level of habitat fragmentation and habitat degradation found within and adjacent to the occurrences resulting from various land uses, especially housing developments, mining, water impoundment, and recreation.

Insect diversity and visitation rates

Eriogonum brandegei (Brandegee wild buckwheat)

We spent a total of 9 person hours collecting insects that visited *Eriogonum brandegei* flowers at two study sites, Droney Gulch and Southeast of Garden Park, Fremont County, Colorado. We collected 54 insects, and identified a total of 49 (Table 2). Of the 54 insects collected, nearly half (44%) were flies (Diptera). The flies were members of the Bombyliidae (bee flies, mostly in the genus *Geron*) and the Tachinidae (tachinid flies). Several Hymenoptera were also represented, accounting for 39% of the taxa collected, including ants (*Dorymyrmex insana* and *Formica* spp.), halictid bees (*Halictus confusus* and *Lasioglossum* spp.), and two wasp species (*Eucerceris fulvipes* and *E. superbus).* Only one other taxon was collected while visiting *E. brandegei,* a hemipteran species (*Phymata* sp.).

Table 2. Insects collected during visitation to *Eriogonum brandegei* at two sites in the middle Arkansas Valley, Fremont County, Colorado, July 18-22, 2001.

Order	**Family**	**Genus**	**Species**	**# collected**	**% of total collected**
Diptera (flies)	Bombyliidae (bee flies)	*Chrysanthrax*	*edititius*	2	4%
	Bombyliidae	*Geron*	sp.	10	19%
	Bombyliidae	*Poecilanthrax*	*willistoni*	1	2%
	Bombyliidae	*Villa*	sp.	2	4%
	Bombyliidae			2	4%
	Tachinidae (tachinid flies)			7	13%
Total Diptera				24	**44%**
Hemiptera (true bugs)	Reduviidae (ambush bugs)	*Phymata*	sp.	4	**7%**
Hymenoptera (bees, wasps, ants)	Formicidae (ants)	*Dorymyrmex*	*insana*	1	2%
	Formicidae	*Formica*	spp.	5	9%
	Halictidae (halictid bees)	*Halictus*	*confusus*	6	11%
	Halictidae	*Lasioglossum*	spp.	4	7%
	Sphecidae (sphecid wasps)	*Eucerceris*	*fulvipes*	4	7%
	Sphecidae	*Eucerceris*	*superbus*	1	2%
Total Hymenoptera				21	**39%**
Unidentified				5	**9%**
Total collected				54	100%

We also conducted 17 30-minute visual observations of insect visitation on *Eriogonum brandegei* flowers. Insects were not collected during these observations, but observers were able to distinguish between flies, ants, wasps, bees, and other insects. We observed a total of 709 insect visits during the course of all 17 30-minute observations. Of the 709 visits, we observed that 72% (512) were by flies, 15% (104) were by ants, 5% (37) were by wasps, 5% (32) were by bees, and 3% (24) were by other unidentified insects (Figure 27).

For each 30-minute observation period we calculated the rate that each open inflorescence was visited by flies, ants, wasps, bees, and other insects (Figure 28). The visitation rates were highest in flies, which visited, on average, 1.55 open inflorescences per 30 minutes (SE=0.73, n=512 visits). Ants visited an average of 0.26 open inflorescences per 30 minutes (SE=0.16, n=104 visits); wasps an average of 0.12 open inflorescences per 30 minutes (SE=0.11, n=37 visits); and bees an average of 0.11 open inflorescences per 30 minutes (SE=0.08, n=32 visits). All other insects combined visited an average of 0.07 open inflorescences per 30 minutes (SE=0.05, n=24 visits). The total average visitation rate for all of the insects that visited *E. brandegei*, including flies, ants, wasps, and bees, was 2.0 visits per open inflorescence per 30 minutes.

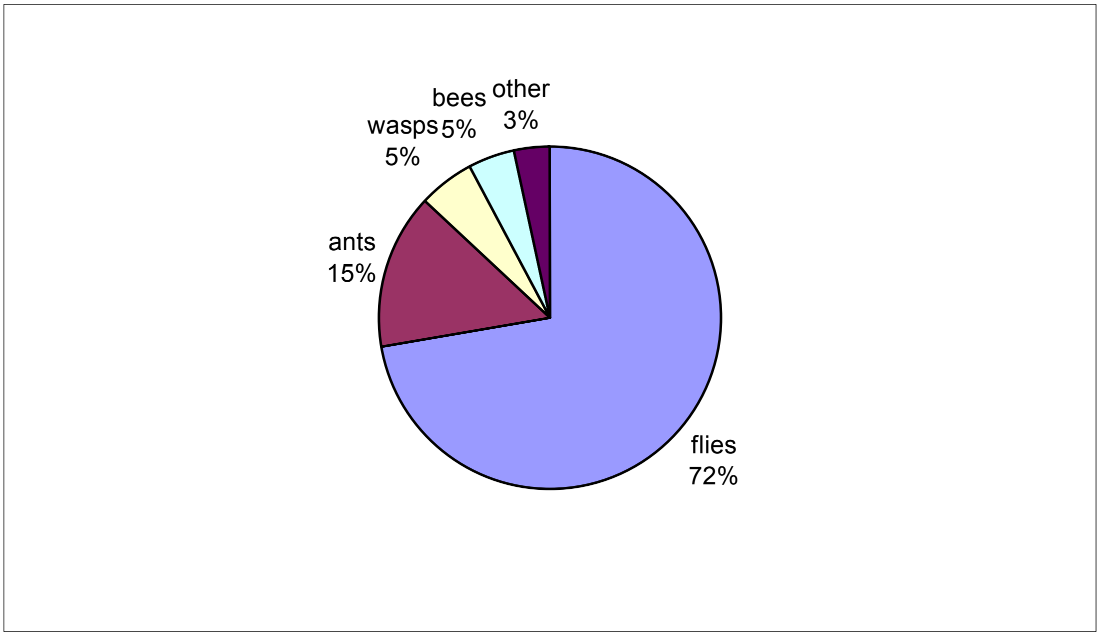

Figure 27. Proportion of observed insect visits by flies, ants, wasps, bees, and other unidentified insects during 17 30-minute observations of *Eriogonum brandegei* at two study sites in Colorado's middle Arkansas Valley: Droney Gulch and Southeast of Garden Park.

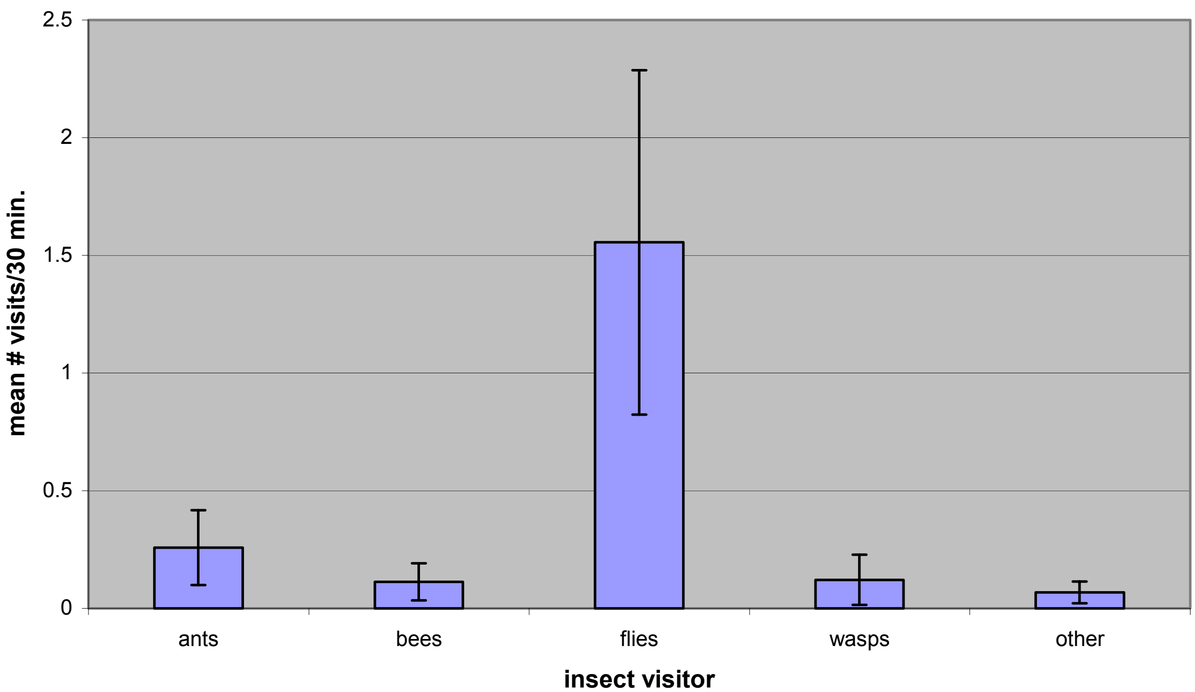

Figure 28. Average number of ant, bee, fly, wasp, and other insect visits per open *Eriognonum brandegei* inflorescences during 17 30-minute observation periods at two study sites in Colorado's middle Arkansas Valley: Droney Gulch and Southeast of Garden Park. Error bars show one standard error.

***Nuttallia chrysantha* (Golden blazing star)**

We spent a total of 6.5 person hours collecting insects that visited *Nuttallia chrysantha* at two study sites, Juniper Road in Pueblo County and Southeast of Garden Park, Fremont County, Colorado (Table 3), and collected a total of 95 insects. Of these, 88 were identified. Of the 95 collected, 61% (58) were bees in the order Hymenoperta. Bees of six genera were represented, most commonly halictid bees (*Lasioglossum* sp.), *Perdita* sp., and the honey bee (*Apis melifera*, a species not native to Colorado). At least five Diptera species were collected from four different families, including bee flies (Bombyliidae) and syrphid flies (Syrphidae). Although fairly common, the Diptera represented only about 7% of the insects collected. Another insect visitor to *N. chrysantha* were thrips (Thysanoptera, 7% of the total collected). Other visiting taxa included two beetles from the genus *Apion* (Coleoptera), and one leaf bug from the family Miridae (Hemiptera).

Table 3. Insects collected during visitation to *Nuttallia chrysantha* at two sites in the middle Arkansas Valley, Fremont and Pueblo County, Colorado, July 17-18, 2001.

Order	**Family**	**Genus**	**Species**	**# collected**	**% of total collected**
Coleoptera (beetles)	Aponidae (a weevil)	*Apion*	sp.	2	**2%**
Diptera (flies)	Anthomyiidae			1	1%
	Bombyliidae (bee flies)	*Poecilognathus*	*scolopax*	2	2%
	Syrphidae (syrphid flies)	*Eristalis*	*stipator*	1	1%
	Syrphidae	*Eupeodes*	*volucris*	1	1%
	Tachinidae (tachinid flies)			2	2%
Total Diptera				7	**7%**
Hemiptera (true bugs)	Miridae (plant bugs or leaf bugs)			1	**1%**
Hymenoptera (bees, wasps, and ants)	Andrenidae. (solitary bees)	*Andrena*	sp.	2	2%
	Andrenidae	*Perdita*	sp.	16	17%
	Apidae	*Apis*	*mellifera* (honey bee)	16	17%
	Apidae	*Bombus* (bumble bees)	*nevadensis*	4	4%
	Apidae	*Bombus*	*griseocollis*	1	1%
	Formicidae (ants)	*Formica*	sp.	11	12%
	Halictidae (halictid bees)	*Halictus*	*confusus*	1	1%
	Halictidae	*Lasioglossum*	sp.	18	19%
Total Hymenoptera				69	**73%**
Thysanoptera (thrips)				9	**9%**
Unidentified				7	**7%**
Total collected				95	100%

We also conducted 13 30-minute visual observations of insect visitation on *Nuttallia chrysantha* flowers. Insects were not collected during these observations, but observers were able to distinguish between flies, ants, wasps, bees, and other insects. We observed a total of 670 insect visits during the course of all 13 30-minute observations. Of the 670 visits, we observed that 37% (249) were by bees, 24% (158) were by wasps, 19% (125) were by flies, 10% (70) were by ants, and 10% (68) were by other unidentified insects (Figure 29).

For each 30-minute observation period we calculated the rate that each open corolla was visited by flies, ants, wasps, bees, and other insects (Figure 30). The visitation rates were highest in wasps, which visited, on average, 2.02 open corollas per 30 minutes (SE=0.96, n=158 visits). Bees visited an average of 0.30 open corollas per 30 minutes (SE=0.44, n=249 visits); flies an average of 1.00 open corollas per 30 minutes (SE=0.54, n=125 visits); and ants an average of 0.89 open corollas per 30 minutes (SE=0.47, n=70 visits). All other insects combined visited an average of 0.78 open corollas per 30 minutes (SE=0.31, n=70 visits). The total average visitation rate for all of the insects that visited *N. chrysantha*, including flies, ants, wasps, and bees, was 6.0 visits per open corolla per 30 minutes (SE=1.15, n=670).

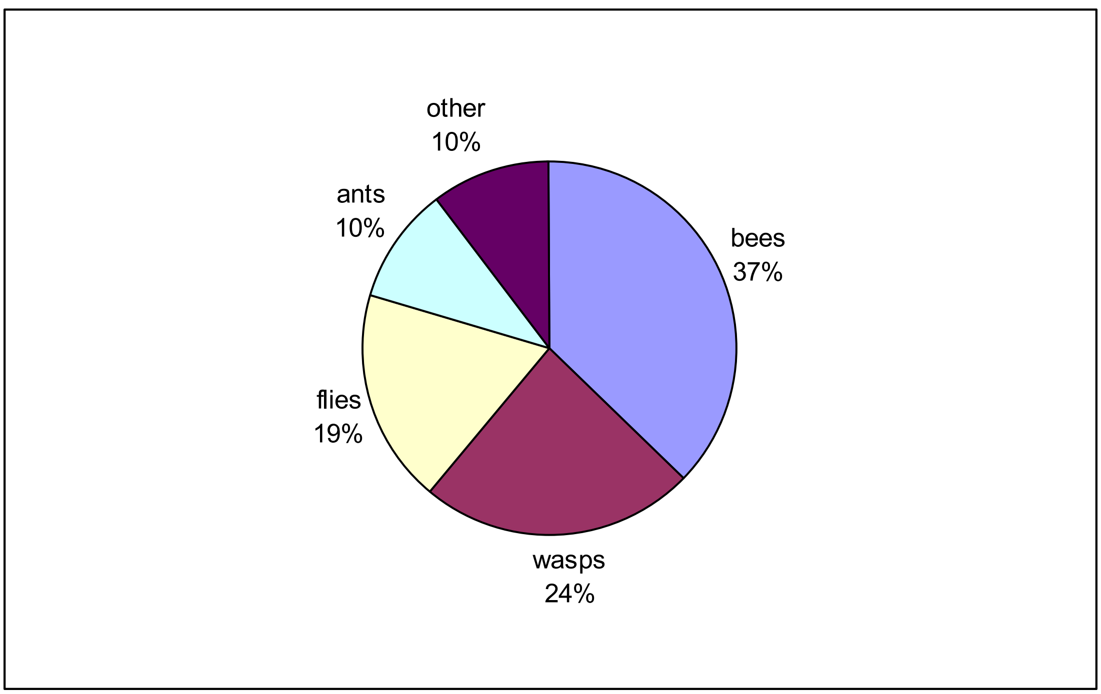

Figure 29. Proportion of observed insect visits by flies, ants, wasps, bees, and other unidentified insects during 13 30-minute observations of *Nuttalia chrysantha* at two study sites in Colorado's middle Arkansas Valley: Juniper Road and Southeast of Garden Park.

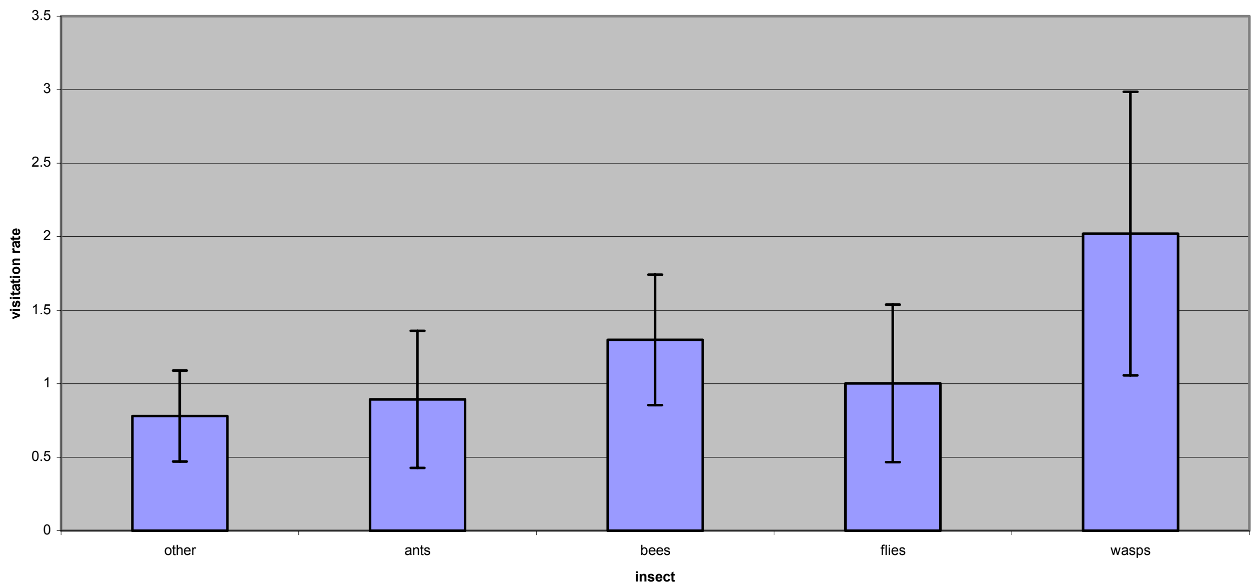

Figure 30. Average number of ant, bee, fly, wasp, and other insect visits per open *Nuttallia chrysantha* corolla during 13 30-minute observation periods at two study sites in Colorado's middle Arkansas Valley: Juniper Road and Southeast of Garden Park. Error bars show one standard error.

***Nuttallia densa* (Arkansas Canyon stickleaf)**

We spent a total of 5 person hours collecting insects that visited *Nuttallia densa* flowers at two study sites, McIntyre Hills and Cotopaxi, in Fremont County, Colorado. We collected 82 specimens, and identified a total of 63 insect taxa (Table 4). All of the insects identified were flies, bees, and one ant. Of the 82 collected, the vast majority (64%) were bees (5 genera in the Hymenoptera). Only one other hymenopteran species was represented, an ant (*Dorymyrmex insana*), accounting for 1% of the taxa collected. The flies (Diptera), 12% of the total collected, were members of the Bombyliidae (bee flies) and the Syrphidae (syrphid flies).

Table 4. Insects collected during visitation to *Nuttallia densa* at two sites in the middle Arkansas Valley, Fremont County, Colorado, July 21-24, 2001.

Order	**Family**	**Genus**	**Species**	**# collected**	**% of total collected**
Diptera (flies)	Bombyliidae (bee flies)	*Poecilognathus*	*scolopax*	2	2%
	Bombyliidae			1	1%
	Syrphidae (syrphid flies)	*Chrysotoxum*	*ypsilon*	4	5%
	Syrphidae	*Eupeodes*	*volucris*	3	4%
Total Diptera				10	**12%**
Hymenoptera (bees, wasps, ants)	Andrenidae (andredid bees)	*Andrena*	sp.	9	11%
	Andrenidae	*Perdita*	sp.	23	28%
	Apidae	*Bombus* (bumble bee)	*huntii*	1	1%
	Braconidae	*Bracon*	sp.	1	1%
	Formicidae (ant)	*Dorymyrmex*	*insana*	1	1%
	Halictidae (halictid bees)	*Lasioglossum*	sp.	18	22%
Total Hymenoptera				53	**65%**
Unidentified				19	**23%**
Total collected				82	100%

We also conducted 10 30-minute visual observations of insect visitation on *Nuttallia densa* flowers. Insects were not collected during these observations, but observers were able to distinguish between flies, wasps, bees, and other insects. We observed a total of 1,095 insect visits during the course of all 10 30-minute observations. Of the 1,095 visits, we observed that 68% (742) were by bees, 21% (230) were by flies, 10% (111) were by wasps, and only 1% (12) were by other unidentified insects (Figure 31).

For each 30-minute observation period we calculated the rate that each open corolla was visited by flies, wasps, bees, and other insects (Figure 32). The visitation rates were highest in bees, which visited, on average, 4.09 open corollas per 30 minutes (SE=1.25, n=742 visits). Flies visited an average of 1.05 open corollas per 30 minutes (SE=0.63, n=230 visits); wasps an average of 0.53 open corollas per 30 minutes (SE=0.51, n=111 visits). All other insects combined visited an average of 0.04 open corollas per 30 minutes (SE=0.02, n=70 visits). The total average visitation rate for all of the insects that visited *N. densa*, including flies, wasps, and bees, was 5.71 visits per open corolla per 30 minutes (SE=1.26, n=1,095).

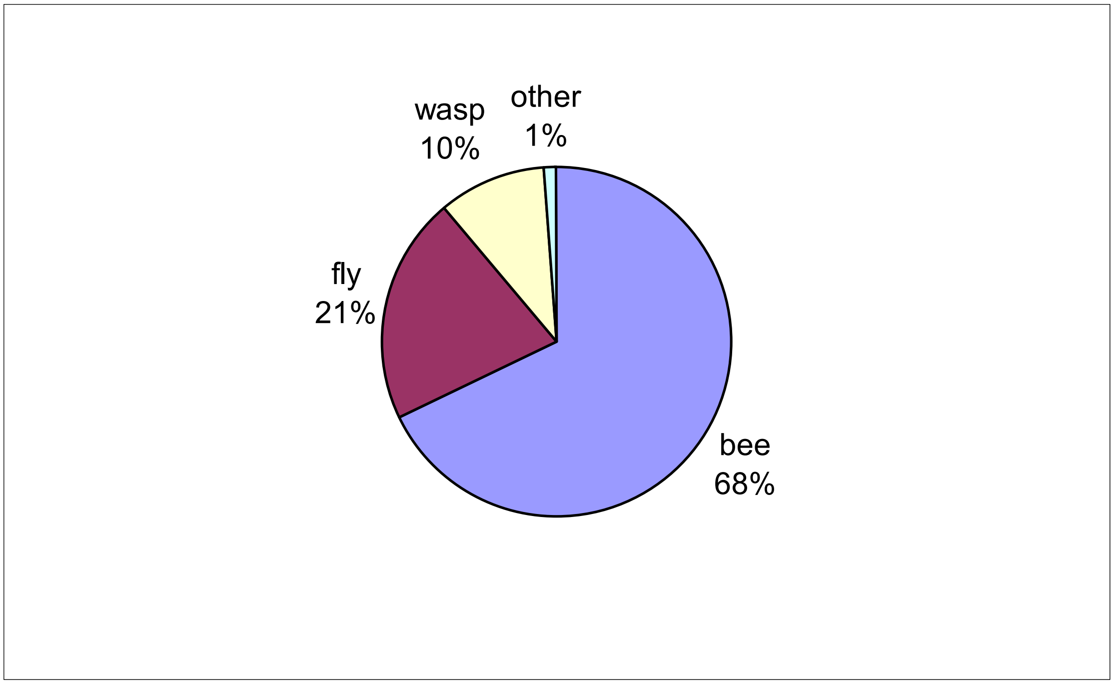

Figure 31. Proportion of observed insect visits by flies, wasps, bees, and other unidentified insects during 10 30-minute observations of *Nuttalia densa* at two study sites in Colorado's middle Arkansas Valley: Cotopaxi and McIntyre Hills.

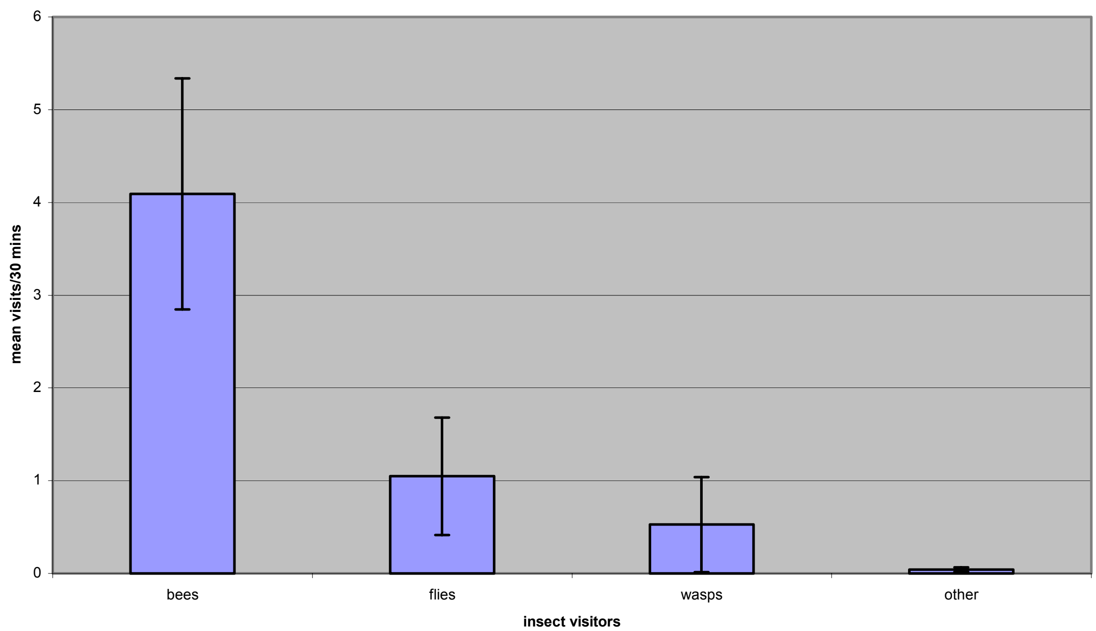

Figure 32. Average number of bee, fly, wasp, and other insect visits per open *Nuttallia densa* corolla during 10 30-minute observation periods at two study sites in Colorado's middle Arkansas Valley: Cotopaxi and McIntyre Hills. Error bars show one standard error.

***Oenothera harringtonii* (Arkansas Valley evening primrose)**
We spent a total of 4.5 person hours collecting insects that visited *Oenothera harringtonii* at two study sites, Juniper Road in Pueblo County and Pryor, Huerfano County, Colorado (Table 5), and collected and identified a total of 7 insects. Of the 7 collected, 85% (6) were bees in the order Hymenoperta. Bees of four genera were represented, including andrenid bees (*Andrena* sp.), halictid bees (*Lasioglossum sedi* and *Agapostemon texanus*), and carpenter bees (*Anthophora portera*). Although collected only one time, the sphinx moth (*Hyles lineata*) was also a noteworthy visitor since it is a known pollinator of other species of *Oenothera* (Stockhouse 1973).

Table 5. Insects collected during visitation to *Oenothera harringtonii* at two sites in the middle Arkansas Valley, Pueblo and Huerfano County, Colorado, June 1-4, 2003.

Order	**Family**	**Genus**	**Species**	**# collected**	**% of total collected**
Lepidoptera (butterflies and moths)	Sphingidae (sphinx or hawk moths, hornworms)	*Hyles*	*lineata*	1	**14%**
Hymenoptera (bees, wasps, ants)	Anthophoridae (carpenter bees)	*Anthophora*	*portera*	1	14%
	Halictidae (halictid bees)	*Lasioglossum*	*sedi*	1	14%
	Halictidae	*Agapostemon*	*texanus*	1	14%
	Andrenidae (andrenid bees)	*Andrena*	sp.	3	43%
Total Hymenoptera				6	**85%**
Unidentified				0	0
Total collected				7	100%

We also conducted nine 30-minute visual observations of insect visitation on *Oenothera harringtonii* flowers. Insects were not collected during these observations, but observers were able to distinguish between flies, bees, beetles and sphinx moths (*Hyles lineata*). We observed a total of 42 insect visits during the course of all nine 30-minute observations. Of the 42 visits, we observed that 79% (33) were by sphinx moths, 14% (6) were by bees, 5% (2) were by flies, and 2% (1) were by beetles (Figure 33).

For each 30-minute observation period we calculated the rate that each open corolla was visited by flies, bees, sphinx moths and beetles (Figure 34). The visitation rates were highest in sphinx moths, which visited, on average, 0.59 open corollas per 30 minutes (SE=0.40, n=33 visits). Bees visited an average of 0.22 open corollas per 30 minutes (SE=0.16, n=6 visits); flies an average of 0.04 open corollas per 30 minutes (SE=0.04, n=2 visits), and beetles an average of 0.03 open corollas per 30 minutes (SE=0.03, n=1 visit). The total average visitation rate for all of the insects that visited *O. harringtonii*, including sphinx moths, flies, bees, and beetles, was 0.89 visits per open corolla per 30 minutes (SE=0.38, n=42).

We also noted predation of the plants by hornworms, the larval stage of the sphinx moth. Bumblebees were noted to visit outside the observation periods. Sphinx moths were observed to move from flower to flower of different plants, and to probe deep within the flowers, suggesting that they make a significant contribution to outcrossing.

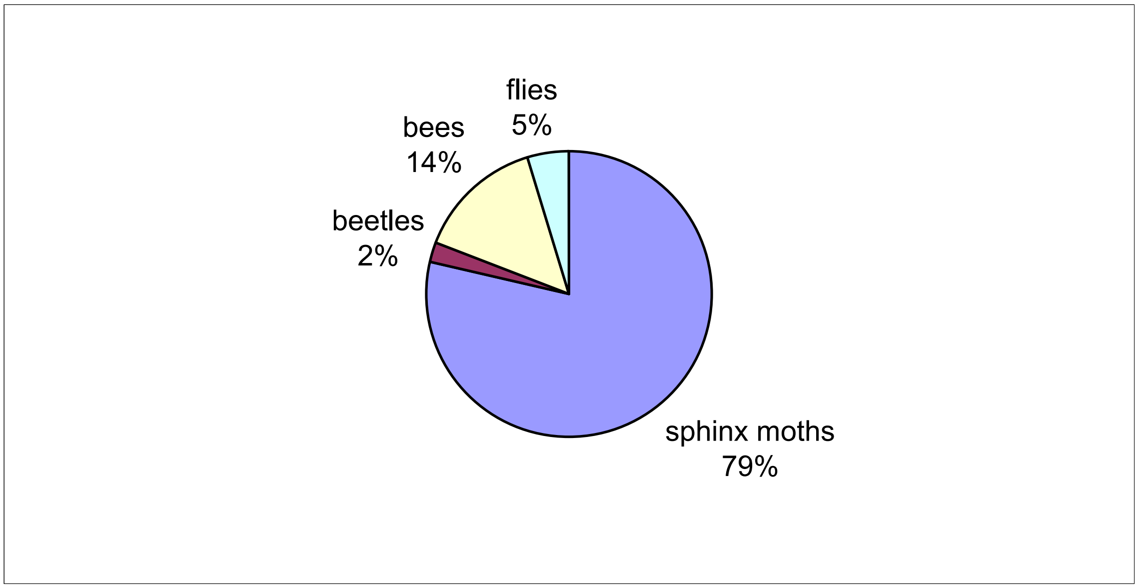

Figure 33. Proportion of observed insect visits by sphinx moths, flies, bees, and beetles during nine 30-minute observations of *Oenothera harringtonii* at two study sites in Colorado's middle Arkansas Valley: Juniper Road and Pryor.

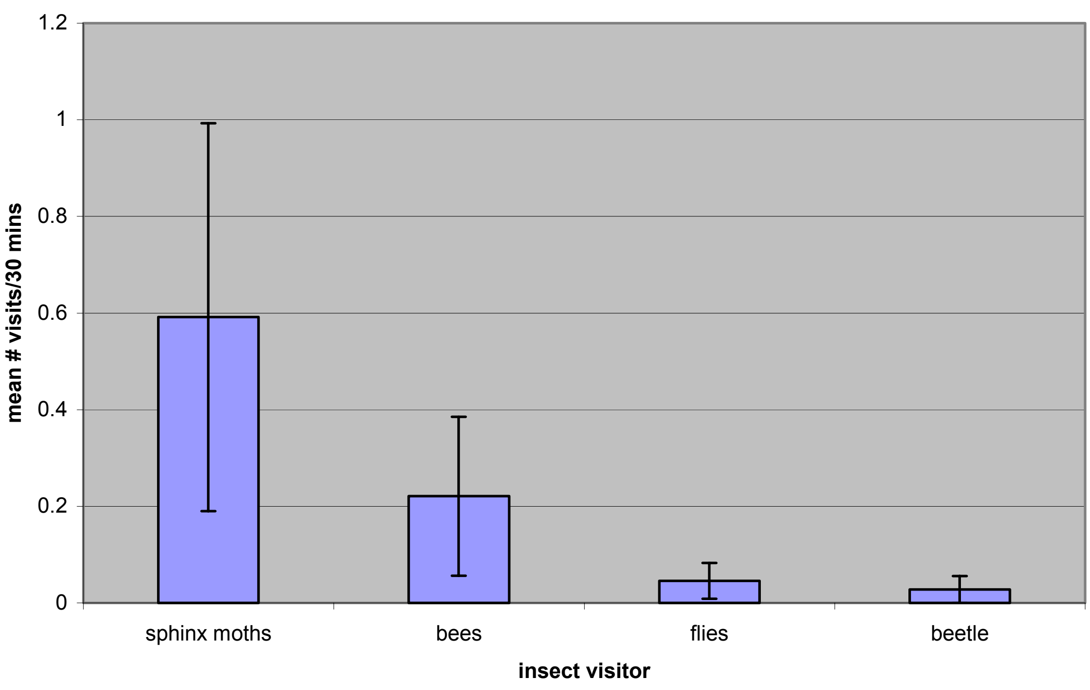

Figure 34. Average number of sphinx moth, bee, fly, and beetle visits per open *Oenothera harringtonii* corolla during nine 30-minute observation periods at two study sites in Colorado's middle Arkansas Valley: Juniper Road and Pryor. Error bars show one standard error.

***Oonopsis puebloensis* (Pueblo goldenweed)**

We spent a total of 13 person hours collecting insects that visited *Oonopsis puebloensis* at three study sites, Walker Ranch, Pueblo Reservoir North, and Pueblo West, in Pueblo County, Colorado, and collected a total of 129 insects (Table 6). Of these, 106 were identified. Of the 129 collected, 30% (39) were bees, wasps, and ants (Hymenoperta). Bees of seven genera were represented, including carpenter bees (Anthophoridae), halictid bees (Halictidae), and leaf cutting bees (Megachilidae). Eight Diptera species were collected from six different families, comprising 29% (37) of the total collected. The most common Diptera taxa were bee flies (Bombyliidae), especially a species in the genus *Geron*. Seven butterfly (Lepidoptera) species were also collected, comprising 13% of the total. Other visiting taxa included at least two grasshopper species (Orthoptera), two beetle (Coleoptera) individuals (*Saxinis omogera*), two seed bugs (*Lygaeus kalmii)*, and three leaf bugs from the Miridae (Hemiptera).

Table 6. Insects collected during visitation to *Oonopsis puebloensis* at three sites in the middle Arkansas Valley, Pueblo County, Colorado, July 16-18, 2001.

Order	**Family**	**Genus**	**Species**	**# collected**	**% of total collected**
Coleoptera (beetles)	Chrysomelidae (leaf beetles)	*Saxinis*	*omogera*	2	**2%**
Diptera (flies)	Asilidae (robber flies)	*Mallophorina*	*guildiana*	2	2%
	Sarcophagidae (flesh flies)	*Sarcophaga*	sp.	3	2%
	Bombyliidae (bee flies)	*Geron*	sp.	19	15%
	Bombyliidae	*Poecilanthrax*	*willistoni*	7	5%
	Bombyliidae	*Poecilognathus*	*scolopax*	3	2%
	Bombyliidae	*Villa*	sp.	1	1%
	Bombyliidae			1	1%
	Muscidae (muscid flies)			1	1%
Total Diptera				37	**29%**
Hemiptera (true bugs)	Lygaeidae (seed bugs)	*Lygaeus*	*kalmii*	2	2%
	Miridae (plant bugs or leaf bugs)			3	2%
Total Hemiptera				5	**4%**
Homoptera (cicadas, hoppers, and aphids)	Cicadellidae (leafhoppers)			1	**1%**
Hymenoptera (bees, wasps, ants)	Anthophoridae (carpenter bees)	*Ceratina*	sp.	1	1%
	Anthophoridae	*Melissodes*	sp.	1	1%
	Anthophoridae	*Orius*	sp.	1	1%
	Formicidae (ants)	*Conomyrma*	*insana*	8	6%
	Formicidae	*Formica*	sp.	4	3%
	Formicidae	*Monomorium*	*minimum*	2	2%
	Formicidae	*Tapinoma*	*sessile*	2	2%
	Halictidae (halictid bees)	*Lasioglossum*	sp.	7	5%

Order	Family	Genus	Species	# collected	% of total collected
	Megachilidae (leafcutting bees)	*Ashmeadiella*	sp.	1	1%
	Megachilidae	*Dianthidium*	sp.	6	5%
	Megachilidae	*Megachile*	sp.	4	3%
	Vespidae (paper wasps, yellow jackets)	*Euodynerus*	*annulatus*	2	2%
Total Hymenoptera				39	**30%**
Lepidoptera (butterflies and moths)	Hesperiidae (skippers)	*Ambliscirtes*	*aenus* (bronze roadside skipper)	1	1%
	Hesperiidae	*Pyrgus*	*scriptura* (small checkered skipper)	1	1%
	Hesperiidae	*Pyrgus*	*communis* (common checkered skipper)	1	1%
	Nymphalidae	*Euptoieta*	*claudia* (variegated fritillary)	10	8%
	Pieridae	*Colias*	*eurytheme* (orange sulfur)	1	1%
	Pieridae	*Nathalis*	*iole* (dainty sulphur)	2	2%
	Pieridae	*Pontia*	*protodice* (checkered white)	1	1%
Total Lepidotera				17	**13%**
Orthoptera (grasshoppers, crickets, katydids)	Acrididae (short-horned grasshoppers)	*Aeoloplides*	*turnbulli*	1	1%
	Acrididae	*Hesperotettix*	*viridis*	1	1%
	Acrididae			3	2%
Total Orthoptera				5	**4%**
Unidentified				23	**18%**
Total collected				129	100%

We also conducted 31 30-minute visual observations of insect visitation on *Oonopsis puebloensis* flowers. Insects were not collected during these observations, but observers were able to distinguish between butterflies, flies, bees, ants, wasps and thrips. We observed a total of 1,565 visits during the course of all 31 30-minute observations. Of the 1,565 visits, we observed that 36% (562) were by butterflies, 30% (474) were by flies, 16% (249) were by bees, 8% (123) were by ants, 3% (54) were by wasps, 1% (14) were by thrips, and 6 % (89) were by other unidentified insects (Figure 35).

For each 30-minute observation period we calculated the approximate rate that each open inflorescence was visited by butterflies, flies, bees, ants, wasps, thrips, and others insects (Figure 36). The visitation rates were highest in butterflies, which visited, on average, 2.51 open inflorescences per 30 minutes (SE=0.71, n=562 visits). Flies visited an average of 2.44 open inflorescences per 30 minutes (SE=1.66, n=474 visits), bees an average of 2.26 open inflorescences per 30 minutes (SE=1.12, n=249 visits), ants an average of 1.26 open inflorescences per 30 minutes (SE=0.69, n=123), wasps an average of 0.60 inflorescences per 30 minutes (SE=0.18, n=54), and thrips an average of 0.19 open inflorescences per 30 minutes (SE=0.13, n=14 visit). All other insects combined visited at an average rate of 0.45

inflorescences per 30 minutes (SE=0.20, n=89). The total average visitation rate for all of the insects that visited *O. puebloensis*, including butterflies, flies, bees, ants, wasps, and thrips, was 7.54 visits per open inflorescence per 30 minutes (SE=2.37, n=1,565). Flies were observed to stay at one inflorescence, probing several different flowers, for long periods of time, up to 12 minutes.

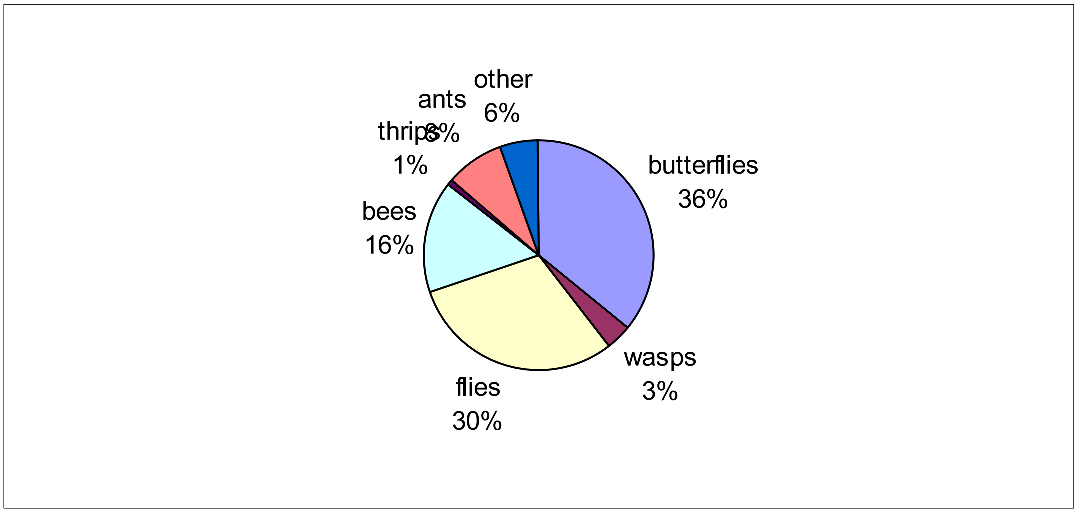

Figure 35. Proportion of observed insect visits by flies, ants, wasps, bees, butterflies, thrips, and other unidentified insects during 31 30-minute observations of *Oonopsis puebloensis* at three study sites in Colorado's middle Arkansas Valley: Walker Ranch, Pueblo Reservoir North, and Pueblo West.

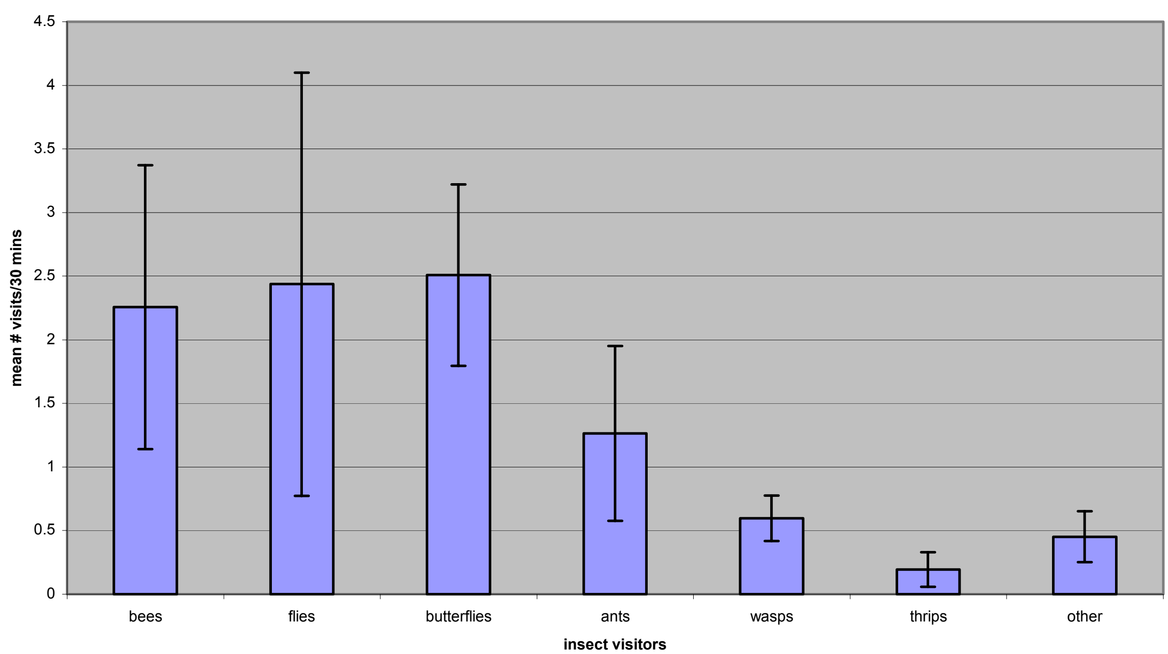

Figure 36. Average number of bee, fly, butterfly, ant, wasp, thrips and other insect visits per open *Oonopsis puebloensis* inflorescence during 31 30-minute observation periods at three study sites in Colorado's middle Arkansas Valley: Walker Ranch, Pueblo Reservoir North, and Pueblo West. Error bars show one standard error.

***Oxybaphus rotundifolis* (Round-leaf four o'clock)**
We spent a total of 2 person hours collecting insects that visited *Oxybaphus rotundifolius* at two study sites, Juniper Breaks and Pueblo Wildlife Area, Pueblo County, Colorado (Table 7), and collected and identified a total of 11 insects. Of the 11 collected, about half (45%) were Anthomyiidae flies (Diptera), and half (55%) were a species of halictid bee, *Lasioglossum sedi* (Hymenoptera).

Table 7. Insects collected during visitation to *Oxybaphus rotundifolius* at two sites in the middle Arkansas Valley, Pueblo County, Colorado, June 2-3, 2003.

Order	**Family**	**Genus**	**Species**	**# collected**	**% of total collected**
Diptera (flies)	Anthomyiidae			5	45%
Hymenoptera (bees, wasps, ants)	Halictidae (halictid bees)	*Lasioglossum*	*sedi*	6	55%
Unidentified				0	
Total collected				11	100%

We also conducted four 30-minute visual observations of insect visitation on *Oonopsis puebloensis* flowers. Insects were not collected during these observations, but observers were able to distinguish between Anthomyiidae flies, other flies, *Lasioglossum sedi* (a bee), and other bees. We observed a total of 207 visits during the course of all four 30-minute observations. Of the 207 visits, we observed that 73% (149) were by Anthomyiidae flies, 2% (5) were by other flies, 24% (50) were by *Lasioglosum sedi*, 1% (3) were by other bees (Figure 37).

For each 30-minute observation period we calculated the rate that each open corolla was visited by Anthomyiidae flies, other flies, *Lasioglossum sedi* (a bee), and other bees (Figure 38). The visitation rates were highest in Anthomyiidae flies, which visited, on average, 1.86 open corollas per 30 minutes (SE=1.86, n=149 visits). Other flies visited an average of 0.03 open corollas per 30 minutes (SE=0.03, n=5 visits); *Lasioglossum sedi* an average of 0.47 open corollas per 30 minutes (SE=0.16, n=50 visits), and other bees an average of 0.02 open corollas per 30 minutes (SE=0.01, n=3). The total average visitation rate for all of the insects that visited *O. rotundifolius*, including Anthomyiidae flies, other flies, *Lasioglossum sedi*, and other bees, was 1.39 visits per open corolla per 30 minutes (SE=0.59, n=207).

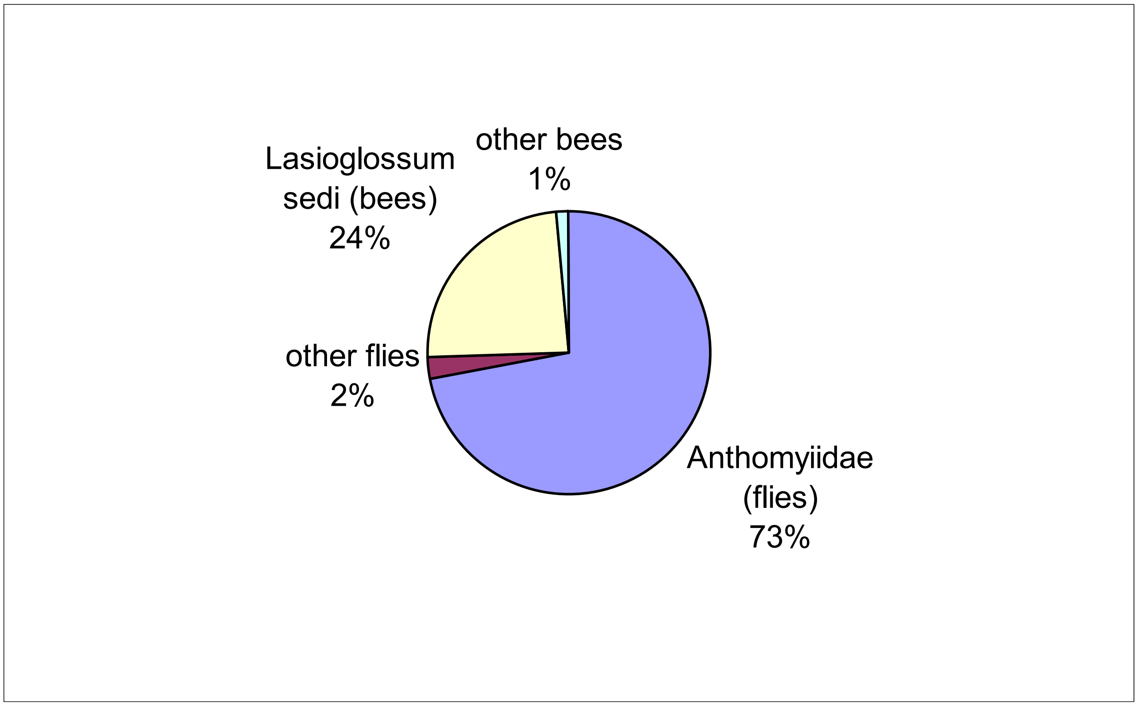

Figure 37. Proportion of observed insect visits by flies and bees during four 30-minute observations of *Oxybaphus rotundifolius* at two study sites in Colorado's middle Arkansas Valley: Juniper Breaks and Pueblo Wildlife Area.

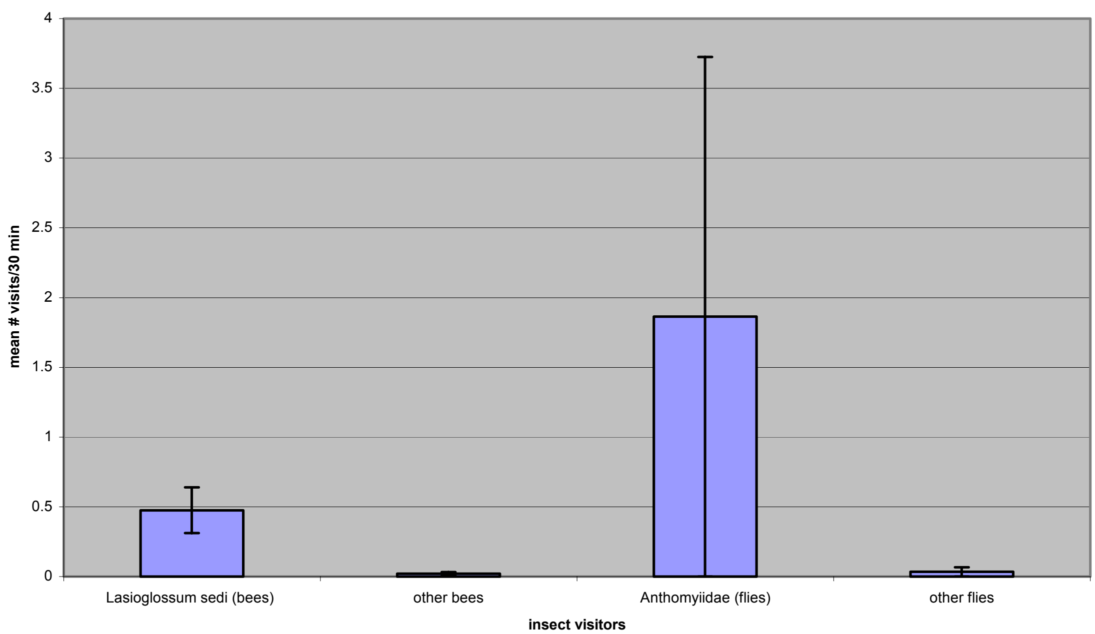

Figure 38. Average number of bee and fly visits per open *Oxybaphus rotundifolius* corolla during four 30-minute observation periods at two study sites in Colorado's middle Arkansas Valley: Juniper Breaks and Pueblo Wildlife Area. Error bars show one standard error.

***Penstemon degeneri* (Degener penstemon)**

We spent a total of 2.5 person hours collecting insects that visited *Penstemon degeneri* at one study site, Royal Gorge, Fremont County, Colorado (Table 8), and collected and identified a total of nine insects. Of the nine collected, 66% (6) were bees and wasps in the order Hymenoperta. At least two species of bee were represented, a carpenter bee (*Anthophora montana*) and a leaf cutting bee (*Osmia cobaltina*) as well as a wasp species (*Pseudomasaris vespoides*). The other species collected were bee flies (*Hemipenthes morio*) and syrphid flies (*Syrphus* sp.), both members of the order Diptera. A bee fly was observed to warm itself on nearby rocks and make repeated sallying visits to flowers of *Penstemon degeneri*.

Table 8. Insects collected during visitation to *Penstemon degeneri* at one site in the middle Arkansas Valley, Fremont County, Colorado, June 3-11, 2003.

Order	**Family**	**Genus**	**Species**	**# collected**	**% of total collected**
Diptera (flies)	Bombyliidae (bee flies)	*Hemipenthes*	*morio*	2	22%
	Syrphidae (syrphid flies)	*Syrphus*	sp.	1	11%
Total Diptera				3	**33%**
Hymenoptera (bees, wasps, ants)	Anthophoridae (carpenter bees)	*Anthophora*	*montana*	2	22%
	Megachilidae (leafcutting bees)	*Osmia*	*cobaltina*	1	11%
	Megachilidae	*Osmia*	sp.	1	11%
	Vespidae (paper wasps, yellow jackets)	*Pseudomasaris*	*vespoides*	2	22%
Total Hymenoptera				6	**66%**
Unidentified				0	0
Total				9	100%

We also conducted five 30-minute visual observations of insect visitation on *Penstemon degeneri* flowers. Insects were not collected during these observations, but observers were able to distinguish between flies, bees, and wasps. We observed a total of 32 visits during the course of all five 30-minute observations. Of the 32 visits, we observed that 40% (13) were by flies, 38% (12) were by bees, and 22% (7) were by wasps (Figure 39).

For each 30-minute observation period we calculated the rate that each open corolla was visited by flies, bees, and wasps (Figure 40). The visitation rates were highest in flies, which visited, on average, 0.23 open corollas per 30 minutes (SE=0.10, n=13 visits). Bees visited an average of 0.21 open corollas per 30 minutes (SE=0.11, n=12 visits), and wasps an average of 0.15 open corollas per 30 minutes (SE=0.10, n=7 visits). The total average visitation rate for all of the insects that visited *P. degeneri*, including flies, bees, and wasps, was 0.6 visits per open corollas per 30 minutes (SE=0.19, n=32).

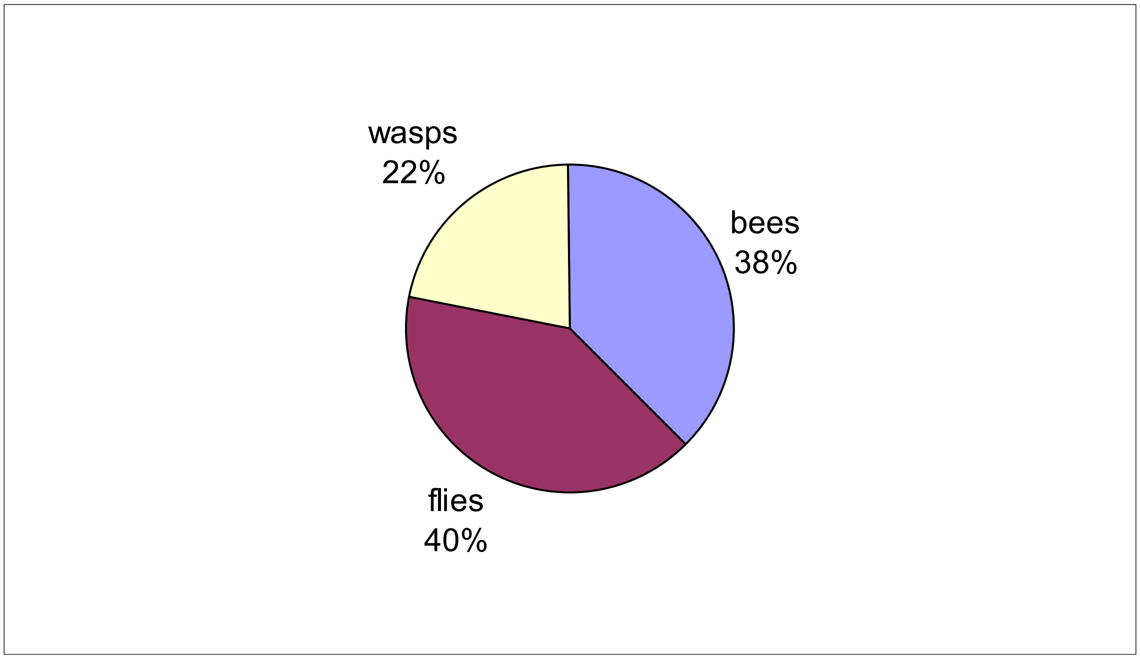

Figure 39. Proportion of observed insect visits by flies, bees, and wasps during five 30-minute observations of *Penstemon degeneri* at one study site in Colorado's middle Arkansas Valley: Royal Gorge.

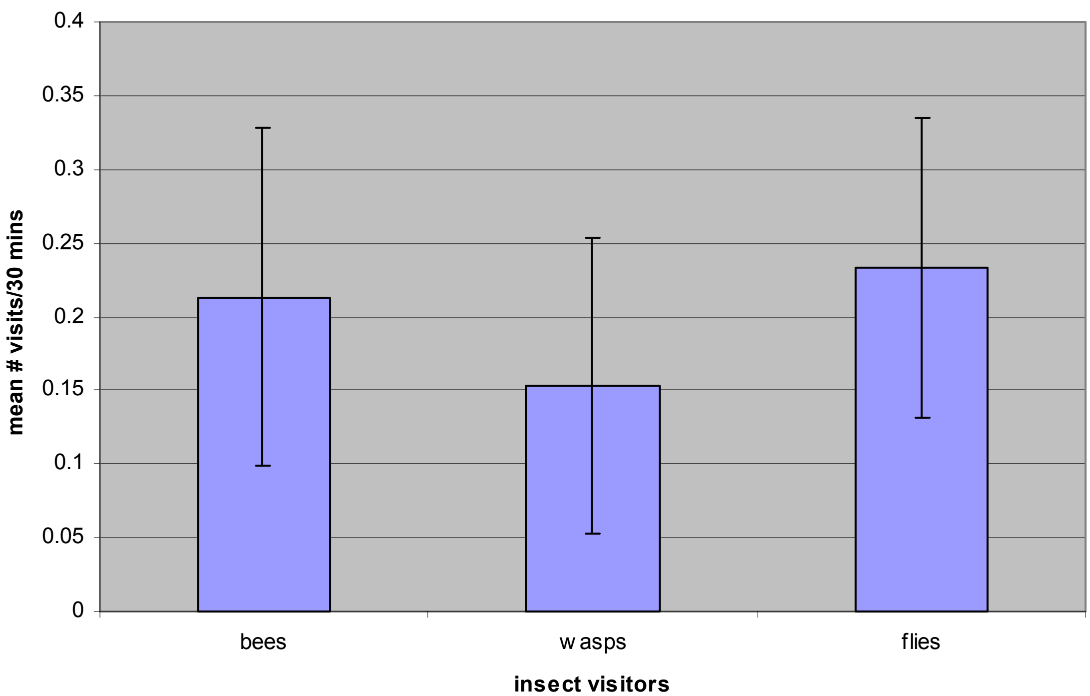

Figure 40. Average number of bee and fly visits per open *Penstemon degeneri* corolla during five 30-minute observation periods at one study site in Colorado's middle Arkansas Valley: Royal Gorge. Error bars show one standard error.

Discussion

Insect diversity

Although specific pollinators cannot be definitively determined with the results of this study, important plant-insect relationships are suggested. *Eriogonum brandegei* was primarily visited by flies, bees, and ants, *Nuttallia chrysantha* was visited primarily by bees and flies, *Nuttallia densa* by bees and flies, *Oenothera harringtonii* by bees and sphinx moths, *Oonopsis puebloensis* by flies, bees, and butterflies, *Oxybaphus rotundifolius* by flies and bees, and *Penstemon degeneri* by flies, bees, and wasps. Although all of the insects are potential pollen carriers, of the 55 insect taxa identified, bees, flies, and sphinx moths are most likely to be important pollinators. None of the insect species are rare, nor are they considered to be specialists (pers. comm. Kondratieff 2004).

The rare plants are probably using a diverse array of unspecialized, generalist pollinators as pollen vectors. Reliance on a variety of pollinators probably buffers plants from population swings of any one pollinator (Parenti et al. 1993). Most plant species are opportunistic. They use more than one pollinator and are usually capable of self- pollination (pers. comm. Fiedler 2004). The plants in this study that are most likely to rely largely on insects for outcrossing, *Oenothera harringtonii*, *Nuttallia chrysantha*, and *N. densa*, are probably capable of self-pollination. Sustaining populations of appropriate pollinators for these species is especially important because of the emphasis in their reproductive strategies on cross-pollination. In more detailed studies of *Oxybaphus rotundifolius*, it was determined that this species uses several different pollinators as well as the ability to self- pollinate (Kelso et al. 2003). Nonetheless, populations of all of the rare plants probably benefit from cross-pollination facilitated by insects because cross-pollination contributes to genetic variation within the species.

Overall, bees are the most likely pollinators of the rare plants because bees are considered to be the most important pollinators of plants in general (Borror et al. 1989, Leahy 1987). All of the rare plants in this study were visited by bees. Bees were especially common visitors to *Nuttallia chrysantha, N. densa, Oxybaphus rotundifolius and Penstemon degeneri*. The most common bee visitors to the rare plants in this study were halictid bees (five species in the Halictidae) and solitary bees (two species in the Andrenidae). These bees are solitary nesters, and nest in the ground (Borror et al. 1989). Sometimes large numbers of the solitary bees will nest close together, usually in areas where the vegetation is sparse (Borror et al. 1989). Open areas of bare ground are abundant in the habitats that support the rare plants (Colorado Natural Heritage Program 2004), so it is not surprising that a high level of ground nesting bee species richness would be found in these areas. Three species of *Bombus* (bumble bees) were collected in association with the *Nuttallia* species. Bumble bees also nest in the ground, but in colonies.

Flies (Diptera) also visited all of the rare plants studied, and were especially common visitors to *Eriognonum brandegei, Oonopsis puebloensis, Oxybaphus rotundifolius* and *Penstemon degeneri*. The most common dipteran visitors were bee flies (six species in the Bombyliidae) and syrphid flies (four species in the Syrphidae). A fly in the Anthomyiidae was a common visitor to *Oxybaphus rotundifolius*. The flies were observed spending especially long periods of time at the flowers of *Oonopsis puebloensis*, and were potentially effecting pollination in all of the species. Although flies are known to be effective pollinators (Borror et al. 1989), they are also thought to be irregular and unreliable pollinators because, unlike bees, they do not gather food to feed their young, and generally utilize many different sources of food (Faegri and van der Pijl 1979). Flies are among the most common insects that visit flowers (Kearns and Inouye 1994), but their role in pollination systems is not well documented (Kearns 2001). Many flies live in water in their larval stage (Borror et al. 1989). Bombyliidae often visit water holes in arid regions (Borror et al. 1989).

Kelso and her colleagues (Kelso et al. 2003) also observed that *Oxybaphus routundifolia* was visited by fly and bees species. They documented two fly (Diptera) species (*Syrphus* sp. and *Hydrophoria* sp.), and eight bee (Hymenoptera) species (*Bombus nevadensis*, two *Anthophora* species, two *Dialictus* species, and three species from the family Halictinae). None of these insects were collected in association with *O. rotundifolius* in the present study, further supporting the notion that *O. rotundifolius* utilizes a diverse array of insects for pollination.

Wasps visited five of the seven rare plants, *Eriogonum brandegei, Nuttallia chrysantha, N. densa, Oonopsis puebloensis, and Penstemon degeneri*. Two species of sphecid wasps (Sphecidae) and two species of vespid wasps (Vespidae) were collected in association with the rare plants. Sphecid wasps commonly visit flowers (Leahy 1987) and nest in burrows in the ground (Borror et al. 1989). However, unlike bees, who feed their larvae honey and pollen, wasps feed larvae animal tissue, so they are less likely to probe flowers and thereby gather pollen. Nonetheless, pollen may be transferred as they visit.

Ants (Formicidae) visited four of the seven rare plants, *Eriognonum brandegei, Nuttallia chrysantha, N. densa,* and *Oonopsis puebloensis*. Pollination by ants is possible, though it is very rare and unlikely (Hickman 1974, Faegri 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).

Three of the seven rare plants, *Eriognonum brandegei, Nuttallia chrysantha,* and *Oonopsis puebloensis*, were visited by true bugs (Hemiptera). Although they may carry pollen, true bugs are probably not important pollinators since they were observed so infrequently. Four ambush bugs (*Phymata* sp. in the Reduviidae) were collected from the flowers of *Eriognonum brandegei*. Ambush bugs use flowers as a site for attacking prey (pers. comm. Kondratieff 2004).

Oenothera harringtonii and *Oonopsis puebloensis* were the only rare plants visited by Lepidoptera. *Oenothera harringtonii* was visited by a sphinx moth (*Hyles lineata*). This species of sphinx moth has been documented as a pollinator of other species of *Oenothera* (Stockhouse 1973). Sphinx moths are known to be strong fliers (Borror et al. 1989), and they have been documented to travel up to 20 miles (Stockhouse 1973). Larvae of most sphinx moths pupate underground (Leahy 1987).

Oonopsis puebloensis was visited by seven butterfly species. It is possible that these species are involved in the pollination of this plant. However, most butterflies are not good pollinators because pollen does not stick to their legs or proboscis and the butterflies do not make proper contact with the flower's stigma (Opler 2003).

A few other insects were observed that probably do not play an important role as pollintors of the rare plants. Thrips (Thysanoptera) tend to be plant feeders, attacking flowers, leaves, fruits, twigs or buds (Borror et al. 1989). Beetles (Coleoptera), leaf hoppers (Homoptera), and grass hoppers (Orthoptera) visited a few of the rare plants very infrequently.

Insect visitors could also have a detrimental effect on the plants. Ants and other insects could be seed predators, and/or nectar thieves (Faegri and van der Pijl 1979, Westoby et al. 1991). The larvae of hawkmoths (hornworms) eat the buds and leaves of *Oxybaphus rotundifolius* (pers. comm. Kelso 2004) and *Oenothera harringtonii*. Two species of ants (*Formica*) were observed stealing nectar and western harvester ants (*Pogonomyrmex occidentalis*) were observed carrying seeds of *Oxybaphus rotundifolius* (pers. comm. Kelso 2004). Bees could also be pollen thieves of *Oenothera harringtonii* (pers. comm. Raguso 2002).

Insect visitation rates

For plants 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 any of the plant species studied. Without additional information about how much pollen is carried by the insect visitors, whether or not they are truly affecting pollination, and the importance of insects to the maintenance of genetic diversity and heterozygosity in the plant species studied, 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 all species appeared to include a healthy mix of size classes. It therefore seems that the current visitation rates for *Eriogonum brandegei* (total of 2.0 visits/open inflorescence/30 minutes), *Nuttallia chrysantha* (6.0 visits/open corolla/30 minutes), *Nuttallia densa* (5.7 visits/open corolla/30 minutes, *Oenothera harringtonii* (0.89 visits/open corolla/30 minutes), *Oonopsis puebloensis* (7.54 visits/ inflorescence /30 minutes), *Oxybaphus rotundifolius* (1.39 visits/open corolla/30 minutes, and *Penstemon degeneri* (0.6 visits/open corolla/30 minutes) are high enough to assure effective pollination of these species. Further research is warranted to increase confidence that this is the case. This study provides baseline data from which this question can be more fully evaluated in the future. If the insect visitation rates fall over time, this may indicate that the reproductive system of the plant species is being compromised. It should be noted however, that visitation rates can respond to subtle changes such as microclimate (Kearns and Inouye 1993), temperature, light, season (McCall and Primack 1992), floral density, and competition for nectar with other species (Kearns 2001), which may not be problematic to the plant-insect relationship. Year to year variation is also common, as is site to site variation, especially with flies (Kearns 2001).

Management implications

Information about insect visitors to the rare plants of the middle Arkansas Valley 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, halictid bees (Halictidae), solitary bees (Andrenidae), and bumble bees (*Bombus*) nest in the ground, and the larvae of most sphinx moths pupate underground. Recreational uses such as hiking, mountain biking, and off-road vehicle use, as well as mining and grazing, may disturb the nest sites. Flies and other insects may need water for certain life stages, which is an important management consideration in the arid habitats of the middle Arkansas Valley. 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 the rare plants of the middle Arkansas Valley. While this area has experienced and continues to experience a great deal of habitat fragmentation, there are areas that are intact and could benefit from long-term protection strategies.

Managing for pollinators is likely to benefit the rare plants as residential, recreational, and industrial developments decrease the amount of natural habitat in the area that can support populations of pollinators. Appropriate management of natural vegetation in the vicinity of populations of the rare plants is likely to benefit pollinators and may improve the likelihood of persistence for currently unknown populations of the rare plants.

Monitoring the rare plant populations to detect non-native plant invasions may also contribute to the conservation of pollinator resources for the rare plants of the middle Arkansas Valley. Weeds could present a problem not only by competing with the rare plants for space, sunlight, and soil moisture, but also by competing with the rare plants for pollinators (Simonson et al. 2001), which could result in inadequate pollination of rare plants.

Pesticides and herbicides may cause pollinators to decline. This stress, in combination with habitat destruction and fragmentation, and introduction of non-native plants could also reduce pollinator population size and distribution (Bond 1995).

Management practices may need to be altered as additional information about mutualistic relationships is discovered. Sustaining populations of appropriate pollinators is especially important for the species that may be obligate cross-pollinators such as *Oenothera harringonii*, *Nuttallia chrysantha, and N. densa*.

Recommendations for further research and conservation actions

Additional research is warranted to better understand the biology and ecology of the rare plants of the middle Arkansas Valley. Further elucidation of the reproductive ecology and plant-insect relationships of the rare plants in this study could be gained with species-specific studies on pollen flow, nutritional content of nectar and seeds, seed set and seedling recruitment success, and the impacts of seed, pollen and nectar predation. Expanding this research to additional study sites may offer a better understanding of 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 ecosystems.

Further inventory is necessary to gain a more complete picture of the full distribution of the rare plants of the middle Arkansas Valley. Habitat inaccessibility, primarily because of the high percentage of private lands, 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.

More information is also needed about the insects found to be common visitors to the rare plants. Specific information about their distribution, habitat, and behavior would assist with the conservation of the rare plants of the middle Arkansas Valley.

Currently, the protection afforded the rare plants is minimal. Although *Eriogonum brandegei, Nuttallia chrysantha, Oenothera harringtonii,* and *Penstemon degeneri* are included on federal sensitive species lists, the majority of the plant populations are on private lands. Populations on state and Department of Defense lands are not provided any special protection. Thus, protection efforts for these species, as well as the numerous other imperiled species in the middle Arkansas Valley, is complicated by the complexity of land ownership and land management patterns. I hope that the information collected through this research is used to examine issues related to land protection, recreation management, restoration, and conservation planning for all of the imperiled species and ecological systems of the middle Arkansas Valley.

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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 communities 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**

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.