Aquilegia laramiensis A. Nelson (Laramie columbine): A Technical Conservation Assessment

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

January 20, 2006

Hollis Marriott and Monica L. Pokorny
Garcia and Associates
7550 Shedhorn Drive
Bozeman, MT 59718
406-582-0661
406-582-0659

Peer Review Administered by
Society of Conservation Biology

Marriott, H. and M.L. Pokorny (2006, January 20). *Aquilegia laramiensis* A. Nelson (Laramie columbine): a technical conservation assessment. [Online]. USDA Forest Service, Rocky Mountain Region. Available: http://www.fs.fed.us/r2/projects/scp/assessments/aquilegialaramiensis.pdf [date of access].

Acknowledgments

We are grateful to several of our colleagues who have authored thorough and clearly-written technical conservation assessments, providing us with excellent examples to follow, including Bonnie Heidel (Wyoming Natural Diversity Database [WYNDD]), Joy Handley (WYNDD), Denise Culver (Colorado Natural Heritage Program), and Juanita Ladyman (JnJ Associates LLC). Beth Burkhart, Kathy Roche, and Richard Vacirca, former and current Biologists for the Species Conservation Project of the Rocky Mountain Region, USDA Forest Service, provided feedback relevant to meeting the goals of the project. Field botanist Dennis Horning generously shared his insights on the distribution and habitat requirements of *Aquilegia laramiensis*. Bonnie Heidel and Tessa Dutcher (WYNDD) provided the data we needed in a timely fashion. We thank Curator Ron Hartman and Manager Ernie Nelson of the Rocky Mountain Herbarium, University of Wyoming, for their assistance, and for continued access to their fine facilities. Other herbaria kindly provided label and database information, including the Charles E. Bessey Herbarium (Nebraska), Utah State University Intermountain Herbarium, and the Missouri Botanical Garden Herbarium. John Proctor and Tim Byer, with Medicine Bow-Routt National Forest, contributed helpful discussions regarding current and future conservation needs of *A. laramiensis*.

Authors' Biographies

Hollis Marriott is currently a freelance botanist based in Laramie, Wyoming. Her education includes a B.A. in Biology from Stanford University, and an M.S. in Botany (floristics, systematics) and an M.A. in Music (composition) from the University of Wyoming. She has worked as a field botanist and conservation biologist since 1977 in Wyoming, western South Dakota, and southeastern Montana. Projects include general floristic inventories, rare plant status surveys, project-based rare plant surveys, rare plant monitoring, natural area assessment, rare plant/recreation conflict resolution, and vegetation classification, characterization and mapping. In addition to independent contract work, she has served as Botanist/Coordinator with the Wyoming Natural Diversity Database (1986-1992), Public Lands Protection Planner with the Wyoming Nature Conservancy (1992-1994), and Ecologist with the Black Hills Community Inventory (1996-1998).

Monica L. Pokorny received her B.S. degree (with honors) in Biology, with an emphasis in Botany and a minor in wildlife biology, from the University of Montana. After completion of her Bachelor's degree, she worked with the USDA Forest Service and The Nature Conservancy on forest inventory and analysis; forest fire fuel planning; and monitoring rare, endangered, and sensitive plant species. Her first professional position was as a Research Biologist for the Craighead Wildlife - Wildlands Institute where she was involved in the development of an improved land cover classification and grizzly bear habitat assessment of the Salmon-Selway ecosystem using Landsat TM imagery and wilderness botanical survey. She obtained a M.S. in Land Resources and Environmental Sciences from Montana State University. Her Masters' research focused on quantifying vegetative species richness and densities in a grassland plant community; determining the ability of functional group diversity at resisting invasion by a non-indigenous invader; and quantifying the ecological role of indigenous and non-indigenous functional groups in a grassland ecosystem. Monica continues to work with invasive non-indigenous plants and rare plants. She has written a botanical guide for the noxious weeds of Montana and works on contract mapping the location and abundance of rare, sensitive, and invasive plant species. Monica is currently developing a Restoration Program for Montana State University and works as a consultant for Garcia and Associates, an environmental consulting company in Bozeman, Montana.

Cover Photo Credit

Aquilegia laramiensis (Laramie columbine) from Fertig 2000 (M. Russell photo).

SUMMARY OF KEY COMPONENTS FOR CONSERVATION OF *AQUILEGIA LARAMIENSIS*

Status

Aquilegia laramiensis (Laramie columbine) is designated a sensitive species in Region 2 of the USDA Forest Service, and it is on the sensitive list for the Bureau of Land Management in Wyoming. This columbine has been found on lands managed by the State of Wyoming, but there are no state laws providing protection for rare plant species. It is not currently a candidate for listing as Threatened or Endangered under the federal Endangered Species Act. NatureServe and the Wyoming Natural Diversity Database have assigned *A. laramiensis* the rank of G2S2, "imperiled because of rarity" on global and state levels, respectively. While heritage ranks may be used by land management agencies as guidance, they confer no legal protection for a species.

The entire known range of *Aquilegia laramiensis* is within Region 2 of the USDA Forest Service, in the Laramie Mountains in southeastern Wyoming. Most of the known occurrences are on public lands managed for multiple use. The majority of the documented occurrences (25 of 43) are on lands managed by the Medicine Bow National Forest. One occurrence occurs within the Ashenfelder Basin Special Interest Area on the Medicine Bow National Forest, an area to be managed for botanical and natural values.

Occurrences of *Aquilegia laramiensis* are generally small. Estimated sizes range from ten to 500 aboveground individuals, with most less than 100. However, some occurrences may be significantly larger than estimated.

Aquilegia laramiensis grows on outcrops of igneous and metamorphic rocks, at elevations ranging from 1,646 to 3,078 m (5,400 to 10,100 ft.). Some of the largest occurrences are on ridgecrests that are essentially all rock outcrop, sometimes several kilometers in length. At only a few sites where *A. laramiensis* has been found are the outcrops small enough to be well-shaded by trees. In all situations, the columbine occupies only a very small fraction of the area covered by rock, with distribution patchy and intermittent. Plants are found on small shaded microsites such as ledges, bases of outcrops, large crevices, and soil pockets among boulders.

Very little is known regarding the autecology, demography, and community ecology of *Aquilegia laramiensis*. There is no information concerning population trends as most of the known occurrences were only recently documented.

Primary Threats

There are no known existing threats to the viability of *Aquilegia laramiensis* across Region 2. Several potential threats have been identified.

Aerial application of herbicide on the Medicine Bow National Forest is the one potential threat that could easily affect the overall viability of *Aquilegia laramiensis*. No invasive species were found on *A. laramiensis* microsites or on outcrops during surveys in 2003 and 2004. However, there is a proposal to aerially apply Plateau® herbicide across the Medicine Bow National Forest for control of cheatgrass (*Bromus tectorum*). This herbicide targets broadleaf plants, like *A. laramiensis*, as well as grasses. A broadcast application of Plateau® herbicide would be a serious threat to native plant species in a target area, particularly any that are already under stress for any reason.

Aquilegia laramiensis is known to be of interest to gardeners. Although cultivated plants and garden-collected seeds are available commercially, collection of this plant for gardening has been identified by others as a potential threat. The USDA Forest Service has prohibitions against the collection of rare plant species. However, because access to *A. laramiensis* sites is difficult and time-consuming and because public use of the area is relatively light, patrol of known sites is not justified given limited agency resources and the likelihood that collectors would be caught or deterred. It is unlikely that the overall viability of *A. laramiensis* would be affected by non-commercial collecting, but extirpation of small accessible occurrences may be a concern. Of 30 occurrences surveyed in 2003 and 2004, three are considered vulnerable due to easy access and small occurrence size.

A similar potential threat to small, accessible occurrences is intentional extirpation. Within the plant conservation community, there is some concern that rare plant occurrences may be at risk of damage by individuals who fear governmental restrictions or even seizure of land for protection of rare species. Whether such risk exists in the case of *Aquilegia laramiensis* is unknown.

Timber harvest and fire are not likely to affect most occurrences of *Aquilegia laramiensis*. In a few cases, trees contribute some shading to occupied microsites, and removal of trees during timber harvest or fire could reduce shading. However, most of the rock outcrops that constitute columbine habitat are unsuitable for timber harvest and have insufficient fuels to burn. *Aquilegia laramiensis* can tolerate intense fire, at least in some cases, as was demonstrated at several sites that burned in 2002. However, the topic of fire impact is controversial, and some believe that catastrophic fire could impact this species.

Aquilegia laramiensis occurs on more mesic and shaded sites within its range, suggesting that climatic warming may reduce habitat for the species. Climate change is potentially the most serious threat to overall population viability, but there is tremendous uncertainty regarding its potential severity and effects

Primary Conservation Elements, Management Implications and Considerations

Assigning conservation status to *Aquilegia laramiensis* is complicated by the existence of conflicting factors. The species is common within its range, but its global range is limited. Many occurrences are small, but it is not clear that this small size is a risk to the overall viability of the species. Large areas of unsurveyed habitat have high potential for *A. laramiensis*. There is little in the way of management conflict and little impact from human use in general. Climatic warming may significantly reduce the abundance of the species, but this threat is outside the realm of management. In summary, *A. laramiensis* appears to be stable at this time.

It is difficult to identify conservation elements for *Aquilegia laramiensis* as little is known about its biology and ecology, but some elements can be hypothesized based on its apparent habitat requirements. It grows on rock outcrops, occupying microsites that are well-shaded for much of the day. While it requires some soil development, it grows on relatively poor soils, typically soil pockets on rock outcrops. These microsites are sparsely-vegetated. At this time, there is no evidence that essential conservation elements for *A. laramiensis* are being significantly compromised by human activity. From a management perspective, the biggest gap in biological knowledge is the absence of population trend data. The complete distribution of *A. laramiensis* is also unknown. Large areas of potential habitat remain to be surveyed on the Medicine Bow National Forest. Most of these areas are difficult to access, and surveying them will take significantly more time than sites visited in 2003 and 2004. A cost-efficient approach would utilize pre-project inventories, thereby putting resources where there might be conflict that could affect this species. While very little is known about other aspects of the biology of *A. laramiensis* (e.g., autecology, demography, community ecology), this information is not currently a high priority need for management.

Table of Contents

EDITORS: Beth Burkhart, Kathy Roche, and Richard Vacirca, USDA Forest Service, Rocky Mountain Region

List of Tables and Figures

Tables:

Figures:

INTRODUCTION

This assessment is one of many being produced to support the Species Conservation Project for Region 2 (Rocky Mountain Region) of the USDA Forest Service (USFS). *Aquilegia laramiensis* (Laramie columbine) has been included in the project because it has been designated a sensitive species by the Regional Forester (USDA Forest Service 2003a, 2005). Within the National Forest System, a sensitive species is a plant or animal for which population viability has been identified as a concern by a Regional Forester because of significant current or predicted downward trends in abundance or in habitat that would reduce its distribution (USDA Forest Service 2003a). A sensitive species may require special management, so knowledge of its biology and ecology is critical.

Goal

Species conservation assessments produced as part of the Species Conservation Project are intended to provide forest managers, research biologists, and the public with thorough discussions, based on available knowledge, of the biology, ecology, conservation status, and management of the species of concern. Assessments are not intended to make management recommendations. Instead, these documents provide the ecological background needed for effective management. Potential environmental changes resulting from management (i.e., management implications) are also discussed.

Scope

This assessment addresses the biology, ecology, conservation status, and management of *Aquilegia laramiensis* throughout its known range, which is entirely within Region 2 of the USFS. Refereed literature, non-refereed publications, research reports, data maintained by the Wyoming Natural Diversity Database (WYNDD), personal communications with experts on this species, and personal observations by one of the authors (Marriott) were the major sources of information. A range-wide survey for *A. laramiensis* was undertaken in 2003 and 2004 and is the source of much of the information in this assessment (Marriott and Horning 2004a, 2004b). Data from these projects, USFS site surveys, and herbarium specimen labels have been incorporated into databases maintained by WYNDD (Wyoming Natural Diversity Database 2004).

Generally, it was not possible to rely on refereed journals in producing this assessment, as most of the information about the species resides in unpublished literature and institutional files. There were some exceptions however, and refereed literature was the main basis for discussions of systematics and pollination biology. Even so, most of the available information did not apply specifically to *Aquilegia laramiensis*, and it was necessary to judge and discuss the relevance of literature pertaining to other species.

Treatment of Uncertainty

Science strives to be a rigorous systematic approach to obtaining knowledge, in which competing ideas regarding how the world works are measured against observations. However, we cannot avoid uncertainty because our descriptions of the world are always incomplete. Observations, inference, critical thinking, and models may guide our understanding, but we must be aware of the associated limitations. In this assessment, we address the availability and strength of evidence for ideas presented, with alternative explanations included when appropriate.

From a management perspective, the most significant limitation in our knowledge of *Aquilegia laramiensis* is the absence of data over time. Much of the information presented here was gathered only recently (Marriott and Horning 2004a, 2004b), and there are large information gaps for the species, especially with regard to autecology, demography, and community ecology. However, at this time these topics are not directly relevant to management decisions for *A. laramiensis*.

Publication of Assessment on the World Wide Web

Assessments produced for the Species Conservation Project are published on the World Wide Web site of the Rocky Mountain Region (http://www.fs.fed.us/r2/projects/scp/assessments/index.shtml). Publication on the Web makes these documents available to agency biologists and the public in a timely fashion and facilitates their revision, which will be accomplished based on guidelines established by Region 2.

Peer Review

Species Conservation Project assessments have been peer reviewed prior to publication on the World Wide Web. This assessment was reviewed by at least two recognized experts on this or related taxa. Peer review was designed to improve the quality of communication and to increase the rigor of the assessment.

MANAGEMENT STATUS AND NATURAL HISTORY

Management Status

Region 2 of the USFS has designated *Aquilegia laramiensis* as a sensitive species (USDA Forest Service 2003a, 2005). The ultimate goal of sensitive species designation and management by the USFS is to avoid listing under the Endangered Species Act (ESA).

Aquilegia laramiensis also occurs on lands managed by the Bureau of Land Management (BLM), and the species is on the BLM sensitive list for Wyoming. Sensitive designation obligates this agency to consider the overall welfare of the species in land management, with the goal of avoiding the need to list the species under the provisions of the ESA (USDI Bureau of Land Management 2002).

Aquilegia laramiensis has been found on lands managed by the State of Wyoming (five occurrences and parts of two other occurrences). In Wyoming, there are no state laws providing protection for rare plant species.

Aquilegia laramiensis is not a candidate for listing as Threatened or Endangered under the federal ESA. It had been listed as a category 2 candidate for listing under the ESA prior to a rule change (Wyoming Rare Plant Technical Committee 1994).

NatureServe (formerly the Heritage Division of The Nature Conservancy) and the Wyoming Natural Diversity Database (WYNDD) have assigned *Aquilegia laramiensis* the rank of G2S2[1], defined as "imperiled because of rarity" on both a global (G) and a state (S) basis (Keinath et al. 2003, NatureServe 2004). Complete definitions of heritage ranks are included in the Definitions section of this document, but in the absence of other factors, a rank of "2" is usually assigned to species represented by six to 20 occurrences. There are 43 documented occurrences of *A. laramiensis*, but small occurrence size is a significant factor in the conservative ranking of this species (Heidel personal communication 2004). Heritage ranks may be used by land management agencies as guidance, but they confer no legal protection for a species.

Existing Regulatory Mechanisms, Management Plans, and Conservation Strategies

The entire known range of *Aquilegia laramiensis* is within USFS Region 2, in the Laramie Mountains of southeastern Wyoming (**Figure 1**). The majority of the documented occurrences (25 out of 43) are on lands managed by the Medicine Bow National Forest. This species is listed as sensitive in Region 2, and the USFS is directed to use a variety of approaches to prevent listing under the ESA, including the development of a conservation strategy for the species. This conservation strategy has not been completed, in part because so little was known about *A. laramiensis* prior to 2003. Range-wide surveys in 2003 and 2004 have significantly increased our knowledge of the species (Marriott and Horning 2004a, 2004b).

Aquilegia laramiensis is also found on lands managed by the BLM, which designates it as a sensitive species in Wyoming (USDI Bureau of Land Management 2002). These sites were documented only recently (Marriott and Horning 2004b), and neither management plans nor conservation strategies for the species have been developed. Sensitive designation by either the USFS or the BLM does not obligate the agency in a legally binding way to avoid harming a species. Rather, it "directs" the agency to use a variety of approaches to prevent listing under the ESA (USDI Bureau of Land Management 2002, USDA Forest Service 2003a.

Aquilegia laramiensis is not currently listed as a candidate for Threatened or Endangered status under the ESA, and there are no federal laws concerned specifically with its conservation. While the species is found on lands managed by the State of Wyoming, there are no laws providing protection for rare plant species in the state. Thus, there is no guarantee that the species would be protected if changes in management or land use threatened its survival.

Most of the known occurrences of *Aquilegia laramiensis* are on public lands managed for multiple use. One occurrence is found within the Ashenfelder Basin Special Interest Area (SIA) on the Medicine Bow National Forest (Jones 1989, Wyoming Natural Diversity Database 2004). SIAs are managed with an emphasis on protecting or enhancing areas of unusual characteristics, and maintaining their special interest

[1]For definitions of "G" and "S" ranking see "Ranking System" in the Definitions section of this document.

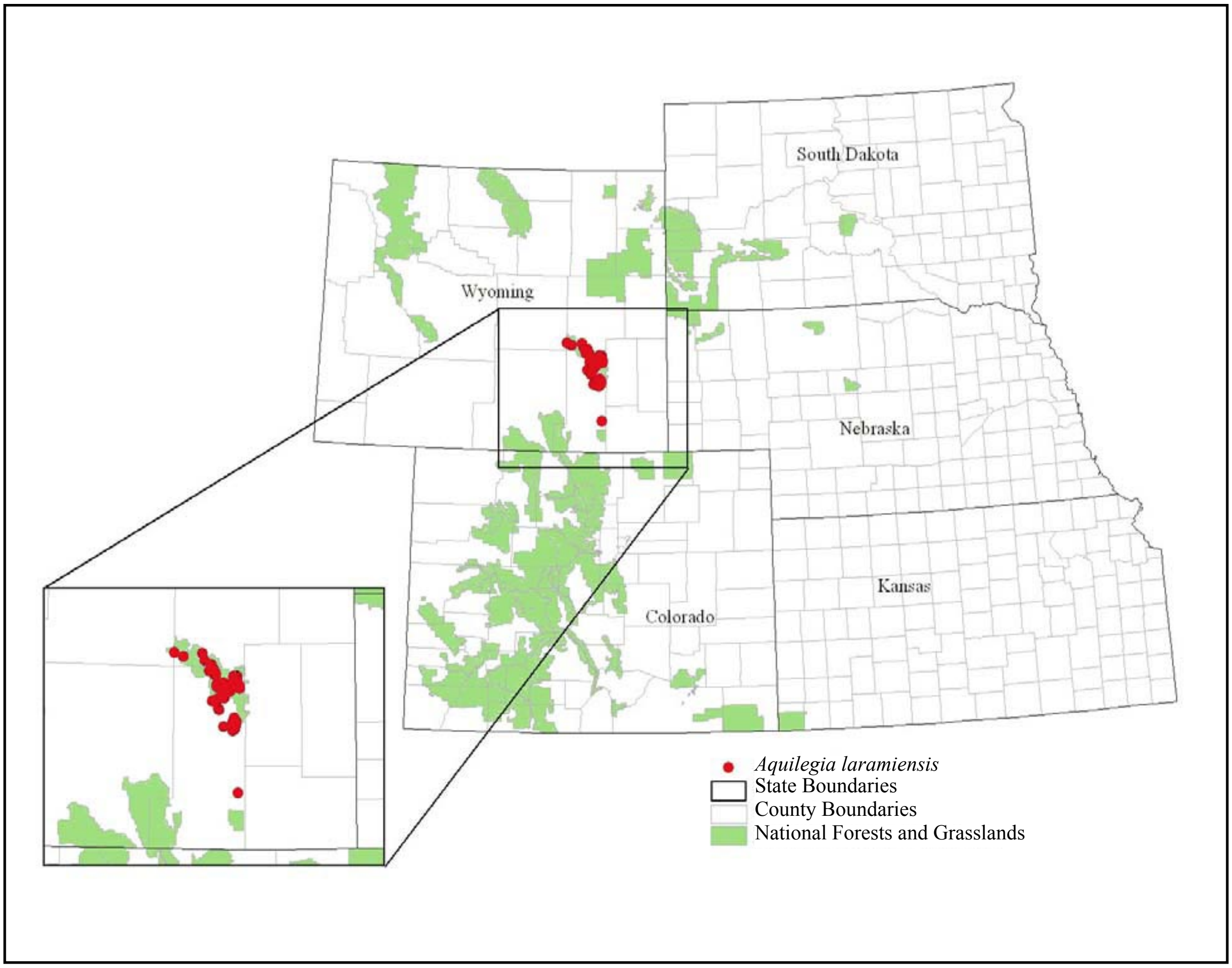

Figure 1. Distribution of *Aquilegia laramiensis* (map from Wyoming Natural Diversity Database 2004).

values, which in the case of Ashenfelder Basin are botanical and natural (USDA Forest Service 2003b). No management plan for this SIA has been developed.

Jankovsky-Jones et al. (1995) reported that there may be potential habitat for *Aquilegia laramiensis* in the LaBonte Canyon Research Natural Area (RNA) on the Medicine Bow National Forest. The columbine was found a short distance west of the RNA during a survey in 2003 (Marriott and Horning 2004a), and potential habitat was seen in the RNA in passing (Horning personal communication 2004). RNAs represent ecosystems in a natural condition and are intended to serve as reference areas in adaptive management. Human impacts that would affect the ecosystem are to be minimized (USDA Forest Service 2003b).

Aquilegia laramiensis does not occur in any Wilderness Areas or on land managed by the National Park Service.

Biology and Ecology

Classification and description

Classification and systematics

Aquilegia laramiensis is a member of the Ranunculaceae Family (buttercup). This family is widespread, but it is especially well represented in temperate and boreal regions of the Northern Hemisphere (Judd et al. 2003). Worldwide, there are 47 genera and approximately 2000 species. Seventy species have been recognized within the genus *Aquilegia*, 21 of which are North American (Whittemore 1997).

Payson (1918) recognized three sections within the genus, placing *Aquilegia laramiensis* in section Cyrtoplecrae, characterized by biternate leaves, small blue or white nodding flowers, large dilated laminae (expanded part of a petal), short usually hooked spurs, mostly included stamens, and short styles. He placed two other North American species in this section. *Aquilegia brevistyla* (small-flower columbine) is a northern species with disjunct occurrences in Montana, Wyoming, and South Dakota. *Aquilegia saximontana* (Rocky Mountain columbine) is restricted to high elevations in the Rocky Mountains in central Colorado (Whittemore 1997, McKee 2002). The other species in section Cyrtoplecrae are found in the Old World.

Munz (1946) referred the reader to Payson's "excellent" account of usable characters and morphology in American columbines, and recognized his three sections within the genus. However, he disagreed with combining North American and Old World species in section Cyrtoplecrae, as well as with Payson's hypothesis that the genus originated in North America. Munz believed that the evidence pointed to Asia as the place of origin; this hypothesis has had recent support (e.g., Hodges and Arnold 1994).

It has long been known that the genus *Aquilegia* is characterized by ecologically and morphologically diverse species, most of which are interfertile (Hodges 1997). However, recent molecular studies using nuclear internal transcribed spacer regions and chloroplast DNA spacers indicate there is little genetic divergence among species of *Aquilegia* (Hodges and Arnold 1994). The genus appears to be a "species flock" resulting from recent rapid radiation, attributed by Hodges (1997) to the evolution of spurred nectar-secreting petals. Such a "key innovation" could result in a shift in pollinators and then speciation (Grant 1952). However, columbines exhibit an unusual distribution for a recently radiated species flock. Their large geographical area is not consistent with other examples of recent radiation, which are restricted geographically.

There are other phylogenetic problems within the genus *Aquilegia*. The status of the single spurless species, *A. ecalcarata* of Asia, cannot be resolved although it is assumed to be the most primitive member of the genus, and is the basis for the hypothesis of Asian origin (Hodges 1997). Ro and McPheron (1997) were not able to determine the most ancient branch of the genus in their phylogenetic analysis using ribosomal DNA markers.

In spite of difficulties delineating relationships within the genus, *Aquilegia laramiensis* presents no taxonomic problems within the species. It is distinct and easily circumscribed (Payson 1918, Munz 1946), and at least in the wild *A. laramiensis* does not appear to hybridize with other members of the genus.

A complete taxonomic classification of *Aquilegia laramiensis* is available online from the PLANTS database (USDA Natural Resources Conservation Service 2004). This classification is not the only accepted one (e.g., Judd et al. 2003), but disagreement over higher taxonomic levels is not relevant to the biology and management of this species.

History of the species

The first known collection of *Aquilegia laramiensis* was made by Aven Nelson in the northern Laramie Mountains (southeastern Wyoming) in 1895. The holotype was collected in "Cotton-wood Canyon at the foot of Laramie Peak" (Nelson 1896). Nelson made more collections in 1900 and 1901, extending the known range to Ragged Top Mountain in the Laramie Mountains east-northeast of the city of Laramie, roughly 100 km south of Laramie Peak. The next new records were not reported until the 1970s and 1980s, and all were in the northern Laramie Mountains in the general area of Laramie Peak. In 1993, C. Refsdal collected the columbine roughly halfway between Laramie Peak and Ragged Top Mountain (**Table 1**, EO#8). Several new records were found during general floristic surveys of the area (Packer 2000), including a range extension about 25 km to the northwest in the vicinity of School Section Mountain by B.E. Nelson in 1997. In 2002, *A. laramiensis* was known from ten extant sites as well as two historical records without precise location information (Wyoming Natural Diversity Database 2004).

While several sites had been surveyed in some detail before 2003, no range-wide surveys for *Aquilegia laramiensis* had been conducted and little population and habitat data were available (Wyoming Natural Diversity Database 2004). No threats had been documented either, but so little was known about the species that it was impossible to assess conflicts with human activities. The columbine appeared to be rare, but there were large areas of unsurveyed potential habitat.

Range-wide surveys for *Aquilegia laramiensis* have since been conducted, focusing on lands managed by the USDA Forest Service in 2003, and the BLM in 2004. Thirty-two new occurrences were documented, and qualitative data concerning habitat, occurrence size, and existing or potential threats were collected (Marriott and Horning 2004a, 2004b). Much of the biological information presented in this assessment is based on this recent work.

Table 1. Summary information for all *Aquilegia laramiensis* occurrences. Included here are element occurrence number, county, location, management/ownership, date last observed, habitat, elevation, and estimated abundance (Marriott and Horning 2004a, 2004b, Wyoming Natural Diversity Database 2004).

EO#[1]	County	Location	Management/ Ownership[2]	Date Last Observed	Habitat	Elevation in m (ft.)	Estimated Abundance[3]
1	Albany	Antelope Basin	exact location unknown	1900	Under overhanging ledges of rock.	2,256 (7,400)	Unknown
2	Albany	Ragged Top Mountain	State of Wyoming	198?	Crevices of granite cliffs and rocky ledges.	2,347 to 2,499 (7,700 to 8,200)	Unknown
3	Converse	Southeast of Buzzard Peak	USDA Forest Service	2004	Sheltered crevices of large granite outcrops among grassland; including northeast aspect in direct light to partial shade.	2,225 to 2,270 (7,300 to 7,450)	Uncommon; infrequent; less than 10
4	Albany	Cottonwood Canyon at foot of Laramie Peak	exact location unknown	1895	Dry crevices in abrupt cliffs within canyon.	2,073 (6,800)	Unknown
5	Albany, Converse	3 miles north-northwest of Harris Park	USDA Forest Service	1974		1,920 (6,300)	Unknown
6	Converse	Horseshoe Creek north of Laramie Peak	Private	1981		1,905 (6,250)	Unknown
7	Converse	Ashenfelder Creek	USDA Forest Service	1988	Cracks in granite cliffs.	1975 (6480)	Unknown
8	Albany	Tunnel Road	Private	1993	Crevices of granite boulder fields.	2,176 (7,140)	Unknown
9	Albany	Friend Park Campground	USDA Forest Service	1993	Northwest-facing granite outcrops along segments of spine-like ridge summit, rising 5 to 12 m above forest of Pinus contorta. Settings include sheer faces, on benches, along fractures with other vascular plants, on ephemeral moss-covered seep zones, and sporadically present in rubble below. Also shady crevices, often with thin deposits of soil, ledges or at base of large granitic rock outcrops in semi-shady Abies lasiocarpa-Pinus ponderosa woods or openings at edge of conifer, aspen groves.	2,304 to 2,597 (7,560-8,520)	over 100; 50-100 (2 visits)
10	Converse	School Section Mountain	State of Wyoming	1997	In cracks and crevices at base of cliff.	2,316 to 2,408 (7,600 to 7,900)	Unknown
11	Albany, Converse	Big Bear Canyon	USDA Forest Service	2003	Crevices of granite cliffs in mixed conifer-aspen forest. 2003 site in horizontal deep crack, with thick vegetation; microsite is well-shaded by overhanging rock.	2,207 to 2,390 (7,240 to 7,840)	20

Table 1 (cont.).

EO #[1]	County	Location	Management/ Ownership[2]	Date Last Observed	Habitat	Elevation in m (ft.)	Estimated Abundance[3]
12	Converse	Deer Creek (Range)	USDA Forest Service	2003	Granite outcrops on ridgecrest, dry open coniferous forest on slopes below, and sagebrush and moist meadow in drainage bottom. Population on shaded east facing slope and crack in granite outcrop, with limber pine and juniper.	2,295 (7,530)	60
14	Converse	Box Elder Creek	USDA Forest Service, State of Wyoming	2003	On soil in shaded, flat microsites associated with rock outcrop, e.g. at base, with conifers and big sagebrush.	2,408 (7,900)	25
15	Converse	Upper Curtis Gulch	USDA Forest Service	2003	Well-shaded microsites in soil pockets among boulders in granite boulder field, with aspen, subalpine fir, and limber pine.	2,560 (8,400)	10
16	Albany	LaBonte Creek near Curtis Gulch	USDA Forest Service	2003	Plants are in a rocky small west-trending gully with many shrubs and scattered conifers. Microsite is flat area, shaded by rocks, with shrubs and conifers.	2,164 (7,100)	300
17	Albany	LaBonte Canyon near Big Bear Canyon	USDA Forest Service	2003	Shaded soil pockets in cracks of granite outcrops, on level microsites. Ledge beneath shade of boulder with shallow gravelly soil with limber pine, ponderosa pine, and sagebrush.	2,225 (7,300)	125
18	Albany	Divide south of LaBonte Canyon	USDA Forest Service	2003	Shaded areas in huge pale-colored granite blocks 30 m (100 ft) high, with subalpine fir grove in northeast-trending gully. There is some limber pine with rock everywhere and not much understory vegetation.	2,499 (8,200)	500
19	Converse	Top of Big Bear Canyon	USDA Forest Service	2003	Plants on shaded northeast-facing sloping ledges on very large granite boulder in a conifer forest.	2,463 (8,080)	18
20	Albany	Spur of Laramie River near Forest Service Rd. 671	State of Wyoming	1998	Among boulders.	2,195 (7,200)	Unknown
21	Albany	Road to Black Mountain	USDA Forest Service	2003	Granite boulder outcrops on east-facing slope, in shaded areas, with ponderosa pine, common juniper, and grassland. The area is lush with many other species and is within perimeter of 2002 fire.	2,073 (6,800)	100

Table 1 (cont.).

EO #[1]	County	Location	Management/ Ownership[2]	Date Last Observed	Habitat	Elevation in m (ft.)	Estimated Abundance[3]
22	Albany	Black Mountain summit	State of Wyoming	2003	North-facing wall of summit block on granite ridge. Columbines are scattered in shaded rock cracks, with limber pine, ponderosa pine, and subalpine fir. This area is within perimeter of 2002 fire and burned areas have been colonized by aspen and raspberries. Some burned areas with fire-cracked rock have no vegetation yet.	2,426 (7,960)	over 100
23	Albany, Converse	Windy Peak	USDA Forest Service	2003	Horizontal crack in large rock outcrop, on flat microsite. This is in east-west gully and is shaded by rock wall. Also on whitish granite rocks in a north-south canyon on west-facing slope. Microsites are level and shaded on pockets of soil with limber pine, subalpine fir, aspen, common juniper, Douglas fir, and ponderosa pine. Smaller outcrops do not have columbines.	2,377 to 2,731 (7,800 to 8,960)	270
24	Albany	Ridge east of Indian Peak	USDA Forest Service	2003	Soil pockets in crevices of granite outcrops, well-shaded by rock (no direct sunlight), with limber pine, aspen, and common juniper.	2,377 (7,800)	40
25	Albany	Cottonwood Creek northeast of Laramie Peak	USDA Forest Service	2003	Shaded base of granite cliff in gravel, near stream course 1.5 m (5 ft) away, with aspen. This area is within perimeter of 2002 fire.	2,103 (6,900)	15
26	Albany	Cottonwood Creek east of Laramie Peak	USDA Forest Service	2003	Shaded horizontal ledges of granite outcrop, on various parts of north face (from top to bottom), with shrubs, aspen, conifers.	2,085 (6,840)	40
27	Albany	Grouse Creek	USDA Forest Service	2003	Shaded soil pockets in crevices on big granite wall with north face, with limber pine, common juniper, and aspen.	2,438 to 2,569 (8,000 to 8,100)	30
28	Albany	Laramie Peak near summit	USDA Forest Service	2003	On top of shaded concave boulder with moss and plants, subalpine fir, and Engelmann spruce.	3,078 (10,100)	30
29	Albany	Albany Peak	USDA Forest Service	2003	Shaded soil pockets in crevices of granite outcrops, with ponderosa pine, aspen saplings, and common juniper.	2,195 (7,200)	15

Table 1 (cont.).

EO #[1]	County	Location	Management/ Ownership[2]	Date Last Observed	Habitat	Elevation in m (ft.)	Estimated Abundance[3]
30	Albany	Between upper forks Friend Creek	USDA Forest Service	2003	Small ledges and in crevices with some soil on steep granite faces, usually northerly or otherwise shaded. With ponderosa pine, limber pine, and common juniper.	2,393 (7,850)	40
31	Albany	Bull Gap/Jack Squirrel Peak	USDA Forest Service	2003	In shaded crevices and at base of granite outcrop, where there is some soil.	2,316 (7,600)	10
32	Albany	Round Mountain	USDA Forest Service	2003	Cliff base in shaded soil pockets among large boulders in east-trending gully between outcrops, with quaking aspen, ponderosa pine, and Douglas fir.	2,371 (7,780)	20
33	Albany	Northwest of Kloer Creek	USDA Forest Service	2003	Large granite outcrops on ridge. Plants found in areas of higher and steeper faces, with shaded microsites. Microsites are level, and found at base of or on steep walls, with scattered ponderosa pine and aspen around and among rocks.	2,256 (7,400)	20 to 25
34	Albany	Upper Arapaho Creek	USDA Forest Service	2003	Shaded microsites on and among granite outcrops and boulders in coniferous forest. Shading provided by overhanging rock and trees (ponderosa pine and aspen).	2,271 (7,450)	at least 12
35	Albany	Elmer's Rock	Bureau of Land Management	2004	Plants growing out of thin crack; limited soil development; microsite has less shading than at other columbine sites surveyed.	2,164 (7,100)	50 to 60
36	Albany	Laramie River downstream from canyon	Bureau of Land Management	2004	Columbines growing in cracks in rock outcrop.	2,012 (6,600)	30 to 40
37	Albany	Sugarloaf Ridge east end	Bureau of Land Management	2004	On summit growing on flat microsites shaded by boulders and rock faces.	2,306 (7,567)	10 to 15
38	Albany	Duck Creek Falls	Bureau of Land Management	2004	Columbines in vertical crack in east-facing corner of rock on south side of creek; limited soil development; rock is peridotite.	1,646 (5,400)	100 to 120
39	Albany	Tributary to Ashley Creek	Bureau of Land Management	2004	North-facing overhanging wall near bottom of canyon, in cracks on granite faces with limited soil development.	1,890 (6,200)	30 to 50

Table 1 (concluded).

EO #[1]	County	Location	Management/ Ownership[2]	Date Last Observed	Habitat	Elevation in m (ft.)	Estimated Abundance[3]
40	Albany	Lower Duck Creek	Bureau of Land Management, State of Wyoming	2004	Canyon bottom adjacent to floodline; flat microsite shaded by overhanging rock and trees; not much soil; also found 30 m (100 ft.) above canyon bottom in prominent meander; plants grow in cracks (foliations); wall faces north, but also well shaded from west and east.	1,786 to 1,902 (5,860 to 6,240)	115 to 150
42	Albany	Laramie River canyon	Bureau of Land Management	2004	In slanting crack in steep granite wall on east side of drainage bottom; shaded in part by overhanging rock. Also found on 7.6 m (25 ft.) granite gneiss outcrop; in crack near base.	1,945 to 2,012 (6,380 to 6,600)	100
43	Albany	Lower Pine Mountain	Bureau of Land Management	2004	Plants found in gully with seep near base of ridge; northeast facing; layered granite; shaded by north-facing wall; plants on small ledges and in cracks.	2,121 (6,960)	60
44	Albany	Rattlesnake Rock	Bureau of Land Management	2004	North-facing granite outcrop; more steps than overhangs; plants on small ledges, very well shaded by aspect. overhanging rock and trees.	2,280 (7,480)	10
45	Converse	Rabbit Creek Rocks	State of Wyoming	2004	In vertical cracks; shaded by trees.	2,158 (7,080)	40
46	Albany	Sellers Mountain	Bureau of Land Management	2004	Horizontal crack on steep faces of granite blocks near summit; summit block is split by a gulch ... plants are lusher in this situation; also on ridge leading to summit from south-southwest; shaded but gets some early morning sun.	2,256 to 2,377 (7,400 to 7,800)	20
47	Albany	Indian Head Peak	Bureau of Land Management	2004	West-facing vertical crack.	2,377 (7,400)	50 to 80

[1]Missing occurrence numbers (13 and 41) are artifacts of data management and do not represent extirpated occurrences.
[2]All USDA Forest Service lands listed are managed by Medicine Bow National Forest. All Bureau of Land Management lands listed are managed by the Rawlins Field Office.
[3]Estimated abundance figures from 2003 and 2004 are for areas surveyed; some occurrences may be larger.

Non-technical description

The following description is based largely on Fertig et al. (1994), with some new information from recent surveys (Marriott and Horning 2004a).

Aquilegia laramiensis is a perennial, leafy, many-stemmed herb 5 to 25 cm tall. Leaves are mostly twice compound with leaflets 0.5 to 3 cm long. Flowers are nodding and borne among the leaves. Members of the genus *Aquilegia* are easily recognized by their distinctive, showy flowers with spurred petals, which contain nectar for attracting pollinators. The sepals, green and leaf-like in many flowers, are "petaloid" in columbines – colored and showy to some degree. *Aquilegia laramiensis* is no exception although the flowers are small. Sepals are greenish-white to lavender. Petals are cream to lavender with spurs less than 10 mm long. Fruits are follicles 10 to 14 mm in length, and they are finely hairy when green. Dried follicles often persist into the next season; they can be used by someone familiar with the species and its habitat to confirm identification of otherwise vegetative material.

Figure 2 contains a line drawing of *Aquilegia laramiensis*. Additional drawings can be found in Munz (1946), Fertig et al. (1994), and Nold (2003). Photographs of *A. laramiensis* are included in **Figure 3**. The largest collection of photographs of this species is on file at the Wyoming Natural Diversity Database. Most were taken during the surveys in 2003 and 2004. Photographs are included also in Fertig et al. (1994) and Marriott and Horning (2004a).

Of other North American columbine species, *Aquilegia saximontana* is most similar to *A. laramiensis*. The most obvious difference between these two species is flower color (Whittemore 1997). The flowers of *A. saximontana* have blue sepals and petals with blue spurs and yellow blades. It is restricted to the subalpine and alpine zones in north-central Colorado, growing on cliffs and rocky slopes (McKee 2002).

Aquilegia laramiensis is unlikely to be confused with other columbines in the field. Besides *A. saximontana*, there are three other species of columbine in Wyoming with cream, blue, or lavender flowers (Dorn 2001): *A. coerulea* (Colorado columbine), *A. brevistyla* (small-flower columbine), and *A. jonesii* (Jones' columbine). Of these, only *A. coerulea* is known from southeastern Wyoming. This species has significantly larger flowers, with spurs 20 to 50 mm long (Dorn 2001). It has been found in the Medicine Bow Mountains and at a single site in the southernmost Laramie Mountains southeast of Laramie (Rocky Mountain Herbarium 1998, Dorn 2001). It has not been documented within the range of *A. laramiensis*.

Technical descriptions, photographs, line drawings, and herbarium specimens

The following technical description is based largely on Whittemore (1997), with some new information from recent surveys (Marriott and Horning 2004a). Earlier descriptions were made by Nelson (1896), Payson (1918), and Munz (1946).

> Stems 5-25 cm. Basal leaves mostly twice compound, 5-25 cm, about as long as stems; leaflets 0.5-3 cm long, not crowded, glabrous. Flowers nodding; sepals divergent from floral axis, greenish white to lavender, linear or lanceolate, 7-15 mm long, apex acute to rounded; petals cream to lavender in color, spurs hooked, 5-8 (10) mm long. Fruits are follicles 10-14 mm in length, with spreading beaks or tips 3-5 mm long; follicles are finely pubescent when green; dried follicles often persist into the next growing season.

Vouchers for *Aquilegia laramiensis* sites, as well as the holotype for the species, are deposited at the Rocky Mountain Herbarium (RM), University of Wyoming, Laramie, Wyoming. Isotypes are deposited at the New York Botanical Garden and Missouri Botanical Gardens Herbarium (Hartman personal communication 2003). Duplicates of early collections in the RM are deposited at the Missouri Botanical Gardens, Charles E. Bessey Herbarium in Nebraska, and at the herbarium at Utah State University (Hartman personal communication 2003). One specimen at the Missouri Botanical Gardens is falsely labeled as to collection location ("Medicine Bow Mountains"). Annotation by Alan Whittemore, 1994, based on personal communication with R. Hartman, Curator, RM, clarifies the mistake. The correct location for this duplicate is Ragged Top Mountain in the Laramie Mountains.

Distribution and abundance

Aquilegia laramiensis is endemic to the Laramie Mountains in Albany and Converse counties in southeastern Wyoming (**Figure 4**). No information is available concerning this species' historical distribution, nor whether there have been changes in its distribution and abundance in historical times. Prior to 2003, *A. laramiensis* was known from only 12 sites, and two of these were based on early collections

Figure 2. Line drawing of *Aquilegia laramiensis* by Isobel Nichols (from Fertig et al. 1994). Additional drawings can be found in Munz (1996), Fertig (2000), and Nold (2003).

(1895, 1900) with little location information. Most of the known occurrences were documented in 2003 and 2004 (Marriott and Horning 2004a, 2004b). Currently there are 43 known occurrences of *A. laramiensis*, as well as the two early collections that lack precise location information. Occurrences were found in the general areas of these early reports during surveys in 2003 and 2004, and they may actually include the early collection sites.

The global range of *Aquilegia laramiensis* is entirely within Region 2. Twenty-five of the known occurrences of *A. laramiensis* are on land managed by Medicine Bow National Forest. The remainder are

Figure 3. Photographs of *Aquilegia laramiensis*. Top from Marriott and Horning 2004a (D. Horning photo); bottom from Fertig 2000 (M. Russell photo).

on lands managed by the BLM (11 occurrences) and State of Wyoming (five occurrences and parts of two others), with two known from private land. *Aquilegia laramiensis* occurrences are summarized in **Table 1**. Complete element occurrence records and maps are on file at the Wyoming Natural Diversity Database.

Occurrences are not evenly distributed throughout the range of the species. Most are clustered in the northern part of the Laramie Mountains, within a zone approximately 55 km (34.2 miles) in length from southeast to northwest. This area is underlain by the Archean Laramie granite (**Figure 5**; Condie 1969, Johnson and Hills 1976). It includes large systems of rock outcrops that provide habitat for *Aquilegia laramiensis* (**Figure 6**).

South of the granite zone, *Aquilegia laramiensis* has been found on gneiss and peridotite (Marriott and Horning 2004b) within what has been called the Central

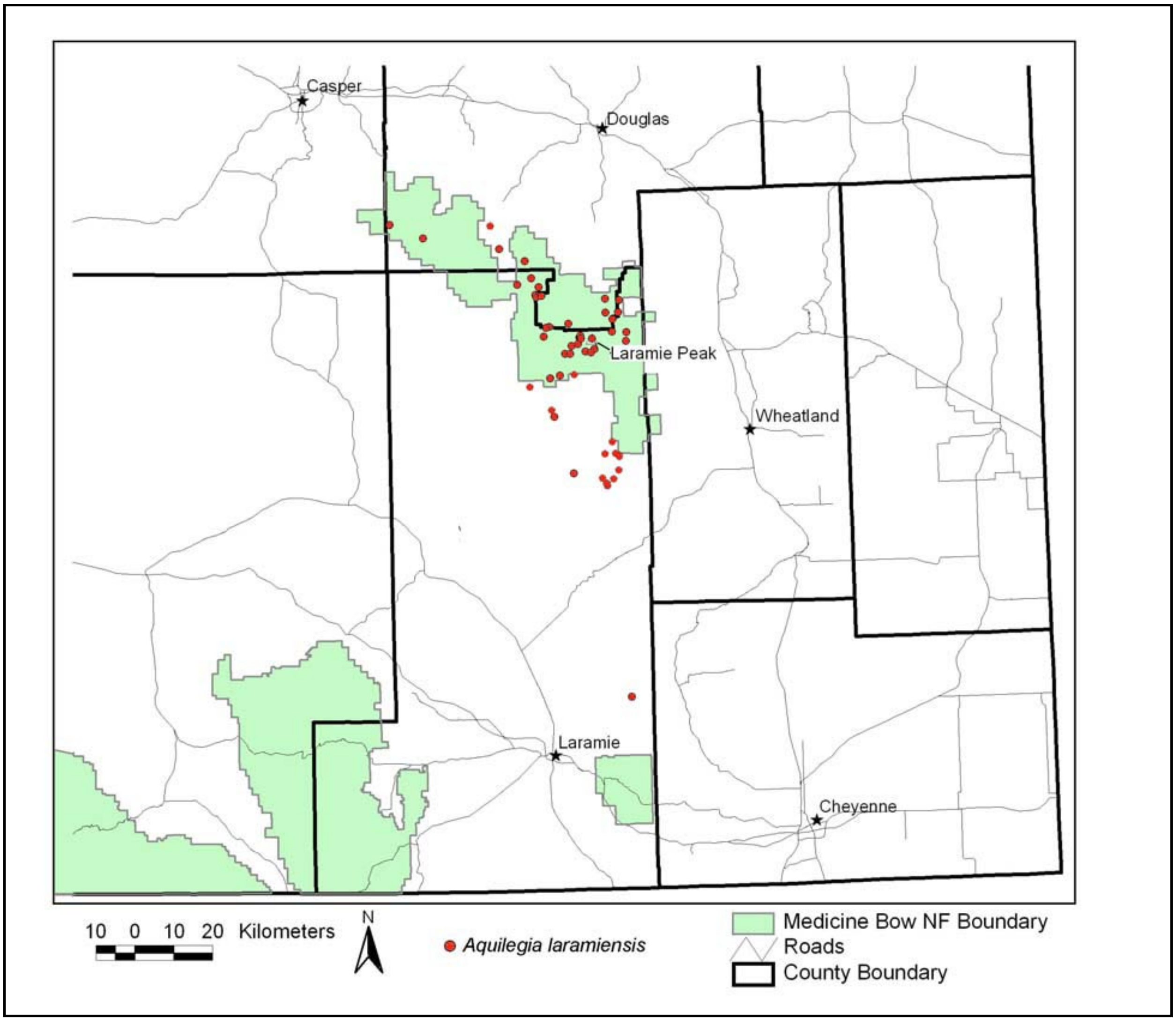

Figure 4. Global distribution of *Aquilegia laramiensis* (map from Wyoming Natural Diversity Database 2004).

Metamorphic Complex (Condie 1969, Johnson and Hills 1976). There are fewer extensive systems of rock outcrops in this area, and sites with potential habitat are more widely separated (Marriott personal observation). A disjunct occurrence of *A. laramiensis* is known from Ragged Top Mountain east-northeast of the city of Laramie, approximately 50 km (31.1 mi) south of the main range of the species. There may be additional occurrences in the vicinity of Ragged Top; little survey work has been conducted in this area, due mainly to private ownership.

The Medicine Bow National Forest also manages lands in the southernmost part of the Laramie Mountains (**Figure 4**). No occurrences of *Aquilegia laramiensis* have been found in this area in spite of easy access and relatively frequent collecting since the establishment of the University of Wyoming in Laramie. The Proterozoic Sherman granite found in this area does not appear to provide appropriate microsites for this columbine. This rock type continues south of the state line into Colorado.

Dorn (1979) indicated that the range of *Aquilegia laramiensis* "may" extend to rocky areas in Larimer County, Colorado. Heidel and Laursen (2001) identified the Roosevelt National Forest as the Forest in Larimer County closest to the known range of the species. However, this should not be interpreted as a report of the species on that Forest. Comprehensive surveys are needed to determine whether the species occurs in the area.

Occurrences of *Aquilegia laramiensis* are generally small. The largest reported occurrence prior to 2003 consisted of "over 100 individuals"

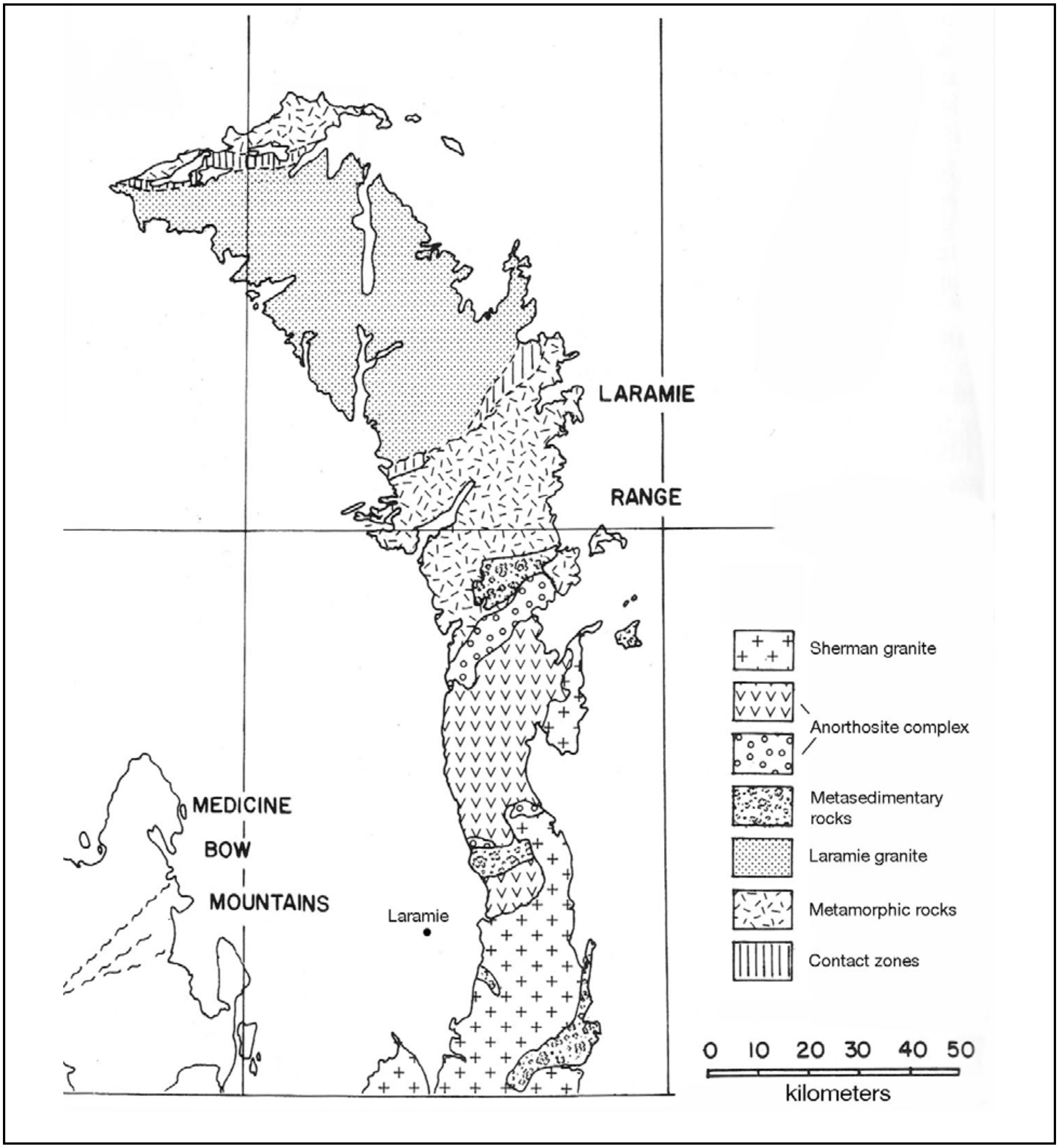

Figure 5. Precambrian rocks exposed in the Laramie Mountains (modified from Johnson and Hills 1976).

spread intermittently over 0.5 km (0.31 miles) of rock outcrop (Wyoming Natural Diversity Database 2004). During surveys in 2003 and 2004, estimates were made of numbers of aboveground individuals within areas surveyed (Marriott and Horning 2004a, 2004b). Estimated sizes ranged from ten to 500 aboveground individuals, with most less than 100. Estimated occurrence sizes are included in occurrence records in **Table 1**.

Recent projects focused on documenting columbine distribution, and sites often were not completely surveyed once *Aquilegia laramiensis* was found (Marriott and Horning 2004a, 2004b). The larger occurrences probably are significantly larger than estimated. *Aquilegia laramiensis* grows on appropriate microsites on rugged rock outcrops. In extensive systems of outcrops, it is difficult to sample potential microsites, and some microsites may be entirely inaccessible.

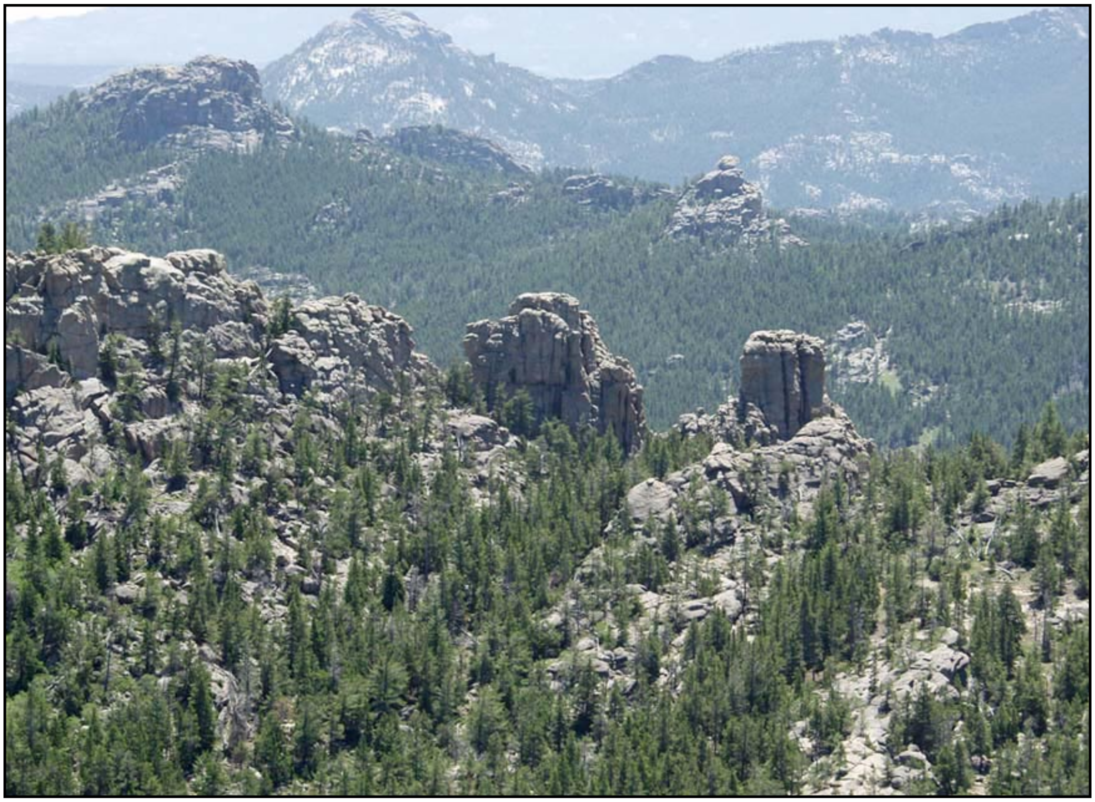

Figure 6. *Aquilegia laramiensis* habitat on extensive outcrops of granite near Laramie Peak (Marriott and Horning 2004a; D. Horning photo).

Population trend

There are no reliable repeat observations available for assessing population trends for *Aquilegia laramiensis*. Several sites have received multiple visits, with the species found each time, but estimates of occurrence size and distribution did not utilize consistent methodologies, nor is it clear that the same area was surveyed during each visit (Wyoming Natural Diversity Database 2004).

Habitat

Specific habitat information for occurrences of *Aquilegia laramiensis* is included in **Table 1**. This columbine grows on suitable microsites on outcrops of igneous and metamorphic rocks (Marriott and Horning 2004a, 2004b, Wyoming Natural Diversity Database 2004). Many of the known occurrences are on large (up to several hundred feet high) outcrops that dominate the landscape. Some of the largest occurrences are on ridgecrests that are essentially all rock outcrop, sometimes several kilometers in length (**Figure 6**). At only a few sites where *A. laramiensis* has been found are the rock outcrops small enough to be well-shaded by tree cover. In all situations, this columbine occupies only a very small fraction of the area covered by rock, with patchy and intermittent distribution. Plants are found on small, shaded microsites such as ledges, bases of outcrops, large crevices, and soil pockets among boulders (**Figure 7**).

Aquilegia laramiensis has been documented at elevations ranging from 3,078 m (10,100 ft.) near the summit of Laramie Peak to as low as 1,646 m (5,400 ft.) in the canyon of Duck Creek about 31 km south of Laramie Peak (Marriott and Horning 2004a, 2004b). The outcrops on which it grows are sparsely vegetated, but there is a fairly consistent set of associated species at microsites (**Table 2**). This columbine grows adjacent to other species at some sites and in isolated patches at other sites, but vegetative cover is always sparse. It may tolerate poor soils that other plants find inhospitable.

At sites on the Medicine Bow National Forest, rock outcrops where *Aquilegia laramiensis* occurs are usually surrounded by forests with some openings that support grassland and sagebrush grassland. To the south, on lands managed by the BLM, the surrounding vegetation is more often grassland or sagebrush grassland (Marriott and Horning 2004a, 2004b).

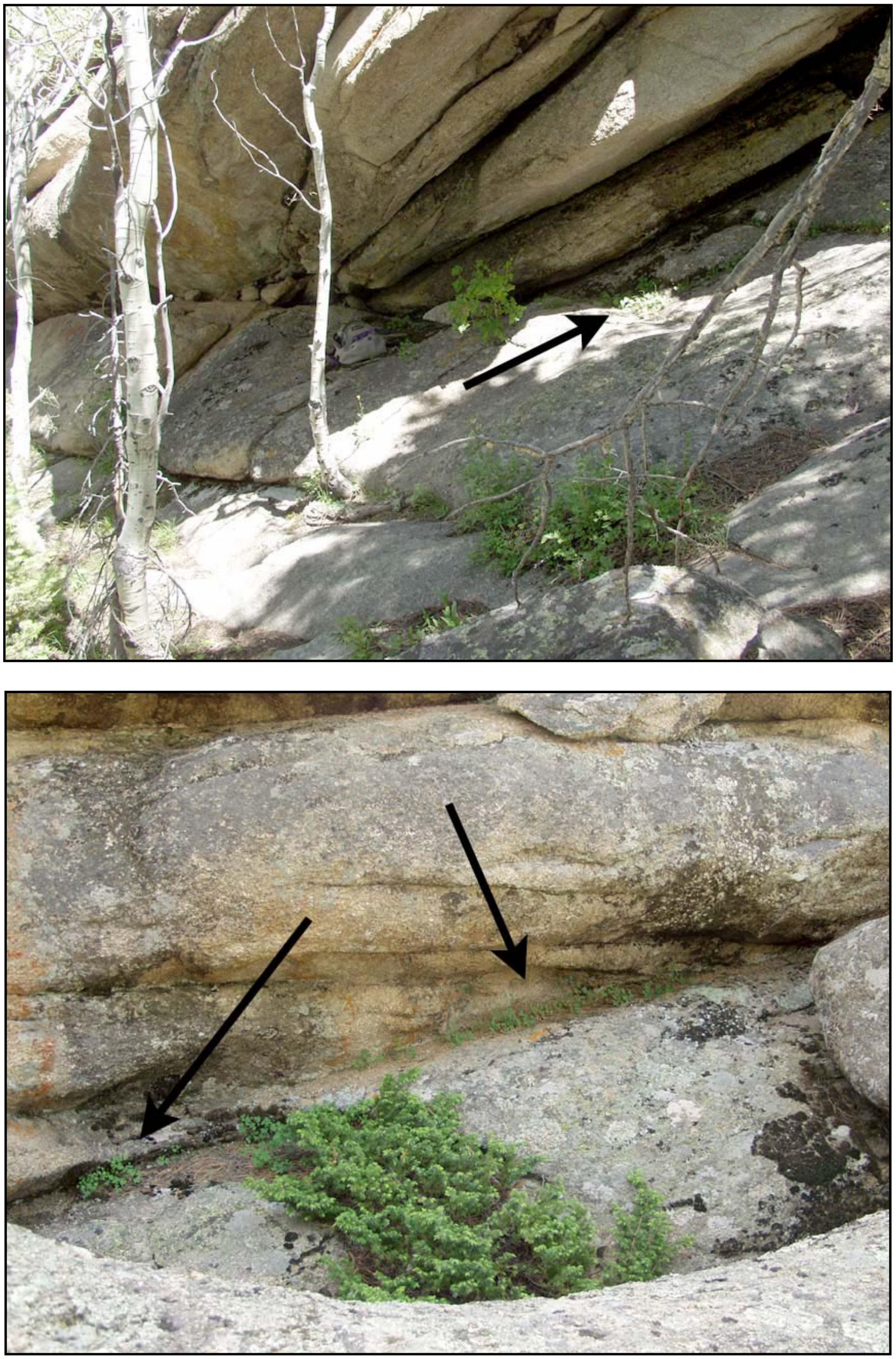

Figure 7. Photographs of *Aquilegia laramiensis* microsites. Top: under overhanging rock at base of outcrop. Bottom: on soil pockets on small ledges. (Marriott and Horning 2004a; D. Horning photos).

Table 2. Associated plant species commonly found at *Aquilegia laramiensis* microsites (Marriott and Horning 2004a).

Scientific Name	Common Name
Cystopteris fragilis	fragile fern
Heuchera parvifolia	little-flowered alumroot
Holodiscus dumosus	glandular oceanspray
Physocarpus monogynus	mountain ninebark
Polemonium brandegei	Brandegee's jacob's-ladder
Potentilla fissa	big-flower cinquefoil
Rubus idaeus	red raspberry
Senecio rapifolius	Idaho ragwort
Woodsia scopulina	Rocky Mountain woodsia

Earlier reports stated that *Aquilegia laramiensis* was associated with northerly aspects (e.g., Fertig et al. 1994). It is now known that the species can be found on all aspects if there are suitable microsites that are well-shaded (Marriott and Horning 2004a). Shade can be provided by aspect, position, or topography, such as under an overhanging rock, inside large crevices, or among large boulders (**Figure 7**). Trees contribute to shading at a few microsites (Horning personal communication 2004).

Aquilegia laramiensis appears to require some soil development. It has been found growing in soil pockets on or adjacent to rock outcrops. However, earlier descriptions characterizing habitat as pockets of "rich soil" are not accurate. Microsites have coarse, poorly-developed soil typical of soil pockets on rock outcrops (Marriott and Horning 2004a).

Surveys on USFS lands in 2003 focused on sites with highest potential for *Aquilegia laramiensis* – large rock outcrops with prominent steep faces and shaded microsites (Marriott and Horning 2004a). There are probably additional occurrences in more marginal habitat, such as smaller outcrops or less mesic sites at lower elevations. Occurrences of this type have been documented in the Laramie Mountains south of USFS lands. Refsdal found *A. laramiensis* in crevices in outcrops less than 30 m (100 ft.) high in sagebrush grassland with scattered conifers (Fertig et al. 1994). Packer (2000) found it among boulders in sagebrush grassland. Marriott and Horning (2004b) reported small occurrences on small outcrops in rolling prairies.

In the main part of its range, almost all *Aquilegia laramiensis* occurrences are in areas underlain by what has been called the Laramie granite (**Figure 5**; Johnson and Hills 1976). However, not all granite provides habitat for this species. Marriott and Horning (2004a) reported obvious differences in types of granite seen. With the exception of one site, *A. laramiensis* was absent from a coarse-grained reddish granite in the northwestern part of the Laramie Mountains. Neither Condie (1969) nor Johnson and Hills (1976) described this distinctive granite type, but Condie's study was limited to reconnaissance, and Johnson and Hills worked on the north edge of Medicine Bow National Forest.

Moving south through the Laramie Mountains, the Laramie granite is replaced at higher elevations by other Precambrian metamorphic and igneous rocks. A disjunct occurrence of *Aquilegia laramiensis* occurs approximately 100 km (62.1 miles) south of Laramie Peak on Ragged Top Mountain, which is underlain by gneiss (McCullough 1974). Refsdal's 1993 collection halfway between Laramie Peak and Ragged Top also is in an area of gneiss outcrops. Marriott and Horning (2004b) found *A. laramiensis* on gneiss and peridotite as well as granite on BLM lands.

The southernmost part of the Laramie Mountains is underlain by the Proterozoic Sherman granite at higher elevations. *Aquilegia laramiensis* apparently is absent from this area (Marriott and Horning 2004a). In spite of easy access and relatively frequent collecting, no columbine occurrences have been found. The area does not have the same types of habitat seen in the northern Laramie Mountains. It appears too dry, perhaps due to climatic differences. Also, the Sherman granite forms different types of outcrops without high steep faces.

Reproductive biology and autecology

Aquilegia laramiensis, like all columbines, is a non-rhizomatous herbaceous perennial (Munz 1946, Grant 1952). The lifespan of an individual plant is not known, even among gardeners (e.g., Nold 2003). Other members of the genus range from long-lived to biennial in the garden (Munz 1946, Nold 2003).

In all cases that have been studied, members of the genus *Aquilegia* reproduce by seed, and propagation for garden use is by seed (Munz 1946, Nold 2003). Phoenix Perennials (2004) states that the species does not set seed well, at least in the greenhouse, but no details are provided. Columbine seed does not appear to have a short life span although Nold (2003) reports that fresh seed germinates more quickly. Seed viability over time for *A. laramiensis* is unknown.

Columbines are considered relatively easy to propagate, with a wide range of sowing and transplanting times (Nold 2003). In the garden, many species can be grown in a wide variety of conditions (Munz 1946). Nold (2003) reports that *Aquilegia laramiensis* is easily grown in lightly shaded, well-watered scree, yet it is not widespread in the wild. A common interpretation regarding species restricted to a very limited set of sites, and yet easily grown in the greenhouse, is that it is unable to compete well. Though such species may grow in a wide range of conditions in the absence of competition (e.g., in the greenhouse), in the wild they are restricted to sites that are harsh, with minimal competition from other plants.

At sites surveyed in 2003 and 2004, *Aquilegia laramiensis* was found mostly in microsites with few other species (Marriott and Horning 2004a, 2004b), providing additional evidence for poor competitive ability. The species may be able to grow on poor soils that characterize rock outcrops, soils that are inhospitable to most other plants. However, without experimental evidence, poor competitiveness must be considered an untested hypothesis.

Marriott and Horning (2004a) reported phenological conditions for *Aquilegia laramiensis* occurrences surveyed. Plants were found in flower as early as June 8, and as late as July 26, by which time fruit were also present. Dried fruits from the previous seasons were found at many sites. Older herbarium specimens with flowers and fruit were collected within a similar time period. Phenology is very likely influenced by elevation, but this has not been documented.

The genus *Aquilegia* is characterized by morphologically-diverse species, many of which are interfertile (Hodges and Arnold 1994). Crosses between columbine species from different continents and with striking differences in floral morphology often are at least partially fertile. Gardeners are well aware of the ease with which hybrid lines can be developed in this genus. In the wild however, hybridization and introgression are not as widespread as might be thought. It is assumed that pollinator specificity serves as an effective isolation mechanism in many cases (Grant 1992, Hodges 1997).

It is unlikely that *Aquilegia laramiensis* hybridizes with other members of the genus. The species exhibits only limited morphological variability, and it is easily circumscribed (Munz 1946, Whittemore 1997). No other columbine species have been documented from the northern part of the Laramie Mountains (Rocky Mountain Herbarium 1998, Packer 2000, Dorn 2001), and none were seen during recent surveys (Marriott personal observation).

Demography

There have been no demographic studies of *Aquilegia laramiensis*, nor is there sufficient information on which to base estimates of minimum viable population size. For example, lifespan, growth rate, seed production rate, and seed longevity are unknown for the species.

The degree of gene flow between populations and its relationship to distance between sites is unknown. Self-pollination is thought to be common in species such as *Aquilegia laramiensis* that grow as small isolated populations, as it would assure reproductive success in the absence of neighbors or pollinators (Eckert and Schaefer 1998). However, since Eckert and Schaefer found nearly normal levels of seed set in emasculated individuals of *A. canadensis*, sufficient cross pollen was apparently deposited even in areas of low plant density. In the absence of information specific to *A. laramiensis*, we cannot assume that the species is capable of self-pollination.

When information is not available, Species Conservation Assessment authors have been directed to extrapolate or synthesize where possible from models and other theoretical discussions, or from other species. At this time, there is insufficient demographic information available for *Aquilegia laramiensis* to extrapolate from other species or from general models for topics such as vital population rates, risk of small populations, population viability analysis, and metapopulation dynamics. As more detailed studies are done for more species, it is becoming apparent that earlier theoretical models are overly simplistic, and that demographic characteristics are often quite species-specific (e.g., Byers and Waller 1999, Gitzendanner and Soltis 2000).

Community ecology

There have been no studies of the community ecology of *Aquilegia laramiensis*, nor of any possible interspecific relationships. In the wild, it is restricted to a very limited set of sites, and yet it is easily grown in the greenhouse (Nold 2003); this suggests that it occupies harsh sites where there is little competition from other species. At sites surveyed in 2003 and 2004, *A. laramiensis* was mostly found on microsites with few other species (Marriott and Horning 2004a, 2004b). These findings suggest that it is a poor competitor.

No clear evidence of predation or browsing on *Aquilegia laramiensis* has been reported from field surveys (Marriott and Horning 2004a, 2004b, Wyoming Natural Diversity Database 2004). In 30 occurrences surveyed, Horning observed two cases in which there appeared to be leaf damage, but the source of the leave damage was unknown (Horning personal communication 2004). While there are some cases where insect herbivores are specific to genera, this pattern is not consistent across flowering plants (e.g., Jordan-Thaden and Louda 2003), and it is not appropriate to extrapolate from other members of the genus *Aquilegia* to *A. laramiensis*.

There also is no knowledge regarding parasites or diseases of *Aquilegia laramiensis*. Nold (2003) reports that in the garden, columbines in general are not subject to many diseases and pests. Although garden situations generally are more conducive to pests and disease due to monocultural conditions, we cannot assume that pests and disease are less frequent in the wild for *A. laramiensis*.

The diagram in **Figure 8** includes generalized interactions between *Aquilegia laramiensis* and its environment. Most factors are common to vascular plant species in general. More specific interactions can be assumed with varying degrees of confidence, based on the life cycle and habitat of the columbine. The degree of confidence is indicated graphically.

Pollinators

Flowers with modified nectar-secreting petals with spurs, such as those of columbines, are thought to be pollinated by nectar-gathering insects (mainly bees) or hummingbirds (Judd et al. 2003). Columbines are animal-pollinated in cases studied (Hodges et al. 2003); pollinators include hummingbirds, bees (including specifically bumblebees in some cases), and moths (Grant 1952).

Nothing is known regarding pollinators of *Aquilegia laramiensis*. The pale colors of the flowers suggest pollination by nocturnal insects such as moths (Grant 1952, Hodges et al. 2003). However, it is possible that floral morphology was "inherited" from an insect-pollinated evolutionary ancestor and is present even though the derived species does not rely on animal pollination (see discussion of self-pollination below).

If *Aquilegia laramiensis* were insect-pollinated, the question would arise as to pollinator effectiveness in transferring pollen among populations. *Aquilegia laramiensis* grows on small isolated microsites on large rock outcrops with limited and intermittent appropriate habitat (Marriott and Horning 2004a). In addition, these outcrops are isolated across the landscape, often separated by several kilometers or more of conifer forest or grassland (Horning personal communication 2004, Marriott personal observation).

Selfing (self-pollination) is thought to be common in species characterized by small, isolated populations as it would assure reproductive success in the absence of neighbors or pollinators (Eckert and Schaefer 1998). Eckert and Schaefer (1998) addressed selfing and possible underlying mechanisms in *Aquilegia canadensis*, which grows as isolated patches on granite outcrops in eastern central North America. Seed set was only somewhat lower in flowers excluded from pollinator visits, indicating that selfing was effective. Anthers and stigmas are in close proximity within the flower when the anthers begin to dehisce, allowing for self-pollination if there is little competition from other pollen (the stigmas are receptive before the anthers dehisce).

It is unknown whether *Aquilegia laramiensis* has the ability to self-pollinate. It is tempting to speculate that it does, given its coarsely patchy habitat and small occurrence size. However, Eckert and Schaefer (1998) also found nearly normal levels of seed set in flowers of *A. canadensis* that had been emasculated prior to anther dehiscence, thereby preventing selfing. Apparently, sufficient cross pollen was deposited even in areas of low plant density. Tepedino (1998) also found that rare plants are not necessarily selfers.

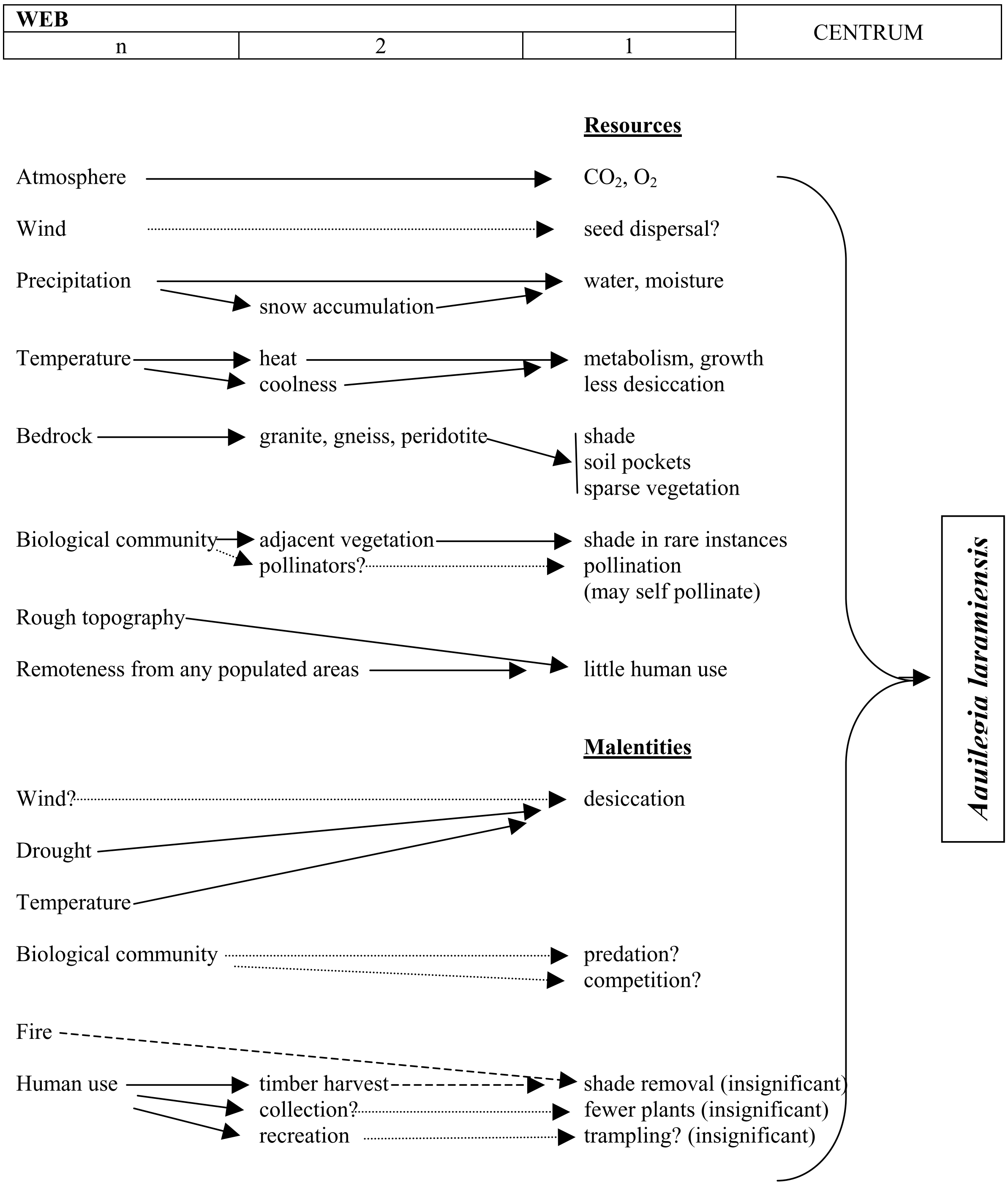

Figure 8. Diagram of resources and malentities for *Aquilegia laramiensis*. Dotted lines indicate possible but unknown factors. Dashed lines indicate known or strongly suspected factors of insignificant impact to species viability.

CONSERVATION

Threats

Currently there are no known existing threats to the viability of *Aquilegia laramiensis* across Region 2. Several potential threats have been identified, but none are thought to affect the overall viability of the species. Extirpation of smaller, accessible occurrences may be of concern.

In this section, potential threats are discussed first in order to clarify management implications. Then, several management activities that do not pose potential risk under current conditions are addressed. Threats to individual plants and threats to habitat are not segregated in these discussions, as there is insufficient information at this time to make such an approach useful.

Collection and eradication

The USFS has two regulations against the collection of rare plant species found in 36 CFR Sec. 261.9 (Subsec. c and d) Property (Burkhart personal communication 2005, Roche 2005), which include:

(c) Damaging any plant that is classified as a threatened, endangered, sensitive, rare, or unique species.

(d) Removing any plant that is classified as a threatened, endangered, sensitive, rare, or unique species.

Access to *Aquilegia laramiensis* sites is difficult and time-consuming, and public use of the area is relatively light. Patrol of known sites is not justified given limited agency resources, so it is unlikely that collectors would be caught or even deterred. Therefore, collection must be considered a potential threat.

In particular, collection for gardening has been identified as a potential threat to *Aquilegia laramiensis* (e.g., Fertig et al. 1994). Nold (2003) states that the species, "once thought to be rare in the wild … is more or less readily available in the trade." He considers it a "first-rate columbine for the rock garden" that is easily grown. Seeds and plants of *A. laramiensis* are available for sale at sites on the World Wide Web (**Table 3**). Sources, where listed, are cultivated plants, with no indication of wild harvesting. Given the difficulty of access to most *A. laramiensis* sites, and the ease with which the species is propagated, it is likely that cultivation is the main source of seed and plants commercially.

Non-commercial collection by gardeners familiar with the species is a possibility, but this has not been documented. It is unlikely that the overall viability of *Aquilegia laramiensis* would be affected by collecting under current conditions. The larger occurrences are found on large systems of rock outcrops that make up ridgecrests and summits. The outcrops themselves are difficult to reach in many cases (e.g., steep topography, rocky slopes, fallen timber), and navigating these systems to find microsites requires good scrambling skills (Marriott personal observation).

Of the 30 occurrences surveyed in 2003 and 2004, only three are considered vulnerable to collection, based on accessibility and small occurrence size (Horning personal communication 2004, Marriott personal observation). Part of one additional occurrence was relatively easy to access, but most of the large area of habitat was difficult to navigate (Marriott personal observation). An occurrence reported by Packer (2000) probably is small based on the site description (boulders in sagebrush). It is near a good gravel road, but the location is not known precisely, and there is little information available about this occurrence.

In addition to possible extirpation by collecting, intentional extirpation is a potential threat. Within the plant conservation community, there is concern that rare plant occurrences may be at risk of damage by individuals that fear governmental restrictions or even seizure of land for protection of rare species. Whether such risk exists in the case of *Aquilegia laramiensis* is unknown. At least some landowners in the area have expressed positive interest in this unusual plant and understand that it is not considered to be threatened or endangered (Horning personal communication 2004).

Fire

There has been concern that fire could damage or extirpate *Aquilegia laramiensis* occurrences, by direct

Table 3. World Wide Web sources for *Aquilegia laramiensis* seed and plants (accessed November 27, 2005).

Site Name	Address	Comments
North America Rock Garden Society	www.nargs.org	seed is garden-collected
Phoenix Perennials	www.phoenixperennials.com	"doesn't set seed well"
Scottish Rock Garden Club Seed Exchange	www.srgc.org.uk	Scotland's friendly society for lovers of beautiful plants
Rocky Mt Rare Plants Alpine Seed	www.rmrp.com	seeds from cultivated plants
Tough Alpine Nursery (northeast Scotland)	www.tough-alpines.co.uk	cultivated plants for sale; out of business in 2005
AlpinesMont Echo (Vermont, Quebec)	www.alpinemtecho.com	cultivated plants for sale

burning as well as indirectly by removing shade. In the Medicine Bow National Forest Revised Land and Resource Management Plan (USDA Forest Service 2003b), it states "Laramie columbine occurs within forested lands where there were frequent fire returns historically. In this area, the fire regimes have been significantly altered from their historical range through fire suppression [*but see discussion below*]. The risk of losing key ecosystem components is high…. Under an extreme wildfire event, the rugged, rocky cliffs may not provide protection from wildfire effects."

At the time of publication of the Medicine Bow National Forest Revised Land and Resource Management Plan (USDA Forest Service 2003b), little was known about *Aquilegia laramiensis*; only ten extant sites were documented, and none had been surveyed in detail. In 2003 and 2004, range-wide surveys were done (Marriott and Horning 2004a, 2004b), and much new information was collected, resulting in rethinking of possible fire impacts.

Based on observations made during surveys, Marriott and Horning stated that fire is not a significant threat to the overall viability of *Aquilegia laramiensis* (Marriott and Horning 2004a, 2004b). Most occurrences, and all of the larger ones, occur on extensive systems of large rock outcrops with little tree cover and little fuel. Shading is provided mainly by aspect, position, and topography rather than by tree cover. Trees occasionally contribute shading to microsites, and it is possible that individual patches of *A. laramiensis* could be lost if trees nearby were killed.

Aquilegia laramiensis apparently can tolerate nearby fire in at least some cases. It was found in several areas that burned in 2002, in what was considered a large fire (Marriott and Horning 2004a). For example, on the summit of Black Mountain, trees burned in the 2002 fire were found next to rock outcrops within 10 to 25 feet of microsites occupied by the columbine. The soil adjacent to the outcrop was still charred and unvegetated during survey in 2004.

Even with significant new information, the issue of fire impacts on *Aquilegia laramiensis* remains controversial. Roche (2005) states that information from recent surveys (Marriott and Horning 2004a, 2004b) does not support the authors' statements that most occurrences would be unaffected by either the heat of fire or the removal of shade. In addition, departure from historical fire frequency is seen as a threat, assuming that *A. laramiensis* requires "natural" fire frequencies. The USDA Forest Service (2003b, Roche 2005) states that "Fire frequencies have departed from historical frequencies by multiple return intervals ..." However, fire frequency data for the area are limited and are based on dating of fire events with standing trees rather than age analyses of stands (Brown et al. 2000, Baker personal communication 2005). In the absence of age-structure data, it is not possible to assess the role of stand-replacing fires. The work of Brown et al. (2000) therefore does not rule out infrequent high-severity fires prior to Euro-American settlement (Baker and Ehle 2003).

The impact of fire retardant on *Aquilegia laramiensis* has been suggested as a concern (Roche 2005). Although it is unlikely that retardant would be applied directly to the barren rock ridges where larger occurrences are found, it is possible that small rock outcrops in forested areas could be affected. It is unlikely that wind would deposit retardant to microsites at larger sites due to locations that are either near vertical or protected by overhanging rock.

There is also concern that fire would affect pollinators of *Aquilegia laramiensis*, specifically those that nest in woody debris (Roche 2005), but it is impossible to evaluate potential impacts at this time. Although bees have been suggested for many species of columbines (Grant 1952), it is unknown what types of animals pollinate this species, which may even be capable of self-pollination (Eckert and Schaefer 1998).

It has been proposed that fuels in the Laramie Peak/Ashenfelder Basin area be reduced to reduce fire hazard (Roche 2005). It would be impossible to reduce fire fuels at most *Aquilegia laramiensis* sites, due mainly to the absence of trees, as well as the expense and difficulty of access (Horning personal communication 2005, Marriott personal observation).

Timber harvest

Prior to the 2003 survey, there were questions regarding the impact of tree removal during timber harvest on *Aquilegia laramiensis* since this species was known to require at least partial shading. Many of the microsites are indeed well-shaded for much of the day (Marriott and Horning 2004a, 2004b, Marriott personal observation), but only rarely was significant shading of microsites by trees observed. Even so, timber harvest could reduce shading at some sites if trees adjacent to rock outcrops were removed. It is unlikely that this would affect the overall viability of the species however, as many of the sites where it occurs are not suitable for timber harvest, including the extensive complex systems of rock outcrops where the largest *A. laramiensis* occurrences are found.

It is unlikely that road construction associated with timber harvest would threaten most occurrences of *Aquilegia laramiensis*. The plant is restricted to rock outcrops, and many of the occurrences (including all of the larger ones) are in areas that are predominantly rock on ridges, crests, and summits. These areas are unattractive for road construction as the current pattern of road distribution shows. The types of roads (i.e., unpaved, lower speeds) that are constructed and used in the areas where *A. laramiensis* grows are routed around rock outcrops.

It is unlikely that *Aquilegia laramiensis* would be affected by fuel-reduction treatments at the wildland-urban interface for two reasons. First, it grows on public land far from any urban areas. Second, most occurrences are found on sites that have little fire fuel; the sites have large areas of bare rock, and it would be impossible to reduce fuel loads at these locations.

Invasive species and herbicide use

No invasive species were seen on microsites occupied by *Aquilegia laramiensis* during recent surveys (Horning and Marriott 2004a, 2004b, Wyoming Natural Diversity Database 2004, Marriott personal observation). The habitat of the species apparently is not suitable to any of the invasive species currently found in the region. Canada thistle (*Cirsium arvense*) has been observed in the vicinity of *A. laramiensis*; it is found in areas of eroded soils and rocks, rock slides, and disturbed soils (Byer personal communication 2003). Herbicide application would be challenging at most columbine sites due to access difficulties, especially for equipment.

Local application of herbicide by qualified personnel would not pose threats to *Aquilegia laramiensis*. However, there is a proposal to aerially apply Plateau® herbicide across the Medicine Bow National Forest for control of cheatgrass (*Bromus tectorum*; Roche 2005). The Plateau® herbicide targets broadleaf plants (dicots) as well as grasses, and the manufacturer warns of damage to ornamental species in garden use. In addition, native species that are under stress for whatever reason will be less resistant to Plateau® (BASF Corporation 2005). Obviously, broadcast application of this herbicide is a serious threat to *A. laramiensis* and other plant species in a target area.

Recreation

The northern Laramie Mountains are sparsely populated, are not accessible by paved road, and are lightly used for recreation. Access to many *Aquilegia laramiensis* sites requires a four-wheel drive vehicle followed by a stiff hike (Horning personal communication 2004, Marriott personal observation). Most forms of recreation in the area do not utilize columbine habitat. Rock-climbing, popular in the southernmost Laramie Mountains, is rare in the northern part due to long and difficult access, and the patchwork of public and private ownership (Marriott personal observation). In addition, rock outcrops suitable for climbing are uncommon in this part of the range.

Grazing

As discussed above (*Collection and eradication*), the habitat of *Aquilegia laramiensis* is rugged and usually difficult to access, for livestock as well as for humans (Marriott and Horning 2004a, 2004b, Wyoming Natural Diversity Database 2004). While some microsites at shaded outcrop bases are accessible, no evidence of livestock use was seen during surveys in 2003 and 2004. Therefore, the overall viability of the species would not be affected by livestock grazing.

A well-worn bighorn sheep trail was observed at one *Aquilegia laramiensis* site in 2004 (Horning personal communication 2004). It was immediately adjacent to an occupied microsite, but there was no evidence of browsing of the columbine.

Mining

Parts of the Laramie Range have potential for gemstones, including diamonds (Hausel et al. 2001). Kimberlites, indicative of diamond potential, have been found in the Iron Mountain district southwest of Chugwater, Wyoming. This area is south of the Cheyenne Belt, which marks a major transition in rock type. *Aquilegia laramiensis* is found north of this zone, mainly on the Archean Laramie Peak granite (Marriott and Horning 2004a; see earlier discussion under Distribution and abundance; Habitat).

In a broad sense, most of Wyoming has the potential for diamonds, as much of the state is underlain by the Archean craton – ancient continental rock. Diamonds are most often found associated with these oldest cratons (Hausel personal communication 2005). However, diamonds are *not* found throughout such areas, and it is difficult to predict where they might occur. Within the range of the Laramie columbine, little exploration for diamonds has been done, and the diamond potential within this area is unknown (Hausel personal communication 2005).

Gemstones have been found southeast of Laramie Peak, in areas of metamorphic rocks south of the Laramie Peak granite zone. It is unlikely that these gems would be found in the granite region, as they occur in areas of aluminum-rich rocks (Hausel personal communication 2005). However the range of *Aquilegia laramiensis* extends south into a zone of metamorphic rocks, mainly on lands managed by the BLM, and so it is possible that mining for gemstones could take place in areas of columbine habitat. However, the overlap of columbine habitat and metamorphic rock is limited, with most occurrences of the species, and all of the larger ones, found on granite rocks to the north. It is thus unlikely that mining would impact *A. laramiensis*.

There is no known potential for oil and gas in the areas where *Aquilegia laramiensis* grows (USDA Forest Service 2003b).

Fragmentation/connectivity

Given the naturally very patchy distribution of *Aquilegia laramiensis*, it is difficult to speculate with any confidence regarding the contribution of discontinuous distribution to stochastic risk. In addition, for this species we have no information regarding the scale at which processes such as pollination, gene flow, and seed dispersal operate.

Global climate change

Aquilegia laramiensis occurs on more mesic and shaded sites within its range, suggesting that climatic warming may reduce its habitat. Although climate change is potentially the most serious threat to this species' overall population viability, it appears last in this discussion of threats because there is great uncertainty regarding its potential severity and effects. Global climate change could possibly cause changes to existing climatic and precipitation patterns (U.S. Environmental Protection Agency 1997) and could subsequently affect this species. However, the factors determining long-term population stability are not well understood; therefore it is difficult to predict the optimal environmental conditions for persistence of the species.

Conservation Status of Aquilegia laramiensis in Region 2

This section is intended to provide an assessment of the biological and ecological status of *Aquilegia laramiensis*, the trends and directions the species is taking, and the impacts of human activity. Conservation status is the result of multiple factors affecting rarity and endangerment. For example, a species represented globally by 15 populations found in remote areas with no human activity may not be of high conservation concern compared with one represented by 50 populations within an area being actively developed for energy resources.

Several programs have developed criteria for assessing the conservation status of a species. NatureServe (2004) uses the following set of standard criteria as guidelines:

- total number and condition of occurrences (populations)
- population size
- range extent and area of occupancy
- short- and long-term trends in the above factors
- scope, severity, and immediacy of threats
- number of protected and managed occurrences
- intrinsic vulnerability
- environmental specificity.

An assessor's overall knowledge of the species influences the importance or weight of each factor.

Region 2 of the USFS also uses a set of eight criteria in evaluating species for sensitive designation (Heidel and Laursen 2001):

- distribution within Region 2
- distribution outside of Region 2
- dispersal capability
- abundance in Region 2

- ❖ population trend in Region 2
- ❖ habitat trend in Region 2
- ❖ habitat vulnerability or modification
- ❖ life history and demographics.

These assessment criteria can be applied to *Aquilegia laramiensis* based on information presented in this assessment. That information and its relevance to conservation status are summarized here.

Assigning conservation status to *Aquilegia laramiensis* is complicated by the existence of conflicting factors (Heidel personal communication 2004, Marriott personal observation). The species is often locally common within its range, but its global range is limited. Many occurrences are small, but it is not clear that this is a risk to the overall viability of the species. Large areas of habitat with high potential for *A. laramiensis* remain to be surveyed, and the larger occurrences that have been surveyed probably are significantly larger than current estimates. No trend data are available. There is little in the way of management conflict and little impact from human use in general. Climatic warming may significantly reduce the abundance of the species but is outside the realm of management. In summary, *A. laramiensis* appears to be stable at this time.

Potential Management of __Aquilegia laramiensis__ in Region 2

Implications and potential conservation elements

This section identifies known environmental and landscape elements and conditions that are essential for maintaining *Aquilegia laramiensis* in a well-distributed, functional, and viable condition across Region 2. This discussion is simplified by the fact that the entire range of the species is within Region 2, and that the majority of the known occurrences of *A. laramiensis* are on USFS land. However, as in the discussion of conservation status above, limitations on available information for the species make it difficult to draw conclusions.

Some conservation elements for *Aquilegia laramiensis* can be identified based on its apparent habitat requirements. It grows on rock outcrops, occupying microsites that are well-shaded for much of the day. Shading is provided by aspect, topography, and position in most cases, with rock generally being the obstacle between plants and the sun. Only rarely is significant shading provided by trees. We also know that while *A. laramiensis* is found on relatively poor soils, it does require some soil development for suitable habitat, typical in pockets on rock outcrops. These microsites are sparsely-vegetated, suggesting that *A. laramiensis* is a poor competitor. It may tolerate poor soils that other plants find inhospitable.

In addition to habitat features, other potential conservation elements that may be essential for continued viability of *Aquilegia laramiensis* include pollinators, seed dispersal vectors or processes, and adequate reproductive isolation to prevent interspecific gene flow. These elements are listed here as examples only. We have no information on which to base educated speculation regarding *A. laramiensis*. We also do not know enough to extrapolate with confidence from other members of the genus, nor from other plant species occupying similar habitat.

At this time, there is no evidence that essential conservation elements for *Aquilegia laramiensis* are being significantly compromised by human activity. Some impacts in the form of reduced microsite shading may result from tree removal if timber harvest takes place adjacent to rock outcrops where the species is found. There is some concern regarding potential extirpation of small accessible occurrences, not by compromising essential conservation elements, but more directly, by intentional removal of plants. Strategies for avoiding these impacts are discussed below under Population or habitat management approaches.

Tools and practices

This section addresses techniques and strategies for managing *Aquilegia laramiensis*, including collecting additional information on the species.

Species inventory

Inventory has been defined as a "point-in-time measurement …to determine location or condition" (Elzinga et al. 1998). The term is commonly used interchangeably with "survey" although some authors distinguish between the two. For example, Palmer (1987) takes a narrower view, distinguishing between an inventory study and a survey study in the context of monitoring. The former is a simple count whereas a survey study is based on sampling. In this assessment, survey and inventory are used interchangeably. Surveys for *Aquilegia laramiensis* in 2003 and 2004 (Marriott and Horning 2004a, 2004b) fit Elzinga's definition of inventory well.

Rare plant inventories are carried out for varying reasons. Elzinga et al. (1998) recognized six objectives that can drive inventory for rare plant species:

1) locate populations of a species.
2) determine total number of individuals of a species.
3) locate all populations of rare species in a specific area (often a project area).
4) locate all rare species occurring within a specified habitat type.
5) assess and describe the habitat of a rare species.
6) assess existing and potential threats to a population.

Surveys done in 2003 and 2004 were inventories as defined by Elzinga et al. (1998), designed to address inventory objectives 1, 5, and 6 above. These studies are typical of those done for species about which little is known. Before significant resources are directed at data collection and management for a species, it must be clear that it is indeed of high priority. Prior to 2003, little was known about *Aquilegia laramiensis*. There were only ten documented occurrences with little information regarding abundance, habitat requirements, and threats.

There had been little survey for *Aquilegia laramiensis* in proportion to the extent of potential habitat. Therefore, projects in 2003 and 2004 were designed to survey as many sites as possible, well-distributed throughout the study areas, to determine if the species was indeed rare (Marriott and Horning 2004a, 2004b). Surveyors spent less than one hour at most sites; access was much more time-consuming. No effort was made to find every plant at a site; some occurrences may be significantly larger than was documented. Remote sites (requiring more than several hours of walking from a road) were surveyed only in areas where *A. laramiensis* had not been previously reported. Surveys in 2003 focused on large outcrops thought most likely to support *A. laramiensis*. There are many smaller outcrops on the Medicine Bow Forest that may provide habitat as well (Horning personal communication 2004).

Habitat inventory

There are still significant areas of unsurveyed potential habitat for *Aquilegia laramiensis* (Marriott and Horning 2004a, 2004b). Areas with highest potential for additional columbine occurrences are the large complex systems of rock outcrops on the Medicine Bow National Forest in the northern Laramie Mountains (Marriott and Horning 2004a). Most of these are difficult to access, and surveys will take significantly more time compared with sites visited in 2003 and 2004. The area is quite rugged with limited road access, complicated in some areas by a patchwork of public and private ownership. Finding smaller outcrops with columbine occurrences also will require more time (Horning personal communication 2004).

There are areas of unsurveyed potential habitat on lands managed by the BLM, west and north of the Medicine Bow National Forest (Marriott and Horning 2004b). These lands are managed by the Casper Field Office and were not included in the 2004 field project. Some sites are thought to have high potential for *Aquilegia laramiensis*, including lands immediately adjacent to the northwest part of the Medicine Bow National Forest where the species was documented in 2003. However, the overall area of potential habitat is small compared with that on National Forest System lands.

Aquilegia laramiensis occurs at a disjunct site on Ragged Top Mountain in the central Laramie Mountains approximately 50 km south of the main range of the species. This area is underlain by gneiss, which is known to provide suitable habitat for *A. laramiensis* in the southern part of its main range (Marriott and Horning 2004b). The area between Ragged Top Mountain and the main range of the species to the north is predominantly private land with scattered sections managed by the State of Wyoming. Access is difficult, and the area has seen very little botanical exploration. It is not clear how much potential habitat exists. Based on geologic and topographic maps however, it is clear that the amount of potential habitat is small compared with USFS lands to the north (Marriott personal observation).

Little survey work was done in the area of the southernmost part of the Laramie Mountains (**Figure 4**) in 2003 as the potential for *Aquilegia laramiensis* appears to be low (Marriott and Horning 2004a). No occurrences have been found in spite of easy access and relatively frequent collecting since the establishment of the University of Wyoming in Laramie. The rocks found in this area do not appear to provide appropriate microsites for this columbine.

The granite of the southernmost Laramie Mountains in Wyoming continues south of the state line within Colorado. Dorn (1979) indicated that the range of *Aquilegia laramiensis* may extend to rocky areas in Larimer County, Colorado. Heidel and Laursen (2001) identified Roosevelt National Forest as the Forest in Larimer County closest to the known range of the species. However, this should not be interpreted as a report of the species on that Forest. Comprehensive surveys are needed to determine whether the species occurs in the area.

Based on work in 2003 and 2004, some guidance can be provided for designing further inventory for the species (Horning personal communication 2004, Marriott personal observation). *Aquilegia laramiensis* occurs as irregularly-distributed patches of plants that are very small in relation to the rock outcrops on which they occur. Presence of favorable microsites on rock outcrops is difficult to predict. Some outcrop features served as good indicators of favorable habitat for the columbine in 2003 and 2004 surveys (Horning personal communication 2004, Marriott personal observation). Steep, northerly rock walls more than 50 feet in height were considered high potential habitat. Marriott and Horning (2004a) found topographic maps to be more useful than aerial photographs for identifying high potential sites for columbine survey, as photographs did not show vertical relief clearly. When shade is present, *A. laramiensis* occurs on smaller outcrops and on different aspects, but these kinds of sites are more difficult to predict.

Inventory for *Aquilegia laramiensis* can be done throughout much of the growing season. Plants in flower were found at relatively high elevations as early as mid-June (Marriott and Horning 2004a). Occurrences are identifiable into the next growing season based on fruit (Marriott personal observation). During surveys conducted in 2003, Marriott and Horning (2004a) did not feel confident basing identification on vegetative material alone since leaves of *A. laramiensis* can be confused with those of *Thalictrum* spp. (meadow rues). Meadow rue typically grows in more mesic, less rocky habitat, but in some cases it was seen close to rock outcrops (Marriott personal observation).

Inventory projects for *Aquilegia laramiensis* must be designed with effectiveness and efficiency in mind, as agency resources are often limited. The first question that must be addressed is whether additional inventory is justified. Areas of potential habitat remain to be surveyed on the Medicine Bow National Forest, but these will be difficult and time-consuming to inventory. Project area inventory may be more appropriate than comprehensive surveys, as resources would not be invested in lands where no management activities are planned.

Although there are outcrop features that serve as good indicators of favorable habitat for the columbine (e.g., steep, northerly rock walls), it is difficult to accurately predict the presence of favorable microsites on all rock outcrops (Horning personal communication 2004, Marriott personal observation). Some areas can be ruled out as columbine habitat based on aerial photos and distance from obvious rock outcrops. However, at many sites it will be necessary to do at least reconnaissance by foot to determine if potential habitat is present.

Fertig and Thurston (2003) used predictive habitat modeling to generate maps of potential habitat for 44 Wyoming rare plant species, including *Aquilegia laramiensis*. Maps from that project were acquired prior to field work in 2003 (Marriott and Horning 2004a). Project investigators surveyed what appeared to be good potential habitat both within and outside of predicted areas. It shortly became clear that high potential habitat existed outside of predicted areas, and thus predicted habitat maps were not used as a first criterion in selecting sites. Of the 46 sites surveyed, 24 were within areas of predicted habitat for *A. laramiensis*. Of these, 15 supported columbine occurrences. Of the 22 survey sites selected outside of predicted areas, eight were found to have columbine occurrences, including several that were relatively large.

The predicted distribution maps for *Aquilegia laramiensis* were based on four habitat variables (listed here in order of usefulness in classifying potential habitat):

- ❖ Wyoming soil classification
- ❖ total January shortwave radiation
- ❖ average January air temperature
- ❖ local relief.

Of the data available as Geographic Information System (GIS) layers for Wyoming, these variables were found to be the most useful for predicting presence/absence based on known locations. Soil classification was found to correlate most strongly with known occurrences of the columbine, probably because the species is restricted to rock outcrops, and these are classified as distinct soils units.

For the 2003 survey project, predicted distribution maps produced with habitat modeling were of limited use for survey site selection (Marriott and Horning 2004a). Identifying potential habitat for *Aquilegia laramiensis* required a much finer level of detail than was available from GIS data. Such maps might be useful for identifying general areas of survey if investigators are unfamiliar with the area. Marriott and Horning found that familiarity with the area, topographic maps, geologic maps, and drive-bys were the most useful tools for selecting sites. More detailed analysis of habitat modeling for *A. laramiensis* can be found in Marriott and Horning (2004a).

Monitoring

Monitoring has been defined as the "acquisition and analysis of quantitative data that document the condition of a population or community over time" (Palmer 1987). Elzinga et al. (1998) define the term as "the collection and analysis of repeated observations or measurements to evaluate change;" thus observations need not be quantitative. Elzinga's concept of monitoring applies specifically to the management arena and includes assessment of progress towards objectives.

Monitoring has become a common and important part of rare plant management programs. Palmer (1987) found that the number of newly initiated monitoring projects increased dramatically from 1974 to 1984, and this trend has continued (Elzinga et al. 1998). Monitoring is a key component in "adaptive management", providing measures of progress toward objectives as well as feedback on management effectiveness (Elzinga et al. 1998).

In spite of the increasingly widespread use of rare plant monitoring by government and private agencies, many such studies are poorly designed and do not provide the information needed (Palmer 1987, Elzinga et al. 1998). Plant species vary widely in features such as growth form, distribution of individuals within populations, and persistence of individuals over time. Any design must to some degree be species-specific. If sampling is utilized, additional difficult questions must be answered. Unfortunately, the challenge of designing appropriate monitoring studies is not widely understood. Palmer (1987) looked at 109 rare plant and plant community monitoring programs and classified factors contributing to inaccuracy and inefficiency. Because there is strong pressure to add monitoring to rare plant management programs, it is worth presenting these problems here:

- ❖ data analysis not planned in advance, resulting in inadequate sampling
- ❖ resources invested in species not of high priority
- ❖ no consideration of appropriate aspects or stages of plant's life cycle
- ❖ grossly inadequate sampling, or no assessment of sampling adequacy
- ❖ no or inadequate controls
- ❖ no or inadequate replication
- ❖ no review of project design before implementation
- ❖ no report or publication of results.

Elzinga et al. (1998) address many of these issues and bring up others, such as between-observer variability. Staff turnover and inadequate funding can further hamper monitoring programs (Marriott personal observation).

Population monitoring

Aquilegia laramiensis has not been monitored, aside from repeat visits to a few sites. These visits confirmed that the species was present, and in some cases, estimates of occurrence size were made. However, consistent methods were not used in assessing occurrence size (Wyoming Natural Diversity Database 2004).

As with inventory, monitoring projects for *Aquilegia laramiensis* must be designed with effectiveness and efficiency in mind. The first question that must be addressed is whether monitoring is justified. To justify investment of limited resources, a target species must be of high priority based on rarity and endangerment (Palmer 1987, Menges and Gordon 1996, Elzinga et al. 1998). As was discussed under Species inventory above, current knowledge of *A. laramiensis* suggests that the species is not at risk. For species such as *A. laramiensis*, if a monitoring program is initiated, a low-intensity one would probably be appropriate (Palmer 1987, Menges and Gordon 1996, Elzinga et al. 1998).

Elzinga et al. (1998) add a second criterion for evaluating monitoring needs. In the management context, monitoring is initiated only if opportunities for management change exist. "What can you do if a population is declining other than document its demise?" If there are no management alternatives, then precious resources should not be invested. Over much of the range of *Aquilegia laramiensis* there are no management activities taking place in columbine habitat, and thus limited or no opportunity for management change. Although *A. laramiensis* may not appear to meet Elzinga's requirement for opportunities for management change, its restricted distribution and small occurrence size suggest that it could be vulnerable to unforeseen threats. A low-intensity monitoring program, perhaps done every few years, would be a cost-efficient way to detect large unforeseen changes.

A simple monitoring method involves visiting all or a set of known occurrences to determine presence or absence. This approach is useful for species with multiple small occurrences, such as *Aquilegia laramiensis* (Elzinga et al. 1998). Menges and Gordon (1996) recommend a more informative approach involving delineation of population boundaries, but this would be impossible at the larger *A. laramiensis* sites. The time required to reach all microsites would be prohibitive, and some microsites may be completely inaccessible.

An approach similar to that recommended by Menges and Gordon (1996) might be appropriate for *Aquilegia laramiensis* occurrences thought to be vulnerable due to small size and ease of access. It is more likely that all patches of columbines could be plotted accurately in these situations. This coarse level of monitoring will detect only large changes, but large changes would be observed if collecting were impacting these occurrences.

If a monitoring program for *Aquilegia laramiensis* is to be implemented, the proposed design needs critical review, especially given the frequency of methodological problems in monitoring (Palmer 1987). The chosen design should be implemented initially as a pilot study, as the first trial of a monitoring method inevitably reveals unanticipated problems (Elzinga et al. 1998, Marriott personal observation). Elzinga et al. (1998) provide step-by-step instructions guiding monitoring plan development within the management context, as well as specific suggestions for maximizing consistency, efficiency, and accuracy.

Habitat monitoring

The monitoring types described above are considered "resource monitoring" by Elzinga et al. (1998) as they focus on the plant resource itself. In contrast, habitat monitoring measures progress towards meeting objectives or standards for habitat characteristics. Habitat monitoring is most effective when there is a clear understanding of the relationship between habitat parameters and the species of concern. However, for most rare plants, these data are lacking, and relationships between habitat parameters and species condition must be inferred from site characterizations (Elzinga et al. 1998). This lack of data is certainly the case for *Aquilegia laramiensis*, making habitat monitoring inappropriate.

Population or habitat management approaches

Two potential threats to some *Aquilegia laramiensis* occurrences have been identified. The risk of collection or intentional extirpation may be reduced by not publicizing plant locations. If it is determined that collecting is occurring at some sites, then it will be very difficult to provide or enforce protection. The northern Laramie Mountains are remote and very lightly used. Agency resources could not be justifiably invested in surveillance sufficient to prevent damage.

Reduced shading during timber harvest could be avoided by not removing trees adjacent to rock outcrops where the columbine is found. This would require project survey if unsurveyed potential habitat occurs in the project area.

Information Needs

There is much that we do not know regarding the biology and ecology of *Aquilegia laramiensis*. From a management perspective, the biggest gap in knowledge is the absence of trend data. However, the habitat of the species combined with no known risks to most occurrences suggests that the species is stable. A low intensity monitoring program designed to flag unexpected, large changes in abundance or distribution is a monitoring approach that could be justified, given the status of the species and limited agency resources.

The complete distribution of *Aquilegia laramiensis* is not known. Large areas of potential habitat remain to be surveyed on the Medicine Bow

National Forest. Most of these are difficult to access, and surveys will take significantly more time compared with sites visited in 2003 and 2004. A cost-efficient approach would utilize pre-project inventory, thereby putting resources where there might be conflict.

Very little is known about other aspects of the biology of *Aquilegia laramiensis*, for example autecology, demography, and community ecology. However, this information is not currently of high priority as it is not necessary for management decisions that might affect the species.

DEFINITIONS

Archean – early Precambrian; 4500 to 2500 million years before present (in Wyoming) (Hausel and Jones 1984).

Autecology – biology and ecology of individual species as opposed to communities (Abercrombie et al. 1973).

Community ecology – interactions within an assemblage of living organisms (Knight 1994).

Conservation element – environmental and landscape elements and conditions that are essential for maintaining a species in a well-distributed, functional, and viable condition (USDA Forest Service Region 2; guidance to conservation assessment authors).

Conservation status – biological and ecological status, the trends and directions a species is taking, and impacts of human activity (USDA Forest Service Region 2; guidance to conservation assessment authors).

Gneiss – a common and broad class of metamorphic rocks; usually strongly-foliated (Mears 1978).

Granite – a common and broad class of igneous rocks formed at depth; granular; composed of quartz, feldspar, hornblende, dark mica (Mears 1978).

Holotype – sole specimen of a species or intraspecific taxon used as the type by the author of a name; the name-bearing specimen (Judd et al. 2003).

Introgression – permanent incorporation of genes and/or organelles of one species into another through hybridization and back-crossing (Judd et al. 2003).

Inventory – point-in-time measurement …to determine location or condition (Elzinga et al. 1998); frequently used synonymously with survey.

Isotype – duplicate specimen of the Holotype, being a part of the same individual or gathering (Judd et al. 2003).

Monitor – acquisition and analysis of quantitative data that document the condition of a population or community over time (Palmer 1987); collection and analysis of repeated observations or measurements to evaluate change (Elzinga et al. 1998).

Peridotite – general term for igneous rocks with notable amounts of olivine (Mears 1978).

Phenology – study of periodical phenomena in plants, e.g. flowering (Abercrombie et al. 1973).

Phylogenetic – representing the evolutionary history (Judd et al. 2003).

Proterozoic – late Precambrian; 2500-570 million years before present (Hausel and Jones 1984).

Rank – NatureServe and Natural Heritage Program plant protection ranking system. Internet site: http://www.natureserve.org/explorer/granks.htm. NatureServe describes G2 occurrences as "imperiled—imperiled globally because of rarity or because of some factor(s) making it very vulnerable to extinction or elimination. Typically 6 to 20 occurrences or few remaining individuals (1,000 to 3,000) or acres (2,000 to 10,000) or linear miles (10 to 50)." N1S1 is described as "critically imperiled—critically imperiled in the nation or subnation because of extreme rarity or because of factor(s) making it especially vulnerable to extirpation from the subnation. Typically 5 or fewer occurrences or few remaining individuals (< 1,000)."

Sensitive species (USDA Forest Service) – plants and animals for which population viability has been identified as a concern by a Regional Forester because of significant current or predicted downward trends in abundance or in habitat capability that would reduce distribution (USDA Forest Service 2003a).

Sensitive species (USDI Bureau of Land Management) – species to be managed with the goal of avoiding the need to list it under the provisions of the ESA (USDI Bureau of Land Management 2002).

Speciation – evolutionary process by which species are formed (Judd et al. 2003).

Systematics – science of organismal diversity; frequently used in a sense roughly equivalent to taxonomy (classification of organisms) (Judd et al. 2003).

Heritage ranking system (from Keinath et al. 2003) – Heritage ranks are based on a system originally developed by The Nature Conservancy and its network of natural heritage programs (now coordinated by NatureServe [Arlington, Virginia]) to indicate the probability of extirpation, at both the global and state scales, of each plant and animal taxon.

The following letters denote the spatial scale at which a taxon's status is scored:

G = Global rank: refers to the range-wide probability of extinction for a species

T = Trinomial rank: refers to the range-wide probability of extinction for a subspecies or variety

S = State rank: refers to probability of extinction from WY for a given taxon

These letters are each followed by a numeric, 1-5 score:

1 Critically imperiled because of extreme rarity (often <5 extant occurrences) or because some factor makes it highly vulnerable to extinction

2 Imperiled because of rarity (often 6-20 extant occurrences) or because of factors making it vulnerable to extinction

3 Rare or local throughout its range or found locally in a restricted range (often 21-100 known occurrences)

4 Apparently secure, although it may be quite rare in parts of its range, especially at the periphery

5 Demonstrably secure, although it may be rare in parts of its range, especially at the periphery

Some taxa receive non-numeric scores, indicating special situations:

H = Known only from historical records (typically pre-1970; varies by taxon)

A = Accidental or vagrant: taxon appears irregularly and infrequently

X = Believed to be extinct

U = Uncertain status: taxon possibly in peril but more information is needed

Some taxa may also receive rank modifiers, indicating other special situations:

B = Breeding rank: indicates the status of a migratory species during the breeding season; applied only to animals

N = Non-breeding rank: indicates the status of a migratory species during the non-breeding season; applied only to animals

Z = Rank not applicable: indicates that a migratory species is essentially absent or unrankable for the season in question (used with "B" or "N"); applied only to animals

Q = Questions exist regarding the taxonomic validity of a species, subspecies, or variety

? = Questions exist regarding the assigned numeric score

References

Abercrombie, M., C.J. Hickman, and M.L. Johnson. 1973. A Dictionary of Biology. Penguin Books, Baltimore, MD.

BASF Corporation. 2005. BASF professional vegetation management. Online at http://www.vmanswers.com/products.aspx?pid=10 [accessed November 27, 2005].

Baker, W. 2005. Professor, Department of Geology, University of Wyoming. Personal communication.

Baker, W.L. and D.S. Ehle. 2003. Uncertainty in fire history and restoration of ponderosa pine forests in the western United States. USDA Forest Service Proceedings RMRS-P-29.

Brown, P.M., M.G. Ryan, and T.G. Andrews. 2000. Historical surface fire frequency in ponderosa pine stands in Research Natural Areas, central Rocky Mountains and Black Hills, USA. Natural Areas Journal 20(1).

Burkhart, B.A. 2005. Botanist, Black Hills National Forest. Personal communication.

Byer, T. 2003. Medicine Bow National Forest, Douglas Ranger District, Douglas, Wyoming. Personal communication.

Byers, D.L. and D.M. Waller. 1999. Do plant populations purge their genetic load? Effects of population size and mating history on inbreeding depression. Annual Review of Ecology and Systematics 30:479-513.

Condie, K.C. 1969. Petrology and geochemistry of the Laramie batholith and related metamorphic rocks of Precambrian age, eastern Wyoming. Geological Society of America Bulletin 80:57-82.

Dorn, R.D. 1979. Status of *Aquilegia laramiensis*. Unpublished report to the U.S. Fish and Wildlife Service. 7 pp.

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

Eckert, C.G. and A. Schaefer. 1998. Does self-pollination provide reproductive assurance in *Aquilegia canadensis* (Ranunculaceae)? American Journal of Botany 85:919-924.

Elzinga, C.L., D.W. Salzer, and J.W. Willoughby. 1998. Measuring and monitoring plant populations. BLM Technical Reference 1730-1. Online at http://nbcweb.blm.gov/pmds/index.htm.

Fertig, W. 2000. State species abstract for *Aquilegia laramiensis*. Wyoming Natural Diversity Database. Online at http://www.uwyo.edu/wyndd [accessed November 27, 2005].

Fertig, W., C. Refsdal, and J. Whipple. 1994. Wyoming Rare Plant Field Guide. Wyoming Rare Plant Technical Committee, Cheyenne, WY.

Fertig, W. and R. Thurston. 2003. Modeling the potential distribution of BLM Sensitive and USFWS Threatened and Endangered plant species in Wyoming. Unpublished report prepared for the BLM Wyoming State Office by the Wyoming Natural Diversity Database, Laramie, WY.

Gitzendanner, M.A. and P.S. Soltis. 2000. Patterns of genetic variation in rare and widespread plant congeners. American Journal of Botany 87:777-786.

Grant, V. 1952. Isolation and hybridization between *Aquilegia formosa* and *A. pubescens*. Aliso 2:341-360.

Grant, V. 1992. Floral isolation between ornithophilous and sphingophilous species of *Ipomopsis* and *Aquilegia*. Proceedings of the National Academy of Sciences USA 89:11828-11831.

Hartman, R. 2003. Curator, Rocky Mountain Herbarium, University of Wyoming, Laramie, WY. Personal communication.

Hausel, W.D. 2005. Senior Economic Geologist, Metals and Precious Stones, Wyoming State Geological Survey, Laramie, WY. Personal communication.

Hausel, W.D. and R.W. Jones. 1984. Self-guided tour of the geology of a portion of southeastern Wyoming. Public Information Circular 21. Geological Survey of Wyoming, Laramie, WY.

Hausel, W.D., R.W. Gregory, R.H. Motten, and W.M. Sutherland. 2001. Report to the Wyoming Legislature on the diamond potential of Wyoming. Wyoming State Geological Survey. Online at http://www.wygs.uwyo.edu/metals/legis_rep.aspx [accessed November 27, 2005].

Heidel, B. 2004. Botanist, Wyoming Natural Diversity Database, University of Wyoming, Laramie, WY. Personal communication.

Heidel, B. and S. Laursen. 2001. USDA Forest Service sensitive species evaluation form. Online at http://www.fs.fed.us/r2/projects/scp/evalrationale/evaluations/dicots/aquilegialaramiensis.pdf [accessed November 27, 2005].

Hodges, S.A. 1997. Floral nectar spurs and diversification. International Journal of Plant Science 158(6 Supplement): S81-S88.

Hodges, S.A. and M.L. Arnold. 1994. Columbines: A geographically widespread species flock. Proceedings of the National Academy of Sciences 91:5129-5132.

Hodges, S.A., M. Fulton, J.Y. Yang, and J.B. Whittall. 2003. Verne Grant and evolutionary studies of *Aquilegia*. Research review. New Phytologist 161:113-120.

Horning, D. 2004. Field Botanist, Poorperson's Enterprises. Personal communication.

Horning, D. 2005. Field Botanist, Poorperson's Enterprises. Personal communication.

Jankovsky-Jones, M., G.P. Jones, and W. Fertig. 1995. Ecological evaluation for the potential LaBonte Canyon Research Natural Area within the Medicine Bow National Forest, Albany and Converse counties, Wyoming. Unpublished report prepared by the Wyoming Natural Diversity Database, Laramie, WY.

Johnson, R.C. and F.A. Hills. 1976. Precambrian geochronology and geology of the Boxelder Canyon area, northern Laramie Range, Wyoming. Geological Society of America Bulletin 87:809-817.

Jones, G.P. 1989. Report on the Ashenfelder Basin Special Interest Area. Unpublished report prepared by the Wyoming Natural Diversity Database, Laramie, WY, for Medicine Bow National Forest.

Jordon-Thaden, I.E. and S.M. Louda 2003. Chemistry of *Cirsium* and *Carduus*: a role in ecological risk assessment for biological control of weeds? Biochemical Systematics & Ecology 31:1353-1397.

Judd, W.S., C.S. Campbell, E.A. Kellogg, P.F. Stevens, and M.J. Donoghue. 2003. Plant systematics: A phylogenetic approach. Sinauer Associates, Inc., Sunderland, MA.

Keinath, D., B. Heidel, and G. Beauvais. 2003. Wyoming plant and animal species of concern. Wyoming Natural Diversity Database, University of Wyoming, Laramie, WY.

Knight, D.H. 1994. Mountains and plains: The ecology of Wyoming landscapes. Yale University Press, New Haven, CT.

Marriott, H. and D. Horning. 2004a. Status of Laramie columbine (*Aquilegia laramiensis*) and results of field survey. Unpublished report prepared for the Wyoming Natural Diversity Database, University of Wyoming, and Medicine Bow National Forest, Laramie, WY.

Marriott, H. and D. Horning. 2004b. Field survey for Laramie columbine (*Aquilegia laramiensis*), Rawlins Field Office. Unpublished report prepared for the Wyoming Natural Diversity Database, University of Wyoming, and Bureau of Land Management, Rawlins Field Office.

McCullough, P.T.P. 1974. Origin of the Ragged Top Gneisses, Laramie Range, Wyoming. Unpublished Ph.D. Dissertation, Department of Geology, University of Illinois at Urbana-Champaign.

McKee, J.P. 2002. USDA Forest Service sensitive species evaluation form (for *Aquilegia saximontana*). Online at http://www.fs.fed.us/r2/projects/scp/evalrationale/evaluations/dicots/aquilegiasaximontana.pdf [accessed November 27, 2005].

Mears, B., Jr. 1978. The changing earth. Second Edition. Van Nostrand Co., New York, NY

Menges, E.S. and D.R. Gordon. 1996. Three levels of monitoring intensity for rare plant species. Natural Areas Journal 16(3):227-237.

Munz, P.A. 1946. *Aquilegia*: the cultivated and wild columbine. Gentes Herbarium 7:1-150.

NatureServe. 2004. NatureServe Explorer: An online encyclopedia of life [web application]. Version 4.1. NatureServe, Arlington, Virginia. Online at http://www.natureserve.org/explorer [accessed November 27, 2005].

Nelson, A. 1896. First report on the flora of Wyoming. Wyoming Agricultural Experimental Station Bulletin 28:78-79.

Nold, R. 2003. Columbines. Timber Press, Portland, OR.

Packer, B.A. 2000. A floristic study of the Laramie Range, WY. Unpublished Master's Thesis, Department of Botany, University of Wyoming, Laramie, WY

Palmer, M.E. 1987. A critical look at rare plant monitoring in the United States. Biological Conservation 39:113-127.

Payson, E.B. 1918. The North American species of *Aquilegia*. Contributions U.S. National Herbarium 20:133-158.

Phoenix Perennials. 2004. Online catalogue. Online at http://www.phoenixperennials.com/nursery/plant.php?1567 [accessed November 27, 2005].

Ro, K.E. and B.A. McPheron. 1997. Molecular phylogeny of the *Aquilegia* group (Ranunculaceae) based on Internal Transcribed Spacers and 5.8S nuclear ribosomal DNA. Biochemical Systematics and Ecology 25:445-461.

Roche, K. 2005. Review of species assessment for *Aquilegia laramiensis* (Laramie columbine) by Hollis Marriott and Monica L. Pokorny for Garcia and Associates (contract #53-82X9-02-0113). USDA Forest Service Region 2: Unpublished document, May 18, 2005.

Rocky Mountain Herbarium. 1998. Atlas of the vascular flora of Wyoming. University of Wyoming Rocky Mountain Herbarium. Oneline at http://www.rmh.uwyo.edu [accessed November 27, 2005].

Tepedino, V.J. 1998. The reproductive biology of rare rangeland plants and their vulnerability to insecticides. *In*: G.L. Cunningham and M.W. Sampson, technical coordinators. Grasshopper integrated pest management user handbook. Technical Buleltin 1809. USDA Animal and Plant Health Inspection, Washington, D.C.

USDA Forest Service. 2003a. Threatened, endangered and sensitive plants and animals. Supplement No.: 2600-2003-1. Unpublished document USDA Forest Service, Region 2, Denver, CO. Online at http://www.fs.fed.us/r2/projects/scp/sensitivespecies/index.shtml [accessed November 27, 2005].

USDA Forest Service. 2003b. Revised land and resource management plan and final environmental impact statement for the revised land and resource management plan, Medicine Bow National Forest. Laramie, WY.

USDA Forest Service. 2005. Threatened, endangered and sensitive plants and animals. Unpublished document USDA Forest Service, Region 2, Denver, CO. 20 p.

USDA Natural Resources Conservation Service. 2004. The PLANTS Database, Version 3.5 (http://plants.usda.gov). National Plant Data Center, Baton Rouge, LA 70874-4490 USA [accessed November 27, 2005].

USDI Bureau of Land Management. 2002. WY BLM update of Sensitive Species list - 2002; Information Bulletin Number WY-2003 0001. USDI BLM WY State Office, Cheyenne, WY.

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

Whittemore, A.T. 1997. *Aquilegia*. *In*: Flora of North America North of Mexico. Volume 3. Oxford University Press, NY.

Wyoming Natural Diversity Database. 2004. Element occurrence data for *Aquilegia laramiensis*. Exported for preparation of species assessment report. University of Wyoming, Laramie.

Wyoming Rare Plant Technical Committee. 1994. Wyoming rare plant field guide. Available from Wyoming Natural Diversity Database, University of Wyoming, Laramie, WY.