THESIS

A FLORISTIC INVENTORY OF PRIVATE AND PUBLIC LANDS IN SOUTHWESTERN GUNNISON COUNTY, COLORADO; AND A SOFTWARE TOOL TO ASSIST IN THE GENERATION OF HERBARIUM SPECIMEN LABELS

Submitted by

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ABSTRACT

A FLORISTIC INVENTORY OF PRIVATE AND PUBLIC LANDS IN SOUTHWESTERN GUNNISON COUNTY, COLORADO; AND A SOFTWARE TOOL TO ASSIST IN THE GENERATION OF HERBARIUM SPECIMEN LABELS

I conducted an inventory of vascular flora on public and private property in southwestern Gunnison County, Colorado. The study area consisted of 3,004 acres of private land and 1,850 acres of adjacent public land managed by the Bureau of Land Management (BLM). While a small part of the BLM area was surveyed in the late 1990s, the majority of the study area represented a gap in the existing floristic research to date in the Rocky Mountains. Fieldwork was conducted in the growing seasons of 2016 and 2017. Six hundred five herbarium specimens were generated, representing 315 species and infraspecific taxa. Combining my findings with reliable observations and existing collections from the area, a checklist of 330 species and infraspecific taxa was compiled, representing ten percent of the known Colorado flora. The variable landscape of the area includes submontane to subalpine forests, wetlands, grasslands, sagebrush shrublands, xeric mesa tops, and rocky cliffs. Taken together these areas provide habitat for two species previously unknown in the county (*Trifolium kingii*, *Pyrola picta*), two further species that are considered vulnerable or imperiled in Colorado (*Iliamna rivularis, Draba rectifructa*), and 30 vulnerable or imperiled plant community types. The presence of species and communities of conservation concern not previously documented in the region emphasizes the need for continued floristic study of private lands and other undersampled areas.

In order to efficiently make labels for the aforementioned herbarium specimens, I developed a Python program to generate formatted, print-ready labels from a comma-separated value (CSV) file. Efficiently generating specimen labels can be challenging for newcomers to the field, or for those unable to use existing tools. Several software tools exist for automatic specimen label generation, but these

either require a significant learning curve to use, are not consistently maintained, are not compatible with multiple operating systems, or rely on proprietary software. My program generates labels in HTML, and these are formatted for print using Cascading Style Sheets (CSS) and the Mustache template system. The program does not rely on any proprietary software, is compatible with any operating system on which Python 3.0 or later can be installed, and is easily customizable to suit the user's needs. The minimal nature of the tool makes it easy and efficient to use. The tool will be especially useful to students learning to manage their collection data and produce their own specimen labels. As such, it could be a convenient resource for plant-taxonomy and related courses in which students make collections.

ACKNOWLEDGMENTS

Charlie and Ruth Maurer generously provided the study area, excellent cabin accommodations, and full funding for my research. Charlie, my co-collector on nearly half my specimens, taught me to drive on mountain roads, assisted me while I scrambled to collect awkwardly-positioned plants, and did a lot of scrambling himself. Ruth Maurer's humorous conversation and hearty mountain meals kept me energized, and her advice regarding thesis-writing and graduate school was invaluable. The Harold D. Harrington Fellowship, sponsored by the Jirsa family, contributed additional funding for my research. I am indebted to my advisor, Mark Simmons, for enthusiastically welcoming an untrained hobby botanist into his lab, for pushing me when I needed to be pushed, for being understanding and rational when I ran into obstacles, for providing helpful and amusing pers. comms., and for helping me grow as a student and scientist. The contagiously exuberant Jennifer Ackerfield taught me to properly collect and identify plants, made the connection with Charlie and Ruth from which I later benefited, and patiently helped me with my friends *Erigeron*, *Epilobium, Poa*, and *Carex*. She also wrote the magnificent *Flora of Colorado*, which I have used daily for the last two years. Gay Austin of the Gunnison BLM provided fieldwork guidance and BLM road maps. Marianne Gonta provided the macro lens with which I took most of my fieldwork photos. Vinit Mahida contributed much manual labor on two collecting trips. Dave Steingraeber taught me the fascinating evolutionary history of plant morphology. Dan Sloan was my on-call advisor during my first year of studies, and Erin Osborne Nishimura taught me to enjoy programming. Alissa Williams, Jess Warren, Chris Miller, Ashley Larson, Gretchen Kroh, and Alyx Shigenaga provided homework help and amusement. I thank Jens Pentenrieder, my husband and co-collector on several specimens, for his unwavering support of my work. Finally, I thank Kathy and Len Maher for providing my first study area (their backyard) and supporting my decision to switch careers (again). The experience you all have given me has been nothing short of life-changing.

DEDICATION

For Alferd Packera (Ursus americanus Pallas), Lucy (Alces alces Linnaeus), and Big Boy (Alces alces), who kept me on my toes and taught me my place in nature, and for the elk families (Cervus canadensis Erxleben) who woke me with their otherworldly songs.

For Anthoxanthum hirtum, Pyrola picta, Calypso bulbosa, Carex aureum, and Sisyrinchium montanum, who taught me how extraordinary it can be to look down at one's feet.

For my husband, Jens Pentenrieder, who is always there for me, and whose love keeps me going even at the most difficult of times.

For my grandfather, Michael Gonta, who encouraged me to go to graduate school, and who has given me the following message: "If you don't get a Ph.D., I will haunt you."

For my mother, Kathy Maher, who seeded my obsession with plants and continues to indulge it.

For my father, Len Maher, who doesn't care about plants, but who still takes the time to tell me where he saw the blues, pinks, and yellows so I can go track them down myself. I am especially grateful for you.

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INTRODUCTION

> "The incompleteness of our floristic knowledge takes on critical significance in an era when decisions are being made that will irrevocably determine the fate of our national floristic heritage." (Ertter, 2000, p. 81)

A floristic inventory involves the collection and preparation of vouchered herbarium specimens of each of the vascular plant taxa present in the area under study, and the documentation of these specimens in field notes. From these voucher specimens, a checklist of the taxa present in the area is assembled. In this way, floristic research generates data in the form of preserved plant material, photographs, and written observations that contribute to our understanding of floristic diversity both at the local level and more broadly.

A voucher specimen demonstrates that a plant was present in a given place at a given time. Such specimens enable the scientific community to track changes in species range, phenology, habit, health, morphology, chemical contents, and genetics (Barkley, 2000; Robbirt *et al.*, 2011; Funk, 2018), and often lead to the discovery of new species (Bebber *et al.*, 2010). Temporal changes can be cross-referenced with climate data, historical accounts of human or animal activity, and geologic events to infer what may have caused the changes, or to anticipate what changes may occur in plant populations in the future. This type of analysis is made possible at a large scale by the digital availability of specimens from herbaria around the world (Hufft *et al.*, 2018), especially on aggregating platforms such as the Southwest Environmental Information Network (SEINet, http://swbiodiversity.org/seinet), the Global Biodiversity Information Facility (GBIF, https://www.gbif.org), and Integrated Digitized Biocollections (iDigBio, http://idigbio.org). Herbarium specimens can also be sampled for DNA extraction (Drábková 2014; Do & Drábková, 2017), in some cases over 200 years after their collection (Andreasen *et al.*, 2009). These DNA samples may be used in systematic studies to infer the phylogeny of taxa as well as to delimit species (e.g., Drábková *et al.*, 2006; Jolles & Wilson, 2014; Shepherd, 2017), in population genetics studies (e.g., Cozzolino *et al.*, 2007; Délye *et al.*, 2013), and in biogeography studies (e.g. Feeley, 2012). Both molecular and morphological information from herbarium specimens have enabled the discovery of new species among existing herbarium collections. For example, *Pyrola crypta* Jolles was discovered after DNA sequences derived from herbarium specimens revealed molecular differences among specimens identified as *Pyrola picta*, which in turn elucidated subtle morphological differences that had previously gone unnoticed (Jolles & Wilson, 2014).

Floristic studies also provide the baseline data necessary for conservation work. Conservation efforts cannot be planned or effectively executed without knowledge of the biodiversity of the area to be conserved (Ertter, 2000), and herbarium specimens provide both evidence of what is present in a given region and details about the populations present in an area in the past. Voucher specimens have been used in recent studies monitoring the effects of climate change and human activity on plant communities (e.g., Feeley, 2012; Calinger *et al.*, 2013). As human populations in a given region grow, plants native to the region are threatened by anthropogenic changes to the environment, including the spread of invasive exotic species, changes in herbivory patterns, chemical and physical alterations made to the soil, and climate change (Tilman & Lehman, 2001). Documentation of biodiversity, and therefore evidence of any subsequent anthropogenic change, is needed in order to improve public awareness of these anthropogenic changes, and to prevent irrevocable damage to plant communities and the ecosystems they support.

The floristic diversity of my study area has little documentation in the form of herbarium records. Forty specimens were collected by Melanie Arnett in 1999 at one site in the study area (Arnett, 2002). One-hundred five species and infraspecific taxa were documented by Jennifer Ackerfield on one day in July, 2015 (Ackerfield, pers. comm., 2016), indicating much greater diversity than is currently documented in herbarium records. The majority of the land is private. Access to private land can be difficult to obtain, since the goal of documenting biodiversity can be at odds with the interests of landowners, since finding protected species could limit possibilities for land use (Ertter, 2000). While much of the flora of the Colorado Rocky Mountains has been documented by large-scale, multi-county floristic studies (e.g., Taylor, 2000; Arnett, 2002), the floristic record does not contain much information about floristic diversity at a smaller scale. Denser sampling in a smaller study area can uncover surprises that were not observed with more dispersed sampling.

As Ertter (2000, p. 87) noted, such undersampled study areas, with "complex geology and rugged terrain," can occasionally yield "a jackpot of undescribed species." This study area is particularly diverse in terms of the habitats it contains, ranging in elevation from a submontane 8,700 feet to a subalpine 10,050 feet, and including vegetative communities from xeric mesa-top shrublands, to riparian willow carrs, to dense spruce-fir forests, to mesic grasslands, to aspen-dominated swamps. Given the relative remoteness of the study area, its terrain, its vegetative communities, the restricted access to the private land, and the relative paucity of the floristic record for the area, this was a promising area for floristic investigation.

Location and description of the study area

I conducted a floristic inventory of approximately 4,850 acres of private and public lands in southwestern Gunnison County, Colorado. The study area, 30 air miles southwest of the town of Gunnison (Fig. 1.1), comprises 3,004 acres owned by the Maurer family (Charles, Ruth, and Wayne Maurer) and approximately 1,850 acres of adjacent public land managed by the Bureau of Land Management (BLM).

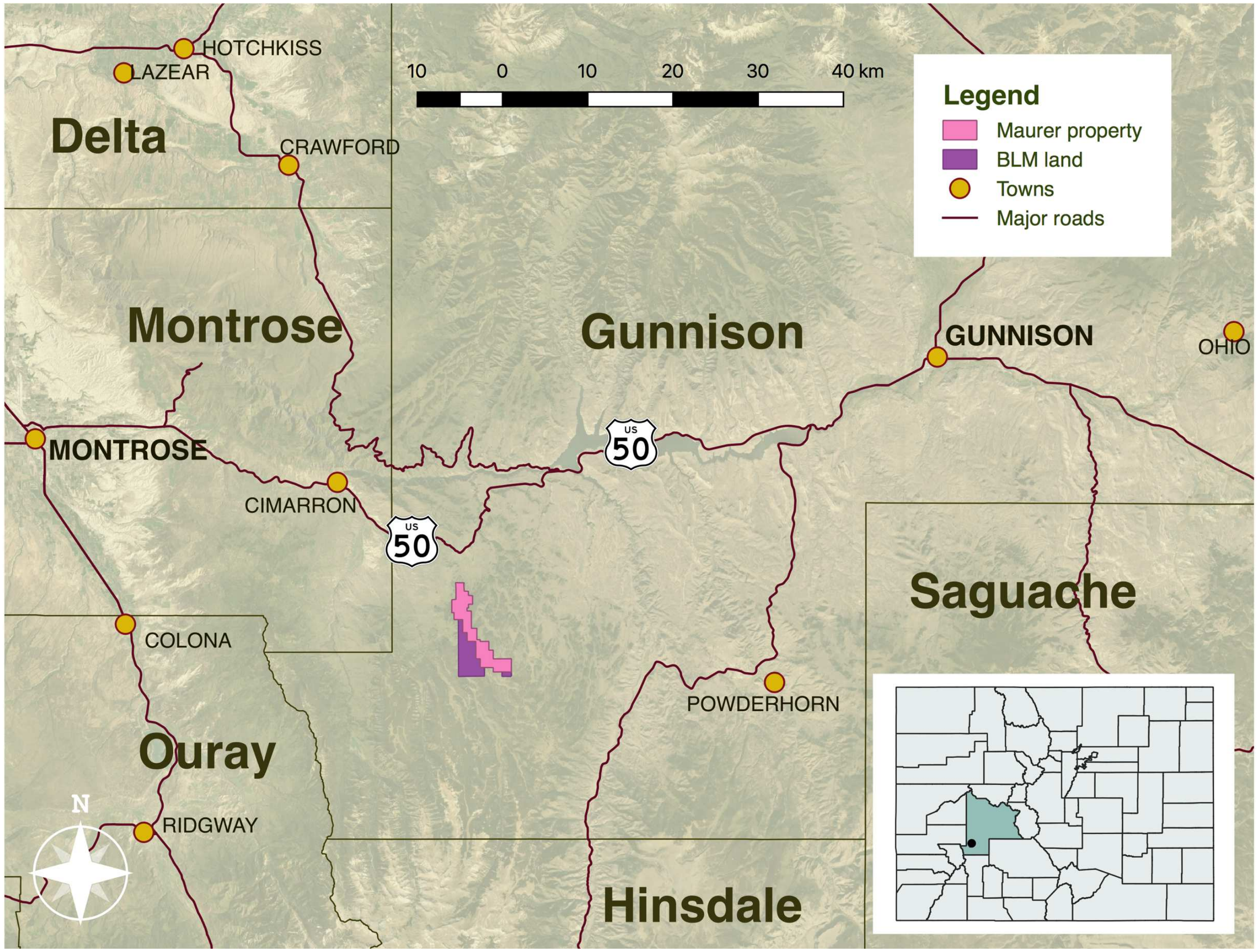

Figure 1.1. Location of the study area within Gunnison County and within Colorado. The northern boundary of the study area is ca. 2.5 miles south of US Highway 50, the western boundary is 4 miles east of the Montrose County border, and the southern boundary is 11 miles north of the Hinsdale County border.

The study area is located at the northern edge of the San Juan Mountains (Fig. 1.2), with the southern property boundary about six miles northwest of the Alpine Plateau. The study area is between latitudes 38.28556° and 38.35973°, and between longitudes -107.37433° and -107.43713°. Elevation ranges from 8,690 feet above sea level, at the intersection of the Big Blue Creek and Maurer property line in the northeast (Fig. 1.3), to 10,070 feet at the southeastern corner of the Maurer property.

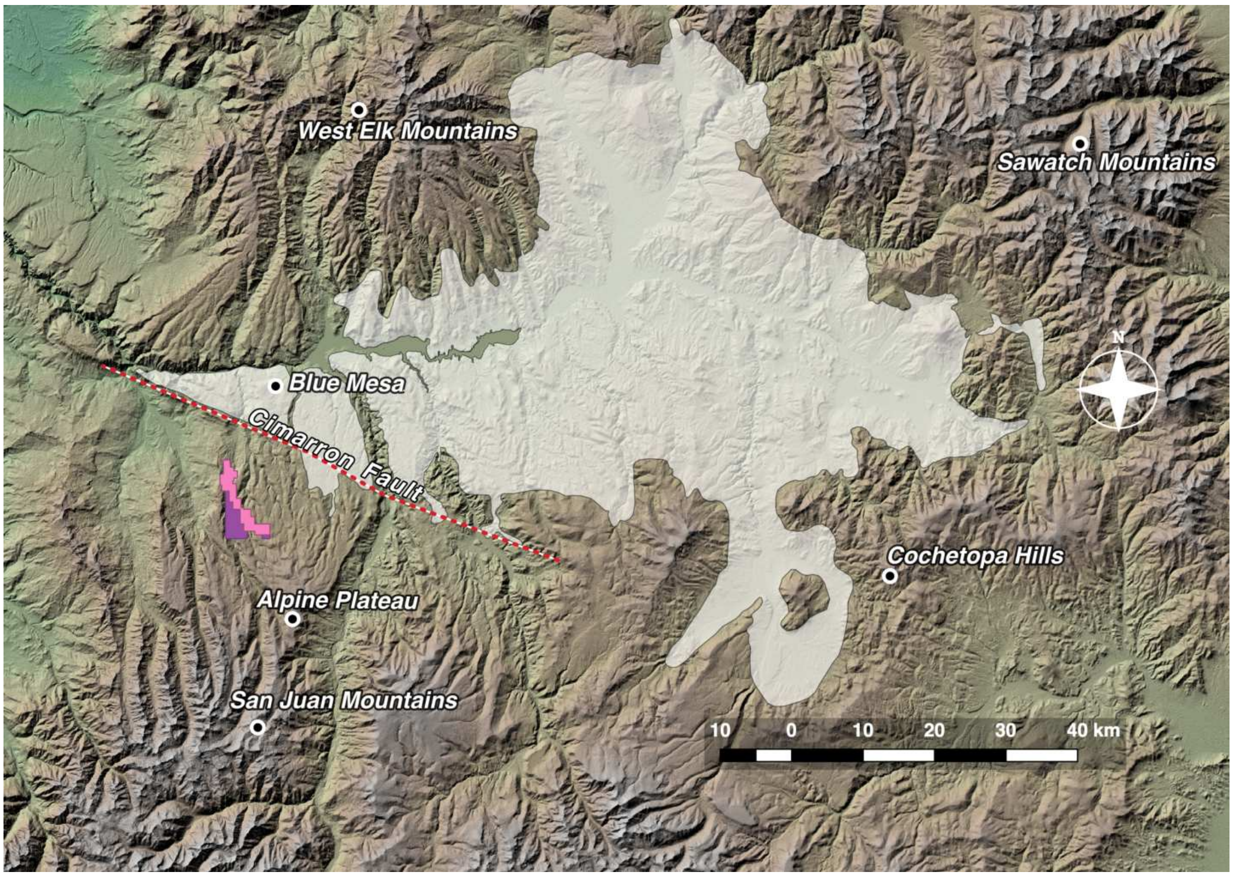

Figure 1.2. The position of the study area (Maurer property: pink polygon; BLM land: purple polygon) in relation to the Gunnison Basin as defined by Barrell (1969). The Gunnison Basin (white polygon) is the area bounded by the Cimarron Fault, the northern San Juan Mountains, the Cochetopa Hills, the Sawatch Mountains, and the West Elk Mountains.

Geology and soils

Several geologic processes contributed to the current landscape of the study area, including orogeny, volcanic activity, erosion, and landslides. The Laramide orogeny, which occurred from

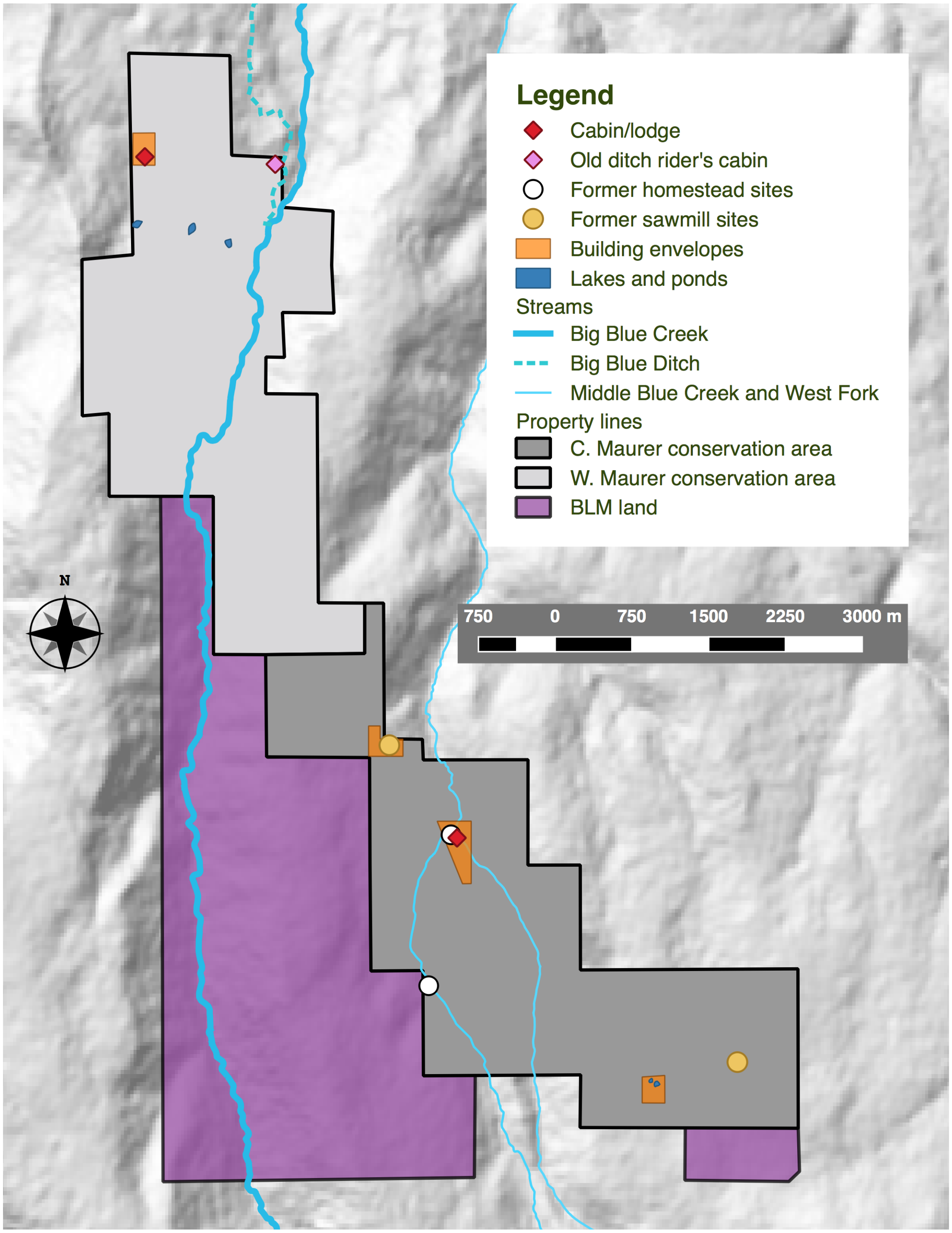

Figure 1.3. Property boundaries and landmarks in the study area.

approximately 80 million years ago (Ma) to 40 Ma (Copeland *et al.*, 2017, and references therein), raised the land that would later become the Rocky Mountains. As the Pacific tectonic plate subducted nearly horizontally under the North American plate during this time period, the resulting seismicity caused North American land over the subduction zone to rise, forming an inland cordillera (Dickinson & Snyder, 1978; Heller & Liu, 2016).

As the Laramide orogeny ended, volcanic activity began. The San Juan Volcanic Field, which included the study area and the greater San Juan Mountain region (Steven & Lipman, 1976), erupted from ca. 35 Ma to 26 Ma (Blair & Gillam, 2011; Drenth *et al.*, 2012), covering the surrounding land with andesitic lava flows during earlier eruptions, and then with ash flows during later eruptions (Drenth *et al.*, 2012; Steven & Lipman, 1976). Within the last 2.5 million years, glaciers and streams have incised these various levels of rock (Hansen, 1965), forming the deep canyons and valleys that make up the current, rugged landscape. Landslides, in part associated with this erosion, have deposited gravel on top of the volcanic bedrock (Reeder, 2013a).

Much of the study area's bedrock (Fig. 1.4) consists of Blue Mesa tuff, Sapinero Mesa tuff, and Dillon Mesa tuff, which are solidified ash flows from San Juan volcanic eruptions (Steven & Lipman, 1976; Reeder, 2013a). Andesitic igneous rock and breccia also form part of the bedrock, primarily in the riparian areas surrounding the Big Blue, Middle Blue, and West Fork Middle Blue Creeks (Reeder, 2013a). Landslide debris covers the volcanic bedrock in the northern portion of the study area (Reeder, 2013a).

Soils in the study area consist of the following six types (Table 1.1, Fig. 1.5): Frisco gravelly loam, Ruby gravelly sandy loam, Shule and Sapinero loams, stony rock land, Sunshine loam, and Youman-Passar loams (Soil Survey Staff, 2017). The base of the Big Blue Canyon is mostly Youman-Passar loams, while the other riparian areas around the Middle Blue Creek and West Fork Middle Blue Creek are Sunshine loam. Seasonally moist meadows on the eastern side of the study area are also Sunshine loam.

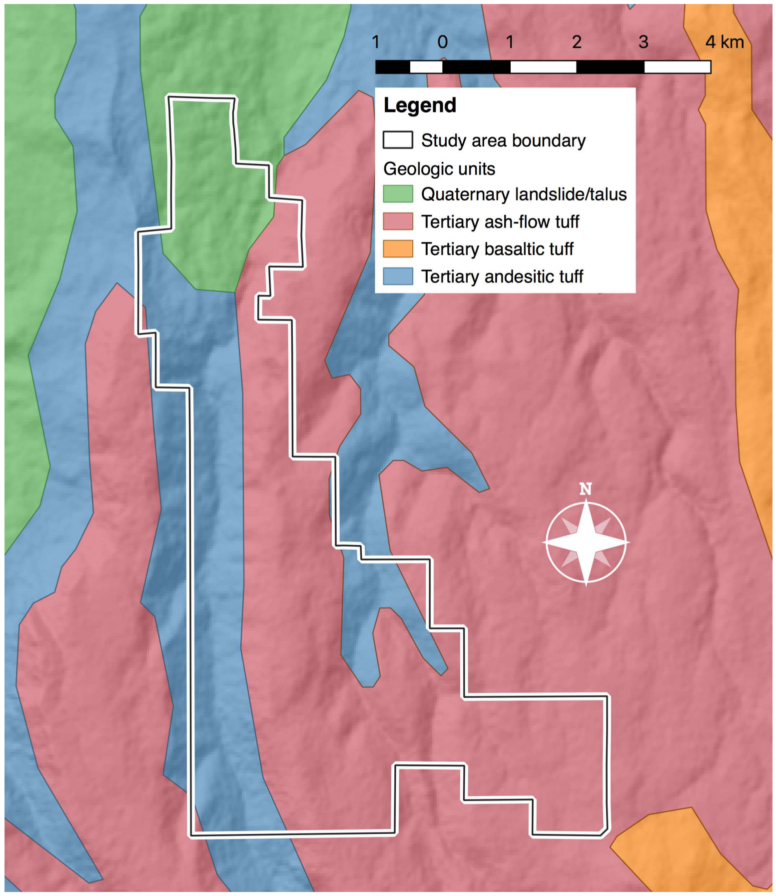

Figure 1.4. Bedrock units in the study area. Geologic data from Horton (2017).

Table 1.1. Soil types in the study area, the slopes on which each type is found, and the vegetative communities associated with each soil type. Slope data from Hunter & Spears (1975) and National Cooperative Soil Survey (Soil Survey Staff, 2018); vegetation data from the National Cooperative Soil Survey (Soil Survey Staff, 2018).

Soil type	**Slope**	**Typical vegetation (dominant spp.; other spp.)**
Frisco gravelly loam	5 to 30%	*Abies bifolia, Paxistima myrsinites, Picea engelmannii, Juniperus* spp., *Vaccinium* spp.
Ruby gravelly sandy loam	5 to 30%	*Achnatherum lettermannii, Artemisia tridentata, Festuca thurberi, Poa* spp.
Shule and Sapinero loams	10 to 50%	*Picea engelmannii*, *Populus tremuloides, Pseudotsuga menziesii*; *Festuca thurberi, Poa* spp.
Stony rock land	not specified	not specified
Sunshine loam	5 to 35%	*Artemisia tridentata, Festuca thurberi, Poa wheeleri*; *Populus tremuloides*
Youman-Passar loams	5 to 30%	*Artemisia tridentata, Festuca idahoensis, Festuca thurberi, Poa* spp.; *Populus tremuloides*

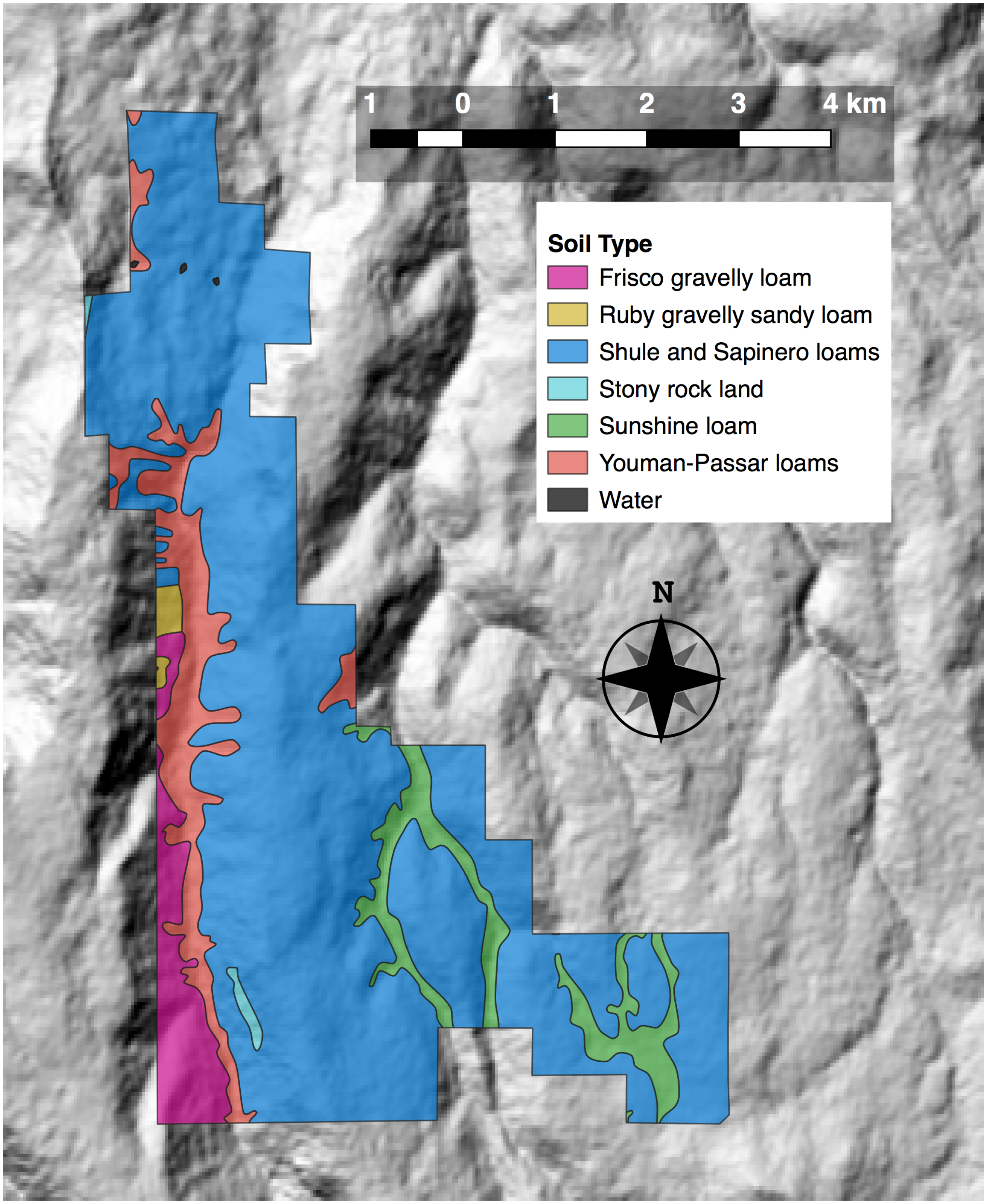

Figure 1.5. Soil types in the study area. Map generated from SSURGO data (Soil Survey Staff, 2017).

Climate

The nearest weather station to the study area is in Cimarron, Colorado, which is approximately 10 air miles northwest of the study area (Fig 1.1). In the 21-year period from 1996 to 2017, this weather station recorded annual precipitation ranging from 9.9 to 19.4 inches, with an average of 14.1 inches (Colorado Climate Center, 2018). Snowfall is included in the aforementioned precipitation measurements, but is scaled to match rain in water volume. Snowfall ranged from 37.2 to 130.5 inches with average annual snowfall of 68.8 inches (Colorado Climate Center, 2018). Average annual temperatures in this same time period ranged from 40.3˚F (2008) to 45.0˚F (2017), with a record high of 97˚F, and a record low of -36˚F.

Major vegetative communities and floristic zones

The major vegetative communities in the study area are coniferous forests, aspen forests, grasslands, sagebrush meadows, and wet meadows. Aspen (*Populus tremuloides*) is abundant in clonal stands of variable size, often at the edges of coniferous forest. The composition of the coniferous forests tends to be a mix of Engelmann spruce *(Picea engelmannii)*, Douglas-fir (*Pseudotsuga menziesii*), and subalpine fir (*Abies bifolia*). While spruce is nearly always present, the forest composition varies with elevation and aspect: lower elevations and more southerly aspects tend to contain more Douglas-fir (*Pseudotsuga menziesii*), while higher elevations and more northerly aspects tend to contain more subalpine fir (*Abies bifolia*).

Wetlands in the study area include swamp forests; lake and pond margins; seasonal pools; snowmelt runoff streams; and riparian areas lining the Big Blue, Middle Blue, and West Fork Middle Blue Creeks. These wetlands are usually dominated by sedges, especially *Carex aquatilis* and *C. utriculata.* Uplands support vegetative communities including spruce-fir forest, aspen forest, fescue-dominated grasslands (*Festuca thurberi, Festuca arizonica*), mountain sagebrush meadows (*Artemisia tridentata* ssp. *vaseyana*), and silver sage/lupine meadows (*Artemisia cana* ssp. *viscidula, Lupinus argenteus* var. *rubricaulis*).

The study area belongs mostly to the montane and subalpine floristic zones. This zone tends to occupy elevations between ca. 8,000 feet and 10,500 feet (Ackerfield, 2015), and consists of a mosaic of aspen stands, coniferous forests, and meadows. Herbaceous species in the montane zone include *Aquilegia coerulea* (blue columbine), *Campanula rotundifolia* (harebells), *Erigeron speciosus* (aspen daisy), *Osmorhiza depauperata* (sweet cicely), *Lupinus argenteus* (silvery lupine), and *Maianthemum stellatum* (false Solomon's seal). The lowest-lying parts of the study area, at elevations around 8,700 feet, and some areas with southern exposure up to 10,000 feet, are submontane, containing elements of the lower-elevation foothills flora, such as *Artemisia dracunculus* (wild tarragon), *Erigeron divergens* (spreading daisy), *Holodiscus dumosus* (rock-spiraea), *Mirabilis linearis* (narrowleaf four o'clock), *Prunus virginiana* (chokecherry), and *Quercus gambelii* (Gambel oak).

Current and past land use

In 1812, the United States government created the General Land Office (GLO) to oversee the sale and purchase of public lands (https://www.blm.gov/about/history/timeline). The Maurer family began to acquire property in the study area about 1918, in the northernmost part of their current property, and gradually acquired land to the south, until the 1950s. (Charles Maurer, pers. comm., 2018; Fig. 1.3). The family operated a sheep and cattle ranch. The 1862 Homestead Act allowed applicants to live on and farm parcels of 160 acres of land, and after five years of cultivation, to acquire the patent (deed) entitling them to the land. In 1916, the Stock-Raising Homestead Act was introduced with similar conditions for homesteaders and ranchers: applicants could earn the patent to a plot of 640 acres, but in this instance, subsurface mineral rights were retained by the government. Albert Maurer purchased a patent to 160 acres of land in 1925 (GLO Patent 965888, 1925), and earned the patent to a plot of just over 640 acres in 1931 (GLO Patent 1046301, 1931).

The Bureau of Land Management was created in 1946, when the GLO and the US Grazing Service were consolidated. Permits are still issued to sheep and cattle ranchers to graze their livestock on the public land in the study area. Old wooden sheep pens, located in the easternmost section of the surveyed BLM land, are still in occasional use. Sheep and cattle ranching operations on the Maurer property ended by the 1990s. Charles Maurer continued to lease his property occasionally for grazing until about 1994, and Wayne Maurer did the same until about 2005 (Charles Maurer, pers. comm., 2018).

Two sawmills were in operation on the Maurer property in the 1950s (Fig. 1.3), and logging of beetle-killed trees was conducted on the property during this time (Reeder, 2013a). Two small, derelict buildings associated with these operations remain, as well as mounds, now partially covered in vegetation, of sawdust and debris.

The Maurer property includes three former cabin sites. Two of these were homesteads. One, the Reynolds Cabin, is no longer standing, but was at the site of Charles Maurer's existing cabin. Part of the log frame of the second former homestead is still standing, near the southern property boundary along the West Fork Middle Blue Creek (Fig. 1.3). The third disused cabin structure is an old ditch rider's cabin (Reeder, 2013b) at the intersection of the property line and the Big Blue Ditch (Fig. 1.3).

Two cabins are currently in use on the property (Fig. 1.3). The southernmost belongs to Charles and Ruth Maurer, and the northernmost to Charles' brother, Wayne Maurer. The study area, on both private and public portions, is frequently visited by game hunters and fishers, though only the BLM land is open for public use. Access to the Maurer property is restricted by locked gates.

Both Wayne and Charles Maurer have placed their entire properties under conservation easements (Fig. 1.3). Wayne Maurer's conservation easement encompasses 1,499 acres, and Charles' easement is 1,505 acres. The conditions of the conservation easements in both cases allow occasional grazing, but neither party currently intends to lease to livestock owners, except perhaps briefly each season to control weeds (Charles Maurer, pers. comm., 2018). There are three building envelopes on the Maurers' property (Fig. 1.3), within which the conservation easements permit further property development.

Previous floristic research in and around the study area

Joseph Barrell, former curator of the Rocky Mountain Biological Laboratory, compiled the *Flora of the Gunnison Basin* (1969), documenting the vascular flora of the region bounded by the Sawatch Mountains to the east, the Elk Mountains to the north, Blue Mesa and the Cimarron Fault to the west, and the San Juan Mountains and Cochetopa Hills to the south (Fig. 1.2). This work is a valuable resource for anyone conducting floristic or ecological research in this region, as it contains detailed descriptions not only of the plant species of the region, but also of their habitats and the floristic zones in which they grow. Barrell constructed his species checklist from existing collections in the region as well as his own collections. My study area is located about 2.5 air miles southwest of Blue Mesa, just beyond the southwestern edge of the Gunnison Basin as defined by Barrell. Barrell's (1969) checklist includes 1,062 vascular plant species, of which 77 (7.3%) are non-native.

Other individual collections in the region have been made along US Highway 50 by botanists including Harold Harrington in the 1940s, Ruth Ashton Nelson in the 1950s and 1960s, Dieter Wilken in the 1980s, and William Weber in the 1940s and 1980s. More recent floristic work in this region includes several projects conducted by University of Wyoming graduate students as part of a long-term effort by the Rocky Mountain Herbarium (RM) to document the flora of the US Rocky Mountain region. Large-scale RM floristic projects in the Gunnison Basin and surrounding regions have been conducted in the

Uncompahgre, Lower Gunnison, and Plateau Creek drainages (Brummer, 2016); the northern Gunnison Basin (Taylor, 2000); and the southern Gunnison Basin (Arnett, 2002).

The BLM portion of the study area was surveyed in part by Melanie Arnett (2002), a former University of Wyoming graduate student, in August 1999. Arnett collected 40 specimens on a ridge in aspen-spruce-fir woodland in the Big Blue Canyon, at an elevation between 9,800 and 9,900 feet. These 40 collections are, to my knowledge, the only collections that have been made in the study area prior to this project. Arnett collected a further 37 specimens about 0.5 miles east of the study area, on BLM land in Cox Park. Voucher specimens for 58 species were obtained from these two sites, of which 37 are within the boundaries of my study area.

The majority of my study area, the private land owned by the Maurer family, has not been included in any previous inventories by other researchers, nor to my knowledge have any formal collections been made on this land prior to this study.

Relevance of this study

My inventory documents the floristic diversity of the study area in the form of herbarium records and this report. The data compiled in this study can be immediately applied as documentation of the conservation value of the private land under study, which is particularly relevant in the context of the two existing conservation easements. Two present-conditions reports have already been compiled by Rare Earth Science for the purpose of documenting the properties' conservation value (Reeder, 2013a, 2013b). The existing reports focus on the value of the land in terms of "relatively natural habitat" (Reeder, 2013a, p. 10), specifically the general vegetative communities on the land and the wild fauna they support. My report complements these, offering a detailed account of the vascular-plant species present, and providing baseline data to inform any future decisions regarding the management of the property. This step is important for any conservation effort, since we cannot know if any biodiversity has been lost unless it was documented at some point in the past.

The study can also be used to inform the management of the BLM land. The Gunnison BLM Field Office has been conducting surveys of wetland vegetation in southern Gunnison County in recent years, with the aim of identifying areas in which human activity and livestock grazing must be restricted in order to preserve biodiversity (Gay Austin, pers. comm., 2017). This study will contribute to these data-collection efforts.

The herbarium specimens generated in this study will be used by the scientific community and the general public, and, disasters notwithstanding, will be available centuries from now. They provide a snapshot of the vascular plant life present in the study area at the time of collection, and will aid future researchers in identification of their own specimens, will provide opportunities to conduct phylogenetic analyses and systematic revisions, will attest to the presence of taxa and communities of conservation concern, and will enable the observation of change in the floristic composition of the study area in the future.

MATERIALS AND METHODS

Site selection and preliminary checklist generation

Fieldwork was conducted during the 2016 and 2017 growing seasons, with one excursion in 2018. Twelve field trips, with an average of between three and four fieldwork days each, were made to the study area: five in 2016, six in 2017, and one in 2018. One field trip was made with the assistant curator of the Colorado State University Herbarium (CS), Jennifer Ackerfield, and nine trips were made with Charles Maurer.

After an initial visit to the study area, I used Google Earth Pro (version 7.1.5.1557, 2016) to identify potential collection sites in addition to those that were visited on the first collection trip. I selected collection sites by applying the following three criteria:

1) The site differs from existing sites in elevation, ecology, hydrology or geology, or is far enough away from other sites to warrant investigation.
2) The site incorporates a border region between two or more vegetative communities.
3) The observed vegetation at the site is substantially different from the vegetation at other sites.

Forty-one sites that satisfied these criteria were sampled (Table 1.2). I also collected in areas outside my prescribed sites if I observed a species new to my collection while traveling from one site to the next.

A preliminary checklist of taxa, on the basis of existing voucher specimens collected within a six-mile radius of the study area, was generated using the map search tool provided by SEINet (http://swbiodiversity.org/seinet/collections/map/index.php). The Colorado noxious weed list (https://www.colorado.gov/pacific/agconservation/noxious-weed-species) was also consulted to help ensure no new occurrences of these species were missed.

Collecting and pressing specimens

When visiting a site, I marked a gallon-size resealable plastic bag with the site number using a permanent marker, took a GPS waypoint for the site, made a dated entry in my field notebook for the site, and proceeded to employ the “meander method” (Nelson *et al.*, 2011) to search for new taxa to collect. At each site, I walked along any boundaries between different vegetative communities, and, where possible, walked a route different from routes previously traversed at that site. A Garmin eTrex 20x GPS unit was used to select new routes through collection sites with each visit. At some sites, the selection of new routes was limited due to steep slopes, bodies of water, or other obstacles.

Upon finding a potential collection specimen, I employed the decision protocol detailed by the dichotomous key below. Each numbered couplet in the key offers two possible, mutually exclusive decisions. Each decision directs the user to either continue to another couplet (by providing the number

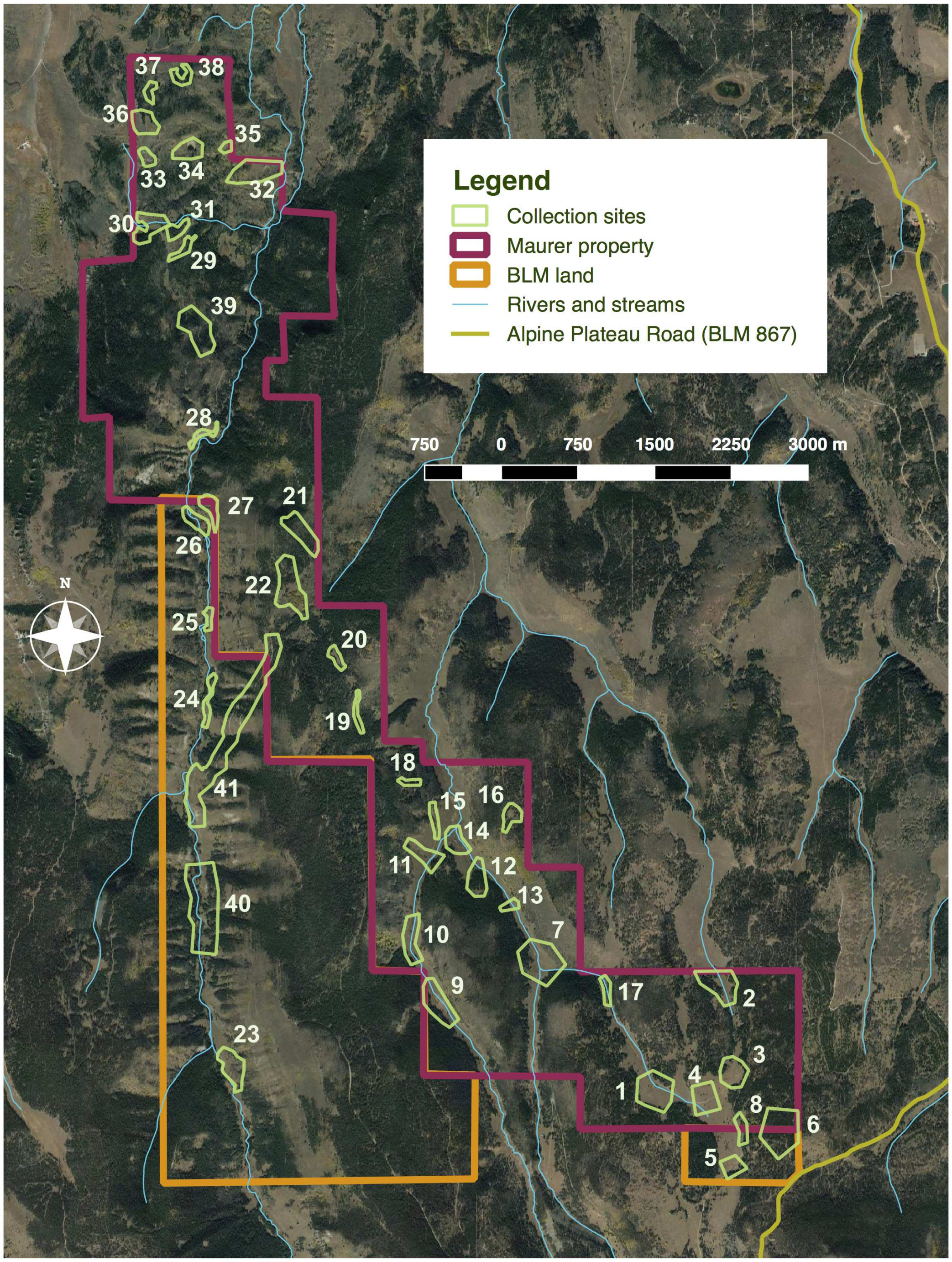

Figure 1.6. Map of the study area and the 41 selected collection sites.

Table 1.2. Sites selected for specimen collection (Fig. 1.6). Names used locally are capitalized; my descriptions are not capitalized. Selection criteria are coded as follows: site incorporates one or more border regions between different vegetative communities (BR), has an elevation substantially different from other sites (EL), differs in its ecology or history of use from other sites (EC), differs in hydrology from other sites (HY), differs in geology from other sites (GE), is a substantial distance from similar sites (DI), and has substantially different vegetation from other sites (V).

Site number	Site name	Location	Selection criteria
1	Twin Ponds	M	BR, HY, V
2	Maurer Spring #9	M	BR, HY, V
3	old sawmiller's cabin/Blue Cabin	M	BR, EC, V
4	south sagebrush	M	BR, V
5	old sheep pens	BLM	EC, V
6	high forest at gate	M/BLM	EL
7	river crosses road	M	BR, HY, V
8	south road	M	BR, EC, HY
9	south West Fork	M	BR, EC, HY, V
10	middle West Fork	M	BR, HY, V
11	runoff stream	M	BR, HY, V
12	Maurer Spring #7	M	BR, DI, EC, HY
13	roadside gooseberry patch	M	BR, EC, V
14	Reynolds Cabin	M	BR, EC, HY, V
15	Alferd's trail	M	BR, HY, V
16	logging road/aspen meadow	M	BR, EC, EL, V
17	road curve near fence	M	BR, HY, V
18	mixed forest	M	HY, V
19	rocky aspen forest	M	BR, GE, V
20	watering hole	M	BR, EC, HY, V
21	talus cliff and forest	M	BR, EL, GE, V
22	lookout mesa	M	BR, EL, GE, V
23	stream at turnaround point	BLM	BR, DI, HY, V
24	mid-canyon riparian	BLM	BR, EC, HY, V
25	second mid-canyon riparian	BLM	BR, V
26	bridge over Big Blue Creek	BLM	BR, EC, HY, V
27	wet meadow	M/BLM	BR, GE, HY, V
28	dry rocky hillside	M	EC, GE, V
29	mosquito lake	M	BR, EC, EL, HY, V
30	Burnt Lake	M	BR, EC, GE, HY, V
31	between two lakes	M	BR, GE, V
32	low aspen	M	BR, EL, HY, V
33	Wayne's cabin	M	BR, EC, V
34	windmill pond	M	EC, HY, V
35	aspen on property line	M	BR, DI, EL
36	north sagebrush	M	BR, V
37	north aspen	M	DI, EL, V
38	North Lake	M	BR, DI, HY
39	Old Trail	M	BR, EC, DI
40	south canyon	M	BR, EC, DI, HY, V
41	switchbacks	M/BLM	BR, EC, EL, GE, V

of the next couplet at the end of the line), or to a required action (by providing a description of the action in italics at the end of the line).

1a. Representative of same taxon has previously been collected for this study and that collection is in good condition .... *do not collect*

1b. Taxon has not yet been collected, or previous collections are in poor condition.......................... 2

2a. After consulting Endangered Species Act, *Flora of Colorado* (Ackerfield, 2015), and *Colorado Rare Plant Guide* (Colorado Natural Heritage Program [CNHP], 1997+), taxon is determined to be rare or threatened, at least locally.. 3

2b. Taxon is not rare or threatened 6

3a. Plant is federally listed under the Endangered Species Act ....*document presence of taxon at this location; take detailed notes and photographs; do not collect*

3b. Plant is not federally listed... 4

4a. Plant is described by *Flora of Colorado* (Ackerfield, 2015) or *Colorado Rare Plant Guide* (CNHP, 1997+)[1] as rare, or is not listed as present in the collection area 5

4b. Plant is not described as rare/absent from area by any consulted sources.................................. 7

5a. Population[2] at current location is greater than 25 individuals.. 6

5b. Population is fewer than 25 individuals .... *take detailed notes and photographs; do not collect*

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[1] The Colorado Rare Plant Guide includes BLM, USFS and CNHP rare plant lists, and is updated at least yearly online.

[2] “Population” here refers not to a genetically defined group, but to plants belonging to the same taxon that are in contiguous groups at a given location.

6a. Population is dispersed enough for one or more entire individuals to be harvested without significant disruption to the remaining plants .... *take detailed notes and photographs; make a collection if this can be done with minimal disruption to nearby individuals in the population*

6b. Population is not dispersed enough for an entire individual to be harvested without significant disruption to remaining plants .... *take detailed notes and photographs; collect partial specimens (aerial parts only, for example) as appropriate to prevent disrupting other plants*

7a. Population at current location is greater than 5 individuals, or is known to be abundant or invasive in the area .... *proceed with collection protocol*

7b. Population at current location is 5 or fewer individuals 8

8a. Population at another known location is greater than 5 individuals ... *document presence of taxon at this location; collect it elsewhere*

8b. Presence of taxon at other locations is unknown .... *document presence of taxon at this location; do not collect*

After determining that it was appropriate to collect a specimen, I employed the collection protocol detailed below.

1. Photograph collection bag marked with site number and date.
2. Take landscape photograph of site, to ensure adequate documentation of vegetative communities present.

3. Make several photographs of plant to be collected, including overall habit, reproductive parts (in macro), leaves (in macro, where appropriate), and any traits thought to be potentially useful for identification (in macro, where appropriate), especially those that may be difficult to observe once the plant is pressed (such as lip petals in Orchidaceae, or bark in Pinaceae).
4. Make detailed notes in waterproof field notebook, beginning with site number and date, and including dominant species in the community, slope, aspect, description of soil, and elevation. Regarding the plant being collected, describe its morphology, paying particular attention to aspects such as calyx/corolla color or stem shape that may change after drying.
5. Carefully, with minimal disturbance to other plants, use digging knife to unearth underground material, or if plant is too large to collect, use clippers to take a branch from the plant. Where appropriate given the population size and size of individual plants, unearth or clip more individuals or branches to fill herbarium page and adequately represent taxon's morphology.
6. If specimen was unearthed, replace and level any disturbed soil so as to minimize damage to the plant community.
7. Place specimen in gallon-sized resealable plastic bag, folding stem if necessary and trying to minimize breakage. Use separate labeled bag if other taxa collected at that site are morphologically similar, to prevent confusion. Seal bag.
8. After visit to site is complete, place specimens in cooler until they can be pressed.

Upon completing a day of collecting, I pressed specimens following the protocol detailed below.

1. Group collection bags by site number. Remove bags from one site from cooler.
2. Assemble materials: stack of ventilators (cardboard), stack of single pages of newspaper, and stack of blotters.

3. Open collection bags from one site; spread collections out on blotters or cardboard, grouping individuals from the same collection.
4. Lay two press straps on table, ensuring both are oriented the same way. Lay bottom half of press on top of the straps. Place one sheet of cardboard on top of the press base.
5. On top of the cardboard, place one blotter, then one sheet of newspaper.
6. Using a permanent marker, at the top of the newspaper sheet, write the date in the left-hand corner, the current collection number in the center, the identity of the taxon to be pressed next to the collection number (as much as is known, whether to family, genus, species, or simply key morphological feature if identity not at all known), and the collection-site number in the right-hand corner.[3]
7. Make corresponding note in field notebook, with date, site number, collection number and specimen identity (to the extent known).
8. Open the newspaper. Arrange the specimen inside the newspaper, avoiding creases in the paper where possible, ensuring no part of the plant is hanging out of the newspaper, and that as many morphological traits as possible will be visible in two dimensions (e.g., both adaxial and abaxial leaf surfaces visible).
9. Close the newspaper. Place a blotter on top of the newspaper, then a piece of cardboard. Press down on the stack and straighten any edges where necessary.
10. Repeat steps 6 through 9 until all collections from one site have been pressed.
11. Remove bags from next site from cooler.
12. Repeat steps 10 and 11 until all plants in cooler have been pressed, or stack reaches 50 specimens.

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[3] Date and site number are written on each sheet of newspaper in addition to collection number to save time when writing labels. Having these data on the newspaper as well as in the field notebook also creates redundancy in case one of the two records is damaged.

13. Place a sheet of cardboard atop completed stack. Place top of press atop stack. Wrap straps around stack, threading ends through buckles and tightening enough to keep stack stable.
14. Move stack to floor. Applying as much of own body weight as possible to top of stack, tighten straps one by one until neither can be tightened any further.
15. Repeat steps 1 through 14 for any remaining specimens.
16. Place stack(s) in dry, well-ventilated indoor area, using a plant dryer if available. Attach a label to top of each stack detailing collector name, any co-collectors, date of collections, and collection numbers represented in stack.

Identifying specimens

Specimens, once dry, were unloaded from presses at the research site, bound between two sheets of cardboard in groups of 10 to 20 specimens, and transported to CS. Specimens were then filed in a herbarium cabinet by family, and subsequently by genus within each family. A targeted collection list was generated for the second field season using existing SEINet (2016) collection data for nearby areas and eliminating those taxa that I had already collected and identified.

Identifications were done using primarily the dichotomous keys in the *Flora of Colorado* (Ackerfield, 2015). Other dichotomous keys and reference literature used included the *Flora of North America* (Flora of North America Editorial Committee, 1993+), *Flora of the Gunnison Basin* (Barrell, 1969), *Flora of Colorado* (Rydberg, 1906), *Grasses of Colorado* (Shaw, 2008), *A Field Guide To Wyoming Grasses* (Skinner, 2010), *Colorado Flora: Western Slope* (Weber & Wittmann, 2012), and *Field Guide to Colorado's Wetland Plants* (Culver & Lemly, 2013).

To check my initial identifications, I used the CS reference collection, which includes nearly all vascular-plant taxa present in Colorado with one specimen each, or sometimes multiple specimens if the morphological traits of the taxon could not be adequately represented with only one specimen (e.g., one flowering specimen, one fruiting specimen). Specimens in the reference collection demonstrate all diagnostically important characters for each taxon, and so tend to have all reproductive parts, above-ground vegetative material, and below-ground material (including roots, bulbs, turions, etc.) needed for identification. The identity of each specimen in the reference collection has been verified by Jennifer Ackerfield, assistant curator of CS and author of the *Flora of Colorado*. Specimens from the general herbarium collection were used in addition to the reference collection where needed to confirm an identification. Identifications for all species within a genus were done consecutively. This approach enabled more efficient identification (Nelson *et al.*, 2011), since morphologically similar taxa could then be readily compared to each other and to specimens in the reference collection. All identifications of which I was uncertain were checked by Jennifer Ackerfield.

Processing specimens

Following identification, each specimen was mounted on 100% rag herbarium paper according to the CS mounting protocol (https://herbarium.biology.colostate.edu/preparing.htm), and was labeled with information including the state and county in which the specimen was collected; the scientific name of the taxon; taxonomic authorities for this name; the name of the vascular plant family to which it belongs; its locality in terms of nearby towns and landmarks, the latitude, longitude, and elevation of the collection site; the names of all collectors present; the collection date; and field observations regarding the appearance of the plant and its habitat. Labels were generated using original software (see Fig. 1.7 and Chapter II), and printed on acid-free, 100% cotton paper. All taxonomy follows the *Flora of Colorado* (Ackerfield, 2015).

For taxa that are designated by Ackerfield (2015) or CNHP (1997+) as rare in Colorado, GPS coordinates reported on the label are redacted to a tenth of a degree, and specific locality information was omitted. This redaction was done to protect rare plant populations from human collection. In these cases, unredacted GPS data were provided to the CNHP for conservation purposes.

Each mounted specimen has been assigned a CS accession number, and all information detailed on the specimen label will be transferred into the CS database. Specimens will then be barcoded. Finally, the specimens will be imaged, and the high-resolution images will be made viewable at different levels of magnification using Microsoft Silverlight Deep Zoom software. Database information and web-compatible, high-resolution images of the specimens will then be freely accessible to the public from both the CS database website (https://herbarium.biology.colostate.edu/collection/specimens/) and from SEINet (http://swbiodiversity.org/seinet/collections/index.php). The availability of these specimens online allows them to be consulted from any location. Increased accessibility via online platforms will enable more people to use the specimens, and may also increase the specimens' longevity, as they will need to be handled less often.

Flora of Colorado

Gunnison County

Asteraceae

Cirsium parryi (A. Gray) Petr.

Loc.: Maurer property, 30 air miles SW of Gunnison, CO. 0.2 miles SE of Reynolds Cabin. 2 air miles NW of junction of Alpine Plateau Road (BLM 867) and BLM road 3004d.

Habitat: Abundant near stream in *Festuca*-dominated meadow at edge of spruce-fir forest.

Notes: Disc corollas yellow.

Elev.: 9478 ft. Lat./Long.: 38.30251°, -107.40298°

17 July 2017 Madeline Maher № **493**, with Vinit Mahida

Figure 1.7. Sample specimen label.

RESULTS

In the 2016 field season, 282 collections were made; in 2017, 302 collections were made; in 2018, seven collections were made. Two taxa were not collected, but were photographed. *Aquilegia coerulea* var. *ochroleuca* (Ranunculaceae), was not formally collected because its populations were too small to meet the requirements of my collection-decision protocol, but two populations were documented and photographed: one individual at site 14 and four individuals at site 21. *Anemone patens* var. *multifida* (Ranunculaceae) was photographed by Charles Maurer at site 21, in a small population of ca. 10 plants. I did not notice this population during my fieldwork, and an effort in August 2018 to locate the population was unsuccessful.

All collections except duplicates are deposited at CS. My 87 duplicate collections will be deposited at the Kathryn Kalmbach Herbarium of Vascular Plants (KHD) at the Denver Botanic Gardens in Colorado.

Summary of findings

The complete species checklist (Appendix A) comprises taxa collected in this study as well as those collected by Melanie Arnett in August 1999 (Arnett, 2002) and those observed by Jennifer Ackerfield in July 2015 (Ackerfield, pers. comm., 2016). The checklist includes 330 vascular-plant species and infraspecific taxa (Table 1.3), representing 9.9%[4] of the 3,322 such taxa present in the wild in Colorado and recognized by Ackerfield (2015). The checklist taxa[5] represent 63 families, or 44.1% of the 143 vascular-plant families present in Colorado.

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[4] All percentages are rounded to the nearest tenth.

[5] *Taxa* refers to species, subspecies, and varieties.

Table 1.3. Summary of checklist taxon diversity at different taxonomic levels.

Taxon level	**Taxa in checklist**
Order	28
Family	63
Genus	192
Species	321
Species and infraspecific taxa	330

The angiosperms make up the vast majority (97.3%, Table 1.4) of the checklist taxa, while only one lycophyte (*Selaginella densa*), three monilophytes (*Cystopteris fragilis, Equisetum arvense, Pteridium aquilinum*), and five gymnosperms (*Abies bicolor, Juniperus communis* var. *depressa, Picea engelmannii, Pinus flexilis, Pseudotsuga menziesii*) were documented. The proportion of non-native species in the study area (9.4%, Table 1.4) is less than the proportion of non-native species found in Colorado at large (16%, Ackerfield, 2015).

Table 1.4. Representation of various categories of interest in the checklist and in Colorado. Noxious-weed data from the Colorado Department of Agriculture (https://www.colorado.gov/pacific/agconservation/noxious-weed-species); count of rare or vulnerable taxa from the Colorado Natural Heritage Program (https://cnhp.colostate.edu/ourdata/trackinglist/vascular_plants/); all other Colorado-level data from the *Flora of Colorado* (Ackerfield, 2015).

Category	**Taxa in checklist (percent of total checklist taxa)**	**Taxa in Colorado (percent of these represented in the checklist)**
Lycophytes	1 (0.3%)	11 (9.1%)
Monilophytes	3 (0.9%)	66 (4.5%)
Gymnosperms	5 (1.5%)	17 (29.4%)
Angiosperms	321 (97.3%)	3,228 (9.9%)
Hybrids	1 (0.3%)	-
Uncommon taxa	7 (2.1%)	-
Rare or vulnerable taxa	4 (1.2%)	525 (0.8%)
Colorado-endemic taxa	0 (0.0%)	108 (0.0%)
Native taxa	298 (90.6%)	2,797 (10.7%)
Non-native taxa	31 (9.4%)	527 (5.9%)
State-listed noxious weeds	7 (2.1%)	67 (10.4%)
New records for Gunnison County	2 (0.6%)	-

The only hybrid taxon collected (Table 1.4) was *Potentilla hippiana* × *P. pulcherrima*, which is common where the two parents species' ranges overlap (Ackerfield, 2015).

The family with the greatest diversity in the study area was the Asteraceae, with 60 species and infraspecific taxa documented (Table 1.5); this finding was expected, since this is also the most-represented family in Colorado (Table 1.6). The second-most diverse family was the Poaceae, also the second-most diverse in Colorado. The Rosaceae and Ranunculaceae were overrepresented in the study area when compared with Colorado at large (Table 1.6). Of the Rosaceae taxa found in Colorado, 18.2% are found in the study area, and while the Rosaceae are the seventh-most diverse family in Colorado, they are the third-most diverse in the study area.

Table 1.5. Eight vascular-plant families with greatest diversity in terms of species and infraspecific taxa present in study area. Colorado-level data from Ackerfield (2015).

Family	**Number of taxa present in study area (percent of study area diversity)**	**Number of species present in study area**	**Number of genera present in study area**	**Number of taxa in Colorado (percent of these present in study area)**
Asteraceae	60 (18.2%)	57	29	552 (10.9%)
Poaceae	30 (9.1%)	30	16	347 (8.6%)
Rosaceae	18 (5.5%)	17	8	99 (18.2%)
Ranunculaceae	16 (4.8%)	16	8	69 (23.2%)
Cyperaceae	15 (4.5%)	15	2	160 (9.4%)
Brassicaceae	12 (3.6%)	12	8	179 (6.7%)
Polygonaceae	12 (3.6%)	11	4	98 (12.2%)
Fabaceae	11 (3.3%)	10	5	260 (4.2%)

Table 1.6. Twelve families with the most taxa present in Colorado, their rank in terms of taxonomic diversity in Colorado (where 1 is the most diverse), and their rank in terms of taxonomic diversity in the study area. Colorado diversity data from Ackerfield (2015).

Family	**Rank in Colorado**	**Rank in the study area**
Asteraceae	1	1
Poaceae	2	2

Family	Rank in Colorado	Rank in the study area
Fabaceae	3	7
Brassicaceae	4	6
Cyperaceae	5	5
Plantaginaceae	6	8
Polygonaceae	7	6
Rosaceae	7	3
Boraginaceae	8	10
Caryophyllaceae	9	8
Chenopodiaceae	10	12
Ranunculaceae	11	4

Similarly, 23.2% of Colorado Ranunculaceae are found in the study area; the Ranunculaceae are the eleventh-most represented family in Colorado, but fourth in the study area. This finding is consistent with other researchers' findings: the Ranunculaceae are especially speciose in montane, forested areas (Wang *et al.*, 2016; Ziman & Keener, 1989), and probably "originated...within montane temperate floras of the Northern Hemisphere" (Ziman & Keener, 1989, p. 1040).

The most diverse genus in the study area is *Carex*, within Cyperaceae, with 14 species.

Noxious weeds

Colorado-listed noxious weeds collected were *Bromus tectorum* (downy brome), *Carduus nutans* (musk thistle), *Cirsium arvense* (Canada thistle), *Cynoglossum officinale* (houndstongue), *Erodium cicutarium* (redstem filaree), *Leucanthemum vulgare* (oxeye daisy), and *Verbascum thapsus* (common mullein). Of these seven species, *Cirsium arvense* (Asteraceae) is by far the most abundant in the study area, and is present throughout both properties, often in large, dense monocultural stands. This species was particularly abundant at sites along the Big Blue Creek (24, 25, 26, and 28), at moist sites (1, 7, 14, 27, 34), and along the Jeep trail on the east side of the Big Blue Canyon (site 41). Three distinct phenotypes of *Cirsium arvense* were observed (Fig. 1.8), and each of the three is represented by at least one collection. All three phenotypes fit existing descriptions of this highly variable species (Keil, 2006;

Tiley, 2010) and in the *Flora of Colorado*. Though my observations are not novel, I have described them here so that this noxious weed is easily recognizable to parties responsible for its control.

The most common observed phenotype of *Cirsium arvense* (*M. Maher & C. Maurer 236, M. Maher et al. 592*) is found throughout the study area. This common phenotype grows to approximately 15 dm[6]; has purple disc corollas; and has leaves that are deeply pinnately lobed with spiny margins, are moderately arachnoid-hairy abaxially, and are pale green and glabrous adaxially. A second phenotype (*M. Maher 571*) was observed only at site 24. This phenotype is taller, growing to approximately 17 dm; has white disc corollas; and has leaves with strongly revolute margins when young, are more densely arachnoid-tomentose abaxially, are slightly arachnoid-hairy adaxially, are shallowly lobed to serrulate to nearly entire, and have much smaller marginal spines than the leaves of the common phenotype. The third phenotype (*M. Maher 570, M. Maher et al. 579*), also only observed at site 24, is shorter than the other two phenotypes, with observed plants growing to approximately 9 dm, has white disc corollas, and has leaves that are darker green and glossy adaxially, with broad midribs, and with margins that are more deeply lobed and more densely spiny than those of the common phenotype.

Each of the three aforementioned phenotypes matches a description of a *C. arvense* variety, and each of these varieties is currently considered synonymous with *C. arvense*. The common phenotype matches descriptions of *C. arvense* var. *arvense* (Moore, 1975); the taller, tomentose phenotype matches descriptions of *C. arvense* var. *vestitum* Wimm. & Grab. (Moore, 1975); and the shorter, spinier phenotype matches descriptions of *C. arvense* var. *horridum* (Moore, 1975). Keil (2006, p. 109) noted that though “extreme variants can be strikingly different, they are connected by such a web of intermediates that there seems to be little value in according any of them formal taxonomic recognition.”

[6] These measurements were taken in the field. Measurements were limited to a few specimens of each phenotype.

At site 24, each phenotype occupied a distinct patch. The *horridum* phenotype was at the western edge of the road, in disturbed soil, immediately south of and bordering a population of the *arvense* phenotype. The *vestitum* phenotype was found about 60 feet east of the road, on a rocky outcrop in a steeply sloping, relatively undisturbed, fescue-dominated meadow.

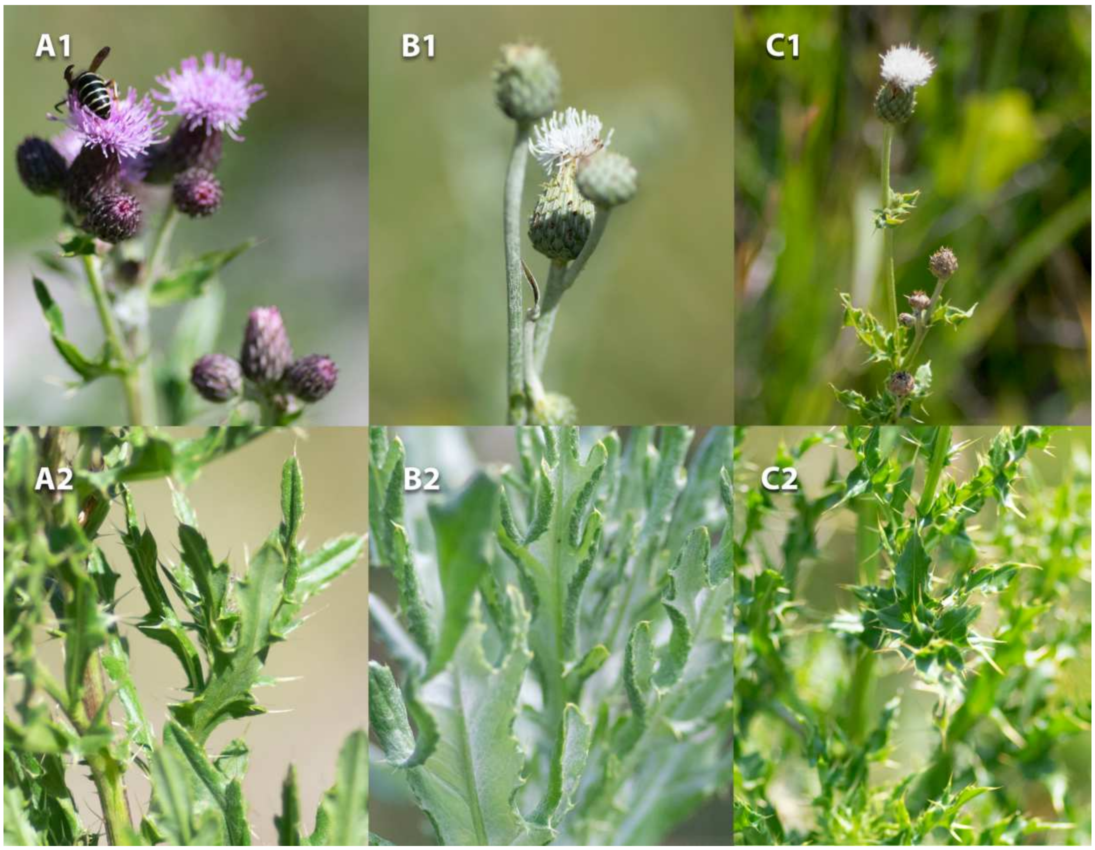

Figure 1.8. Three phenotypes of *Cirsium arvense*. A1-A2: inflorescences and leaves of most common, purple-flowered phenotype (*M. Maher et al. 592*); B1-B2: tall, tomentose, white-flowered phenotype (*M. Maher 571*); C1-C2: short, spiny, white-flowered phenotype (*M. Maher et al. 579*).

Since *C. arvense* is a dioecious species that reproduces both sexually and vegetatively (Lalonde & Roitberg, 1994), often forming clonal stands, any mutation that arises can persist in the clonal shoots of the mutant plant. Therefore, each phenotype may be genetically distinct, with each of the two populations with uncommon phenotypes being mutant clonal stands. On the other hand, phenotypic plasticity seems a likely explanation for the tall, tomentose population, since it occupies an area with a different substrate, different slope, and different disturbance regime. Without further testing, it is not possible to say with any certainty whether the observed phenotypic variation is the result of phenotypic plasticity, of genetic difference, or of both.

Verbascum thapsus (Scrophulariaceae) was collected at site 26, and documented at site 28, with populations exceeding 50 plants at each site. Barrell (1969) noted the rarity of this noxious weed in the Gunnison Basin, which was already common elsewhere in Colorado at the time. Specifically, Barrell recounted observing only one small roadside population of *V. thapsus* in the entire Gunnison Basin. In the half century between Barrell's study and my own, this species has become common in the Gunnison Basin.

Bromus tectorum (Poaceae) was collected on a dry, rocky, southeastern-facing roadside slope (site 28), where the population exceeded 50 plants, though it was not documented at any other sites. *Carduus nutans* (Asteraceae) was commonly observed along roadsides and in dry, rocky soil throughout the study area, and was particularly abundant at sites 11, 26, and 28. *Cynoglossum officinale* (Boraginaceae) was collected at site 35, on a Jeep trail through aspen forest, and was documented at sites 24 and 25, between the road through the canyon and the Big Blue Creek. *Erodium cicutarium* (Geraniaceae) was collected at site 28 from a population of approximately 20 plants, in dry, rocky roadside soil, and was not documented at any other sites. *Leucanthemum vulgare* (Asteraceae) was present in meadows on both properties, though it was particularly abundant at and near former homestead sites (9, 10, 14, 15).

Although it was not observed within the boundaries of the study area, one small patch of *Convolvulus arvensis* (Convolvulaceae) was observed within a quarter-mile of the northern boundary of the Maurer property, and as such could easily spread into the study area.

New county records

Two taxa were collected that had not previously been documented in Gunnison County. *Trifolium kingii* var. *kingii* (Fabaceae; *M. Maher et al. 51*; Fig. 1.9) was found on the Maurer property in moist aspen forest (habitat code G506, Appendix A), at an elevation between 8,600 and 9,100 feet, in a population of over 100 individuals.[7] To the best of my knowledge, this is the easternmost collection of *Trifolium kingii* in the United States.

Pyrola picta (Ericaceae; *M. Maher & J. Pentenrieder 578*; Fig. 1.9) was found on BLM land in spruce-fir forest (habitat code G226, Appendix A) at an elevation between 9,150 and 9,650 feet[8], in one population of 32 individuals.

Taxa of conservation concern

While no taxa listed under the Endangered Species Act (https://ecos.fws.gov/ecp/) were observed, four species of conservation concern were collected. The Colorado Natural Heritage Program (CNHP) maintains a list of all vascular plant species of conservation concern in Colorado, including species that are fully tracked and known to be rare, as well as those that are placed on a watchlist. Watchlisted taxa are not fully tracked and not currently considered rare by CNHP, but are candidates for future tracking.

Species tracked or watchlisted by CNHP are assigned a global abundance rating (G1-G5) and a state abundance rating (S1-S5), where G1 or S1 indicates that the species is rare and critically imperiled,

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[7] Arnett collected a specimen of *T. kingii* var. *kingii* in 1999 at a site described as being in Gunnison County (*M. Arnett 4717*), but the coordinates given on the specimen label are in Ouray County. Another specimen determined to be *T. kingii* was collected in northeastern Gunnison county in 1984 (*M. Bargers s.n.,* Adams State University Herbarium accession number 05890), but this specimen appears to be *Trifolium hybridum*, given the elevation (9,500 feet) and time of the collection (August), the shape of the specimen's leaves, and the fact that its flowers are not reflexed.

[8] Detailed locality and elevation information for *Trifolium kingii* and *Pyrola picta* has been omitted here in order to protect the populations from collection by humans.

G3 or S3 indicates vulnerability, and G5 or S5 indicates that the species is common and secure. Where a species' status is uncertain, multiple codes are assigned (e.g., S2S3 for a species that is vulnerable to threatened in the state).

Two watchlisted taxa were collected: *Pyrola picta* (G4G5 S3S4), which according to Ackerfield (2015) is rare in Colorado, and *Draba rectifructa* (Brassicaceae; G3G4 S3; *M. Maher et al. 7, M. Maher 383*), which is not listed as rare or uncommon by Ackerfield (2015). *Draba rectifructa* (Fig. 1.9) was collected in moist soil, once near the edge of a pond in a montane meadow (habitat codes G268 and G527, Appendix A) at an elevation between 9,300 and 9,800 feet, and once at the boundary between a spruce-fir forest and a montane meadow (habitat codes G219 and G527, Appendix A) at an elevation between 9,500 and 10,000 feet.

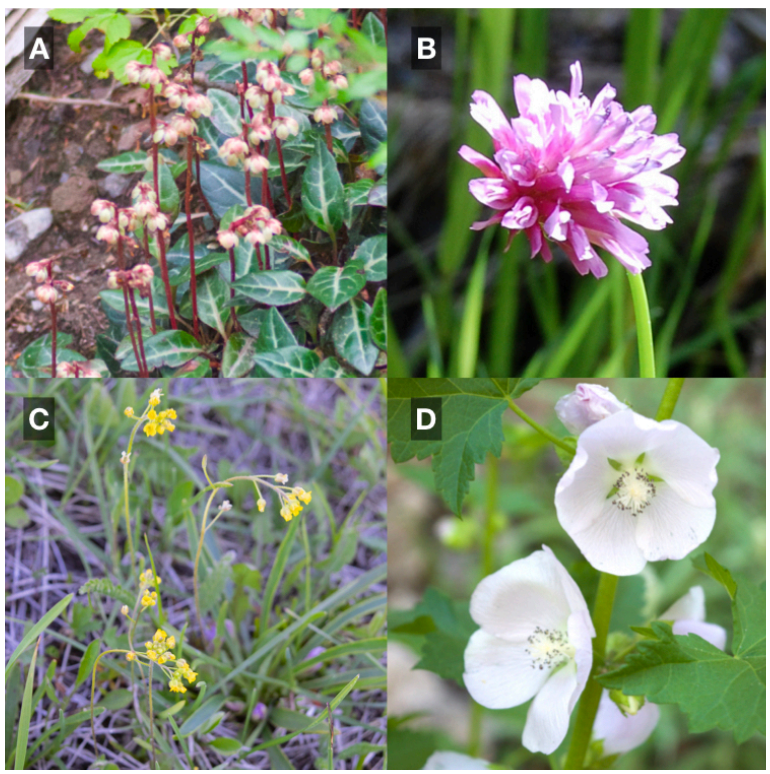

Figure 1.9. Taxa of conservation concern. **A**: *Pyrola picta* (*M. Maher & J. Pentenrieder 578*), rare to uncommon and watchlisted by the Colorado Natural Heritage Program (CNHP); **B**: *Trifolium kingii* var. *kingii* (*M. Maher et al. 51*; photograph by Jennifer Ackerfield), rare and fully tracked by CNHP; **C**: *Draba rectifructa* (*M. Maher 383*), rare to uncommon and watchlisted by CNHP; **D**: *Iliamna rivularis* (*M. Maher 165*), rare and fully tracked by CNHP.

Two fully tracked taxa were collected: *Trifolium kingii* (G5 S1, *M. Maher et al. 51*) and *Iliamna rivularis* (G3 S1S2, *M. Maher 165*). *Iliamna rivularis* (Fig. 1.9) was collected on BLM land in moist, rocky soil in mixed forest (habitat codes G219 and G226, Appendix A), between 9,300 and 9,800 feet in elevation.

Rare and tracked plant communities

Fifty-three plant-community types found in the study area are tracked by CNHP (https://cnhp.colostate.edu/ourdata/trackinglist/plants_communities/). A complete list of these plant community types, their conservation status, the sites at which they were observed or are expected to occur, and the owner(s) of the land on which they were found is provided in Appendix B. A summary is provided here (Table 1.7).

Thirty of these plant-community types are ranked critically imperiled (S1), imperiled (S2), or vulnerable to critically imperiled (S3) at the state level. Of these communities of conservation concern, 23 are wetland communities.

Table 1.7. Summary of plant-community types in the study area that are tracked by the Colorado Natural Heritage Program (https://cnhp.colostate.edu/ourdata/trackinglist/plants_communities/), in terms of their global and state conservation status ranks. Note that some communities are not assigned a rank in either the global or the state category, and some are assigned multiple ranks in one or both categories.

	Conservation status rank	**Number of plant community types in the study area with this conservation status rank**
	all ranks	53
global	G5 (demonstrably secure)	13
	G4 (apparently secure)	24
	G3 (vulnerable to extirpation)	20
	G2 (imperiled)	2
	G1 (critically imperiled)	0
	GU (unranked)	1
state	S5	10
	S4	12
	S3	9

Conservation status rank	Number of plant community types in the study area with this conservation status rank
S2	13
S1	9
SU (unranked)	2

Comparison with previous research

Melanie Arnett's specimens, collected in August 1999 at one site in the study area, in aspen-spruce-fir woodland on BLM land, were examined at the Rocky Mountain Herbarium (RM) in Laramie, Wyoming, in 2018. Two of Arnett's specimens were determined to be misidentified: a specimen identified as *Nassella viridula* (*M. Arnett 7160*) was found to be *Achnatherum nelsonii*, and a specimen identified as *Packera streptanthifolia* (*M. Arnett 7134*) was found to be *Packera neomexicana* var. *mutabilis.* These revised identifications were confirmed by Burrell E. Nelson, curator of RM. The two specimens were annotated and will be updated in the RM database.

Arnett collected the following species that I did not observe during my fieldwork: *Achnatherum nelsonii, Bromus ciliatus, Danthonia intermedia,* and *Erigeron eximius. Achnatherum nelsonii* and *Achnatherum lettermannii* are distinguished by the lengths of their paleas (Ackerfield, 2015). Since this is not a character readily observable in the field, it is likely *A. nelsonii* was present during my fieldwork, but missed because of its resemblance to *A. lettermannii*. Similarly, *Bromus ciliatus* resembles *B. porteri*; *Danthonia intermedia* resembles *D. parryi*; and *Erigeron eximius* resembles *E. subtrinervis* and *E. speciosus*.

Ackerfield (pers. comm., 2016) observed the following species that I did not observe in the study area: *Carex pellita, Cirsium scariosum, Delphinium barbeyi, Erythronium grandiflorum, Iris missouriensis, Oenothera villosa* ssp. *strigosa, Packera fendleri, Prunella vulgaris, Rhodiola rhodantha, Thermopsis rhombifolia* var. *divaricarpa* and *Viola nuttallii.* I observed *Iris missouriensis* in abundance on nearby BLM land and private land in 2017, but did not encounter it within the boundaries of the study area.

While some of the above discrepancies are probably the result of either a failure of observation on my part or the absence of these species at my chosen collection sites, differences in rainfall between research years may explain why some of these species were not observed. Previous years in which collection or documentation was conducted (1999 and 2015) had more precipitation in May and June than in the same months of 2016 and 2017 (Table 1.8).

Many of the unobserved species occur in moist to wet habitats. *Carex pellita, Delphinium barbeyi, Iris missouriensis, Oenothera villosa* ssp. *strigosa, Prunella vulgaris,* and *Rhodiola rhodantha* are all wetland obligates. A lower water table in my two field seasons may have resulted in decreased abundance of these species.

Table 1.8. Precipitation data from the Cimarron weather station for the water years 1999, 2015, 2016, and 2017 (Colorado Climate Center, 2018). Each water year extends from the October to September, such that the water year of 1999 is measured from October 1998 through September 1999. Precipitation values at least 20% below normal are highlighted in red, with deeper red denoting values at least 50% below normal. Values at least 20% above normal are highlighted in blue, with deeper blue marking values at least 50% above normal. Months in which collections or observations were made in the study area are indicated by black outlines.

Month	**1999**	**2015**	**2016**	**2017**
	Precipitation in inches (percent of normal)			
October	2.70 (191%)	1.00 (71%)	1.82 (129%)	0.29 (21%)
November	0.49 (44%)	1.11 (51%)	1.43 (129%)	2.05 (185%)
December	1.04 (100%)	0.71 (68%)	1.40 (135%)	1.40 (135%)
January	1.44 (173%)	0.15 (18%)	1.52 (183%)	2.05 (247%)
February	0.69 (84%)	1.03 (126%)	0.54 (66%)	1.09 (133%)
March	0.07 (7%)	0.66 (66%)	0.96 (96%)	0.91 (91%)
April	2.34 (202%)	0.85 (73%)	0.96 (83%)	1.19 (103%)
May	2.00 (163%)	3.67 (298%)	0.92 (75%)	1.31 (103%)
June	1.92 (246%)	1.46 (187%)	0.21 (27%)	0.06 (8%)
July	1.33 (106%)	0.82 (65%)	0.47 (37%)	1.67 (133%)
August	2.41 (159%)	1.35 (89%)	2.01 (132%)	1.24 (82%)
September	1.41 (81%)	1.07 (61%)	1.13 (65%)	1.84 (106%)
Total	17.84 (128%)	13.34 (96%)	13.37 (96%)	15.10 (109%)

Notable morphological observations

One specimen of *Equisetum* (*M. Maher & V. Mahida 488*) was unusual: one of its shoots resembled the typical vegetative shoot of *Equisetum arvense,* but bore a strobilus at its apex. *Equisetum arvense*, according to descriptions in the *Flora of North America* (Hauke, 1993) and in the *Flora of Colorado* (Ackerfield, 2015), is a species with dimorphic shoots, wherein shoots are either achlorophyllous and reproductive, or chlorophyllous and vegetative. Descriptions of *Equisetum* hybrids did not match this specimen (Hauke*,* 1993). But *Equisetum arvense* is not strictly dimorphic, with many observed specimens at RM and CS having achlorophyllous shoots with chlorophyllous branches, and some having chlorophyllous shoots with strobili (Fig. 1.10).

Indeed, *E. arvense* is known to have occasional reproductive shoots that later produce photosynthetic branches, as well as occasional vegetative shoots that later produce strobili (Hauke, 1967; Hauke, 1985; Page, 1972), though this phenomenon is not mentioned in either the *Flora of North America* or the *Flora of Colorado*. In his systematic study of *E. arvense,* Hauke (1967, p. 106) did not count dimorphism among the "reliable features which characterize the field horsetail." Instead, Hauke relied on the shape of the branches in cross-section, the length of the first branch internode, the shape of the stem sheaths and their teeth, and the vestiture of the rhizomes to distinguish this species from its relatives. My *E. arvense* specimen and the two inspected *E. arvense* specimens (*W.A. Weber s.n.* [RM accession 79201-S]; *L. Kelso 7206*) that bore the greatest resemblance to it were collected within the same two-week period, July 4 to 17, though in different years. I hypothesize that this observed conversion from vegetative to reproductive shoot may occur at this point in the growing season if conditions are opportune.

Many observed specimens of *Juncus arcticus* var. *balticus* had twisted, compressed culms. While these specimens conformed to the description of *J. arcticus* var. *balticus* in the *Flora of North America* (Brooks & Clemants, 2000), with true leaf blades lacking, Harold LeRoy Lint (1977, p. 22) described twisted culms as “a character usually associated with subsp. *mexicanus.*” Lint (1977, p. 7) emphasized the difficulty of distinguishing between these two taxa, referring to their seeming inconsistencies as “a major problem in this species complex,” citing frequent hybridization between *J. balticus* ssp. *vallicola* (= *J. arcticus* var. *balticus*) and *J. balticus* ssp. *mexicanus* (= *J. arcticus* var. *balticus*).

Figure 1.10. Reproductive, vegetative, and monomorphic shoots of *Equisetum arvense*. From left to right: typical, strictly reproductive, achlorophyllous shoot with enlarged sheath and strobilus (*B. E. Nelson 43676,* COLO accession 520438); reproductive shoot with minor chlorophyllous branching at base (*R. G. Walter 1487,* CS accession 47504); partially chlorophyllous reproductive shoot with significant chlorophyllous branching near base (*R. D. Dorn 1344,* RM accession 288637); fully chlorophyllous shoot, extensively branched, with strobilus (*M. Maher 488*); typical, strictly vegetative, chlorophyllous shoot (*A. J. Roderick 2327,* RM accession 665632). Specimen images from University of Colorado Herbarium (COLO), Rocky Mountain Herbarium (RM), and Colorado State University Herbarium (CS).

To make matters more difficult, in the northern part of its Pacific range, *J. balticus* var. *mexicanus* apparently tends to lack leaf blades (Lint, 1977). There do not seem to be reliable morphological characters that allow straightforward distinction among *J. arcticus* var. *balticus*, *J. arcticus* var. *mexicanus*, and their hybrids. While the *Flora of North America* reports *J. arcticus* var. *mexicanus* for southwestern Colorado (Brooks & Clemants, 2000), Ackerfield (2015, p. 509) stated that "no specimens have been seen." But I suggest that this variety may not be consistently distinguishable from *J. arcticus* var. *balticus*, and so it is possible both are present in Colorado.

Observations of plant pathogens and plant predators

Several plant pathogens and plant predators were observed:

- Many *Pyrola chlorantha* populations were affected by a rust fungus, possibly *Chrysomyxa pirolata* Wint. or *Pucciniastrum pyrolae* Dietel ex Arthur (Horst, 2008).
- Many young shoots of *Populus tremuloides* are affected by the aspen shoot blight, *Venturia macularis* (Fr.) E. Müll. & Arx (identification confirmed from photos by Paul Langlois, pers. comm., 2018), with the symptomatic "shepherd's crook" at their shoot apices (Jacobi, 2013).
- Some older stands of *Populus tremuloides* (sites 21 and 41) are affected by a fungus that gives trunks the appearance of having been burst open and scorched, as if by lightning. The fungus is possibly black canker, *Ceratocystis fimbriata* (Ellis & Halst.) Sacc. (High Plains Integrated Pest Management, 2016).
- *Urtica dioica* plants were often found covered in larvae of the red admiral butterfly, *Vanessa atalanta* Linnaeus (larvae identified from photos by Hanna Royals and Todd Gilligan, pers. comm., 2018).
- Larvae of the spotted tussock moth, *Lophocampa maculata* Harris (identification confirmed from photos by Hanna Royals, pers. comm., 2018), were often found on the leaves of *Alnus incana* and *Salix drummondiana* along the Big Blue Creek at sites 24, 25, and 26.
- *Abies bifolia, Picea engelmannii,* and *Pseudotsuga menziesii* trees were often affected by the larvae of western spruce budworm, *Choristoneura freemani* Razowski, which feed on the young

leaves and shoots (Cranshaw, 2009). Affected branches had undergone light defoliation at their apices. Larvae were often seen abseiling from coniferous branches.

- Maggots of a member of the Cecidomyiidae (gall fly family) fed on *Mirabilis linearis*, as evidenced by a series of holes at the base of the stems (*M. Maher et al. 271, M. Maher 471*), punched from the inside out, and by the remnants of pupal shells protruding from these holes (identification made by David Wagner, pers. comm., 2018).

DISCUSSION

The results of this study provide a baseline with which to understand current and future threats to biodiversity, such as climate change and development, on the floristic diversity of the study area, and to predict how the study-area flora may change in the future. This study helps inform land-management decisions, such as the measures that should be taken to maintain the current abundance and diversity of native species in the study area. The species checklist and documentation of plant communities of concern provide context with which to determine the conservation value of the study area.

Current and future threats to biodiversity

Climate change

Global temperatures, which are predicted to increase between 1.6°C and 4.3°C by 2100 (IPCC, 2013), affect phenology, water availability, fire regime, species distributions, and the prevalence of plant predators. Some species in a given area may respond phenologically to temperature variation, and some may not (Calinger *et al.*, 2013). It has been observed in a study at Concord, Massachusetts, that those species that do not respond phenologically tend to decline (Willis *et al.,* 2008). Furthermore, that study found that "[s]pecies that are declining are more closely related than by chance" (Willis *et al.*, 2008, p.

17030), suggesting that an inability to adapt to seasonal temperature changes will affect not just the prevalence of random species, but of entire clades. Measurement of phenological response in various species of conservation concern in the study area, then, may clarify which species are most at risk of decline. Calinger *et al.* (2013) determined that non-native species in their study area of Ohio were more likely to flower earlier in response to warmer springs than were the native flora. Three of the non-native species studied by Calinger *et al.* (2013) are present in my study area: *Carduus nutans*, which flowered 12 days earlier per 1°C increase above normal temperatures; *Trifolium pratense,* which flowered 7.6 days earlier per 1°C increase; and *Trifolium hybridum*, which flowered 6.4 days earlier per 1°C increase. Assuming this behavior is true of the same species in the Rocky Mountains (although I have no evidence to this effect), it appears that climate change may favor several of our weedy species, making noxious weed control increasingly important for conservation.

As climate change progresses, drought conditions are likely to worsen in the western United States (Meixner *et al.*, 2016). The southwestern United States is predicted to receive roughly the same amount of precipitation as temperatures increase, but we can expect less precipitation to fall as snow, which will likely result in lower water tables (Earman *et al.*, 2005). Drought stress can prevent plants from growing, flowering, reproducing, or defending against predators. Drought also seems to exacerbate outbreaks of *Choristoneura freemani,* or western spruce budworm (Flower *et al.*, 2014). In the growing seasons of 2016 and 2017, the larvae of western spruce budworm caused light defoliation at the apices of *Abies bifolia, Picea engelmannii,* and *Pseudotsuga menziesii* branches in the study area. If exceptionally dry periods increase in frequency, this predation may cause more severe defoliation.

The spruce beetle (*Dendroctonus rufipennis* Kirby) is another major threat to coniferous forests in the Rocky Mountain region (Veblen *et al.*, 1994). About six large-scale spruce beetle outbreaks occurred in the southern Rocky Mountains between 1850 and the 1970s, with one outbreak affecting the study area, between 1939 and 1951 (Baker & Veblen, 1990). It is likely that another outbreak will eventually occur in the study area, and such an outbreak could be especially damaging given the combined effect of drought, temperature, and predation stressors.

It has been predicted that the range of *Picea engelmannii* will reduce drastically in response to climatic stresses over the next century, and, conversely, that the range of *Quercus gambelii* will increase (Rehfeldt *et al.*, 2006). Both of these species are also predicted to occur at higher elevations in the future than they currently do, by ca. 985 feet (Rehfeldt *et al.*, 2006). If these predictions are accurate, *Picea engelmannii* populations in the study area and associated communities are at extreme risk. Since this species is one of the dominant canopy species in the area, its presence is critical to the local survival of the many spruce-fir or mixed coniferous forest understory species, such as *Calypso bulbosa, Linnaea borealis, Paxistima myrsinites, Vaccinium myrtillus,* and *Pyrola picta*.

Property development

While property development is restricted by the terms of conservation easements on the Maurer property, the designated building envelopes on the property include habitat for species of conservation concern. A building envelope surrounding the Twin Ponds (site 1) includes a site at which a rare species and the uncommon *Carex tahoensis* were found. In order to minimize disturbance to these populations, any buildings constructed in this envelope, and any paths taken by large vehicles to the building site, should be as far away as possible from the ponds. The species of concern were found within ca. 50 feet of the pond margins, so a buffer zone of 50 feet around the ponds is to be avoided, at a minimum.

The site of Charles and Ruth Maurer's cabin (site 14) is one of the building envelopes allowed by the conservation easement. This site includes five tracked plant communities: *Artemisia cana* ssp. *viscidula/Festuca thurberi* shrubland (G2G3 S2S3); *Caltha leptosepala* wet meadow (G4 S4); *Carex aquatilis – Carex utriculata* wet meadow (G4 S4); *Carex microptera* wet meadow (G4 S1); and

Deschampsia caespitosa wet meadow (G4 S4). It is recommended that disturbance to these communities be minimized, particularly to the small patches along the Middle Blue in which *Carex microptera* is abundant, and that development projects be avoided in this area.

Noxious-weed management

Communities of noxious weeds are particularly concerning where they may encroach on communities of rare or uncommon native plant species or plant communities. Many noxious-weed populations in the study area co-occur with vulnerable species or communities. For this reason, herbicides should be avoided in case of accidental contamination of unintended areas, or used only on large infestations. Preferred strategies for noxious-weed control are detailed in Table 1.9 below for each of the target species.

A measure that would aid control of all species would be spray-washing stations near property boundaries or near infested areas, at which visitors could wash off their vehicles, shoes, and pets to prevent the spread of noxious weed seed. The BLM currently recommends this action on permits issued to collectors, but it is not always feasible to follow this advice. Another such general measure is monitoring, so that new weed populations can be eradicated before they spread further.

Conservation value of the study area

The study area is home to nearly ten percent of the Colorado flora, four plant species that are rare or vulnerable in the state, and at least 30 plant community types listed as vulnerable to extirpation, imperiled, or critically imperiled in the state. *Trifolium kingii* var. *kingii*, in particular, is critically imperiled in Colorado, and occurs on the Maurer property at one location in abundance. Four nearby areas down- and upstream along the Big Blue Creek from the study area have been designated Potential Conservation Areas (PCAs) by the CNHP (https://cnhp.colostate.edu/ourdata/pca-reports/). The Big Blue

Table 1.9. Recommended control methods for noxious weed species in the study area.

Noxious weed species	Recommended control methods
Bromus tectorum	• Pull by hand frequently, including rhizomes and roots, both before flowering (to prevent seed spread) and after flowering (when storage reserves are lower; USDA Forest Service, 2014a). Care should be taken not to cause excessive disturbance, since the disturbance could exacerbate the infestation (USDA Forest Service, 2014a). Hand-pulling is easiest to do after a rain early in the season, when the ground is moist. • Introduce light grazing by sheep or cattle at the beginning and end of the growing season. Overgrazing may exacerbate the infestation (USDA Forest Service, 2014a). • Mow affected areas throughout the growing season (USDA Forest Service, 2014a).
Carduus nutans	• Cut or hand-pull affected areas throughout the growing season. • Cut inflorescences when seen, and place in trash bag. It is preferable to burn rather than discard the heads to prevent spread. Damaging the root crown with a shovel or knife will prevent new inflorescences from forming (Heidel, 1987).
Cirsium arvense	• Repeated pulling (every 1-3 weeks) will eventually slow infestations, but will not be effective for large stands. Place any stems with inflorescences in a trash bag, seal, and remove from site (USDA Forest Service, 2014b). Pulling will be most effective in early summer, at anthesis, when carbohydrate reserves in the root system are lowest (Moore, 1975). Expect regrowth. • Mow dense, easily accessible stands repeatedly, every 1-3 weeks (USDA Forest Service, 2014b; Tiley, 2010). • Introduce cattle, at the beginning and at the end of the growing season, to graze infested areas lightly (Pywell *et al.*, 2010; Tiley, 2010). • Keep a lint roller in the vehicle to collect loose fruits on clothing.
Cynoglossum officinale	• Weed occurs infrequently. Pulling on sight and placing the plant in a trash bag is probably sufficient for control.

Noxious weed species	**Recommended control methods**
Erodium cicutarium	• Weed occurs infrequently. Pulling on sight and placing the plant in a trash bag is probably sufficient for control. • If infestation grows, hand pulling is still the preferred method of control (Francis *et al.*, 2015).
Leucanthemum vulgare	• Graze sheep in confined infestation area before anthesis. Remove sheep when 50% of the grass in the area has been consumed (Jacobs, 2008).
Verbascum thapsus	• Cut any stems that have grown above rosette stage but are not yet flowering. Injure root crown (with knife or shovel) to prevent regrowth (Wilbur & Hufbauer, 2012). • Later in season, collect and bag inflorescences and fruit to prevent seed spread (Wilbur & Hufbauer, 2012).

Creek at the Curecanti Needle, ca. six miles north of the study area, has been designated a PCA of high biodiversity significance, with an occurrence of a globally rare community (*Picea pungens – Alnus incana* riparian woodland). Halfway House, ca. 2.5 miles north of the study area, is of moderate biodiversity significance, with an historical occurrence of a rare species (*Gilia penstemonoides*). The Gunnison River at Curecanti Needle, ca. six miles north of the study area, is of moderate biodiversity significance, also with an historical occurrence of *Gilia penstemonoides*. The Big Blue Campground in the Uncompahgre National Forest, ca. four miles south of the study area, is of general biodiversity significance, with an occurrence of a state-rare community (*Salix wolfii/Carex aquatilis* wet shrubland). The study area's proximity to other areas previously identified as being of significant conservation value; its watershed connections to these PCAs; the occurrences of rare species and communities documented in this study; and the study area's relatively undisturbed condition all indicate that the study area is of high biodiversity significance.

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CHAPTER II:
LABELMAKER: A SOFTWARE TOOL TO ASSIST IN THE GENERATION OF HERBARIUM SPECIMEN LABELS

INTRODUCTION

After a botanical voucher specimen has been collected, pressed, and mounted, it must also be labeled with various details associated with its collection and identification, providing context for future researchers unfamiliar with the specimen. These label data, recorded in a collector's field notes, include at a minimum the name of the collector(s), collection number, date of collection, locality of collection including latitude and longitude, description of habitat, family name, genus-species binomial, and taxonomic authority. Generating such specimen labels can be a tedious task, particularly when many hundreds or thousands of specimens must be labeled, as is typical for floristic studies. Improvements in efficiency are valuable when generating this volume of voucher specimens. Programs that automate specimen-label generation, and minimize the need for post-processing of these auto-generated labels, make the process more efficient.

While there are existing programs that enable the generation of specimen labels from spreadsheets of data, some aspects of these programs' construction prevent their use in certain cases (Table 2.1). Some programs, such as the UC/JEPS Specimen Label Mail Merge (http://ucjeps.berkeley.edu/bryolab_files/FIMS_label_instructions.pdf), the herblabel R package (https://github.com/helixcn/herblabel), and the mobile application ColectoR (Maya-Lastro, 2016) rely on proprietary software such as the Microsoft Office suite to generate labels. Others such as Symbiota (https://github.com/Symbiota/Symbiota) are designed to be used by herbaria, and have extensive system requirements, including configuring a web server and using a database management system, which is likely to require more time and effort than is worthwhile for individual users. The effort involved in learning how to navigate such a software system might well outweigh the amount of effort required for such users to generate their labels by hand, particularly if they are collecting small numbers of specimens. Researchers processing large numbers of specimens and/or running older operating systems may be better able to use a label generator that uses minimal computational power and does not require an internet connection. Botanists who wish to generate their own labels quickly, with minimal computational load, and with a minimal learning curve, may not currently have any options, depending on the operating systems they are running and their access to proprietary software.

Table 2.1: Comparison of a selection of free, open-source software products supporting herbarium specimen label generation.

Product:	**Labelmaker**	**Symbiota** (Brandt, Gilbert, & Franz, 2018)	**herblabel** (Zhang, Zhu, Liu, & Fischer, 2016)	**colectoR** (Maya-Lastra, 2016)
Operating systems supported	Linux, Mac OS, Microsoft Windows	Linux, Mac OS, Microsoft Windows	Mac OS, Microsoft Windows	Android 3.0+ (for data entry); Mac OS, Microsoft Windows
Last software update	September 2018	September 2018	May 2018	July 2016
Functions without proprietary software	Yes	Yes	No	No
Additional software required	Python 3.0+; Pystache Python package; web browser	Apache HTTP server 2.0+; PHP 5.0+; MariaDB or MySQL 5.1+; web browser	R; Rtools; Microsoft Excel	Microsoft Word, Microsoft Excel
Internet connection required to run software	No	Yes	No	No
Automatically formats label for printing	Yes	Yes	Yes	Partially: collection number must be manually added in an extra column of spreadsheet before printing.

Product:	**Labelmaker**	**Symbiota** (Brandt, Gilbert, & Franz, 2018)	**herblabel** (Zhang, Zhu, Liu, & Fischer, 2016)	**colectoR** (Maya-Lastra, 2016)
Ensures labels never break across pages	No	Unknown	Unknown	Yes. Text is cut off if it exceeds a character limit, which is not specified.
Number of labels printable at once	No limit	No limit	No limit	48

In response to these needs, I developed a lightweight label-generating program that relies only on free software that can be installed on any operating system, namely the Python programming language and any web browser. The program, executed with one command in the terminal, is written in Python (version 3.5), and converts comma-separated value (CSV) files into a Hypertext Markup Language (HTML) file containing specimen labels. Once generated, the HTML file containing the labels can be opened in a web browser and printed. While a web browser is required to generate the labels, no internet connection is necessary. The labels are formatted using Cascading Style Sheets (CSS) and HTML. The HTML label file, when printed, will fit six specimen labels to a letter-size page. The software is licensed under the GNU General Public License 3.0, and is publicly available for download on GitHub (https://github.com/wundalous/labelmaker), with instructions for use (see Appendix C).

In addition to the aforementioned groups for whom this label-generating software may be of interest, students and instructors of plant-taxonomy or plant-identification courses may find such software particularly useful. Students in such courses are often required to make plant collections, and may wish to avoid typing labels individually without learning new software systems. Instructors of such courses may wish to offer their students a simple label-generating program to help students understand what information is necessary in a specimen label, and to prevent incomplete and improperly formatted labels from being submitted in collection projects.

METHODS

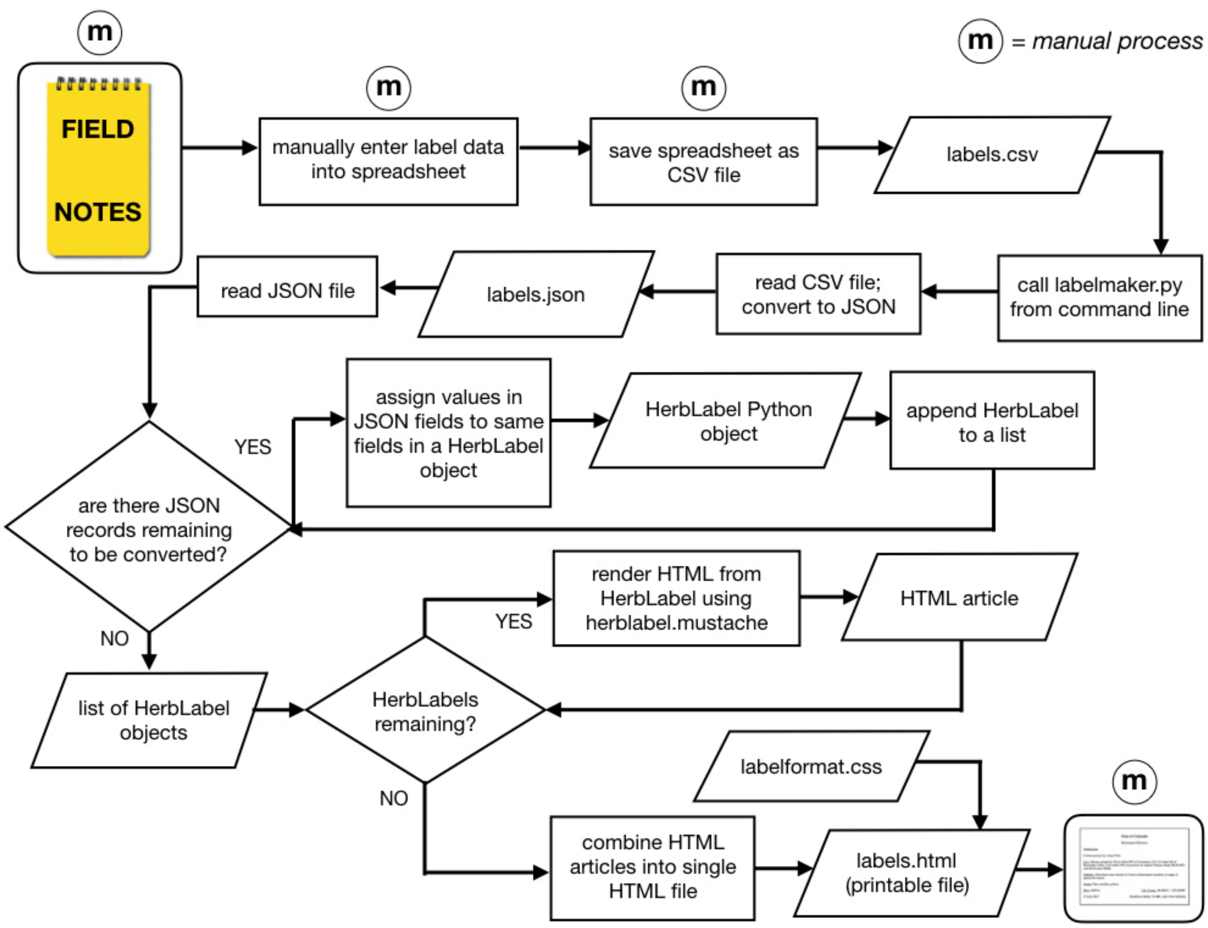

Figure 2.1. Flowchart illustrating the main software components and processes of the Labelmaker program.

To convert a CSV file into printable specimen labels, I used a pipeline (Fig. 2.1) that first converts each record in the CSV file into a JavaScript Object Notation (JSON) record. Each JSON record is then converted into an HTML article. The HTML articles, which will become the individual specimen labels, are populated with the data contained in the JSON records by way of a template, written using Mustache (https://mustache.github.io/mustache.5.html). Mustache templates were implemented using the Pystache package (https://github.com/defunkt/pystache). The final step in the program is to combine all generated HTML articles into a single HTML document, which is then formatted with CSS. This HTML document is saved in the working directory, and can be opened in any modern web browser. Once open in a browser, the document can be printed directly or saved to a Portable Document Format (PDF) file to print later.

The required field names for the input CSV file are *geoSecondaryDivision* (corresponding to US State), *geoTertiaryDivison* (corresponding to US County), *family, genus, specificEpithet, authority, rank* (var. or ssp., for instance), *infraspecificName, infraspecificAuthority, locality, ecology* (e.g., plant communities, associate species), *observations* (miscellaneous notes that do not correspond to any other categories), *elevation, elevationUnit, latitudeDecimal, longitudeDecimal, date* (of collection), *collector, collectionNumber,* and *additionalCollectors*. The program will run even if all inputs are absent; the user's input is not checked for completeness or errors.

RESULTS

My floristic research (Chapter I) required the creation of 602 specimen label records in a CSV file. I tested the program using this CSV file. On a mid-2015 MacBook Pro running Mac OSX 10.12.16, with a 2.5 GHz processor and 16 GB of RAM, 602 labels were generated in 0.275 seconds. The program was also tested successfully on a computer running Windows 10. Output files were opened and printed to PDF successfully in the Safari web browser on the Mac, and in the Firefox and Chrome web browsers on both Windows and Mac operating systems.

DISCUSSION

Future work

If the text of a given label is sufficiently long, the two lowermost labels on the page will split over two pages, which is suboptimal. None of my 602 labels were too long to be fit six to a page using the current formatting settings of the program, but labels written for software testing confirm that this issue could arise. Currently, two workarounds are possible. One can make the label text smaller by modifying the CSS, although the default is currently 9.5pt text in order to avoid this problem. Alternatively, one can cut the problematic entry from the original CSV file, and paste it into a CSV file in which it is the only entry, then follow the same steps to print the label. Work is planned to find a built-in solution for this issue, for instance, printing longer labels on their own page, as it is not practical or efficient for users to have to address this problem themselves.

The field names currently required in the input CSV file only partially conform to Darwin Core terms (http://rs.tdwg.org/dwc/terms/index.htm#dcindex). Darwin Core terms are used by curators of biocollections to simplify the sharing of data between institutions; iDigBio, for instance, encourages users to contribute records with Darwin Core field names (https://www.idigbio.org/content/idigbio-data-ingestion-requirements-and-guidelines). Using these terms, then, would increase the compatibility of one's collection dataset with international datasets. It would therefore be an improvement if the standard field names were made to conform to Darwin Core. Instructions and guidelines for changing these standardized field names would also be helpful, in case a user wishes to change the field names, for instance, to match those of their local herbarium's database.

It would be useful to add a section to the user guide (Appendix C) that would help users customize the software according to their needs. Such an addition to the guide would describe, for instance, how to modify the CSS file to change label formatting, with examples conforming to the standards of exemplar herbaria that use significantly different templates; and how to modify the number of labels printed per page. Several CSS files, representing different label-formatting standards, could be included in the downloadable code repository.

The current user guide could easily be made clearer with the addition of screenshots demonstrating installation and operation on various operating systems. It may also be of value to make a short instructional video to this effect.

A web-based alternative to this program would improve access for users with an internet connection, but who are unable to install Python on their computers, or who do not wish to install Python. Such users could access the program from a website, on which they would be able to upload their CSV-formatted label data. The program could then be run on a server, on which users' label data would be temporarily stored. Users' labels would then be remotely generated, and users could be provided with a download link for their HTML- or PDF-formatted label files. I plan to implement such a system for undergraduate students taking BZ223 Plant Identification at Colorado State University (CSU). The program will be run on the CSU Herbarium server, and will be accessible from the herbarium's website. Students will enter a password before uploading their data, to prevent malicious software being uploaded. Students will be able to upload a CSV file, and receive a link to open the program output. This step may increase buy-in from BZ223 undergraduate students, who produce between 10 and 15 specimen labels, and who will likely not be interested in spending time installing new software.

For greater efficiency, Labelmaker should be integrated with a mobile botanical data-collection application, which would eliminate the need for paper-based field notes and manual entry of data into a spreadsheet or database. In order to meet the needs of field botanists, who often collect in remote locations, such an application must be functional in the absence of cellular service or internet connection. Ideally, such an application should also have a companion web or desktop interface to allow for easy post-processing of data when the collector is not in the field. Such data-collection apps are few, and to my knowledge, only available for the Android operating system (Maya-Lastra, 2016; Welcome, 2015). The Digital Botanical Voucher Book application (Welcome, 2015) appears from its description to be a good software solution for this problem, but it has not been maintained since 2015. My attempts to test it were unsuccessful, as the program crashed upon opening, perhaps because of incompatibility with newer operating systems.

Fabian Mürmann, Jens Pentenrieder, and I designed and built a functional prototype of a web-based mobile data-collection application in 2016. The prototype was able to record photographs and notes, and sync them to a server once an internet connection became available. The continued development of this product would be a valuable addition to the field botanist's toolkit. I plan to collaborate on this project with Paul Wolf and Sylvia Kinosian at Utah State University, who are currently working on a similar development project (Wolf & Kinosian, pers. comm., 2018).

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APPENDIX A:
ANNOTATED CHECKLIST OF VASCULAR-PLANT TAXA
PRESENT IN THE STUDY AREA

INTRODUCTION

This complete checklist includes species and infraspecific taxa determined to be present in the study area (Chapter I) on the basis of my own collections and observations, collections made by Melanie Arnett in 1999 (Arnett, 2002), and observations made by Jennifer Ackerfield in 2015. The taxonomy in this checklist follows the *Flora of Colorado* (Ackerfield, 2015). Collected specimens were identified to variety or subspecies where applicable, except in two cases. First, a specimen of *Lappula occidentalis* (*M. Maher 402*) lacked mature fruits and so could not be identified beyond species. Second, the specimen of *Heliomeris multiflora* (*M. Maher & V. Mahida 214*) is equally consistent with descriptions of both *H. multiflora* var. *multiflora* and *H. multiflora* var. *nevadensis*. Melanie Arnett's specimen of *Heliomeris multiflora* var. *nevadensis* (*M. Arnett 7138*) is consistent with that variety description in the *Flora of Colorado*. I have included *Heliomeris multiflora* in the checklist, represented both by my collection and Arnett's. I have chosen not to include varieties of *H. multiflora* in the checklist because they are not consistently distinguishable from each other.

Location abbreviations

The following abbreviations are used to denote the properties on which the checklist taxa were collected, photographed, or documented in field notes: **BLM** (public land managed by the Bureau of Land Management), **M** (Maurer property).

Habitat abbreviations

I used the United States National Vegetation Classification (NVC) to describe the plant communities present in the study area (http://usnvc.org/explore-classification). This system is used by the Colorado Natural Heritage Program (CNHP). In all but one case, I specified plant communities to NVC's group level, and have provided examples in parentheses of genera or species observed that match the description of each NVC group. In one case, the vegetative community observed, a xeric area occupying approximately one acre at the top of a mesa, did not match any NVC descriptors, so I gave this community my own abbreviation: MT, for "mesa top." The MT vegetative community is at the south end of a mesa top, is exposed to sun and high winds, and is characterized by exposed bedrock or thin rocky soil, an abundance of lichens, a few occurrences of *Selaginella densa,* sparse shrub cover (*Ceanothus fendleri, Juniperus communis* var. *depressa,* and *Ribes cereum*), and xeric herbaceous cover including *Artemisia dracunculus, Berberis repens, Comandra umbellata* ssp. *pallida, Eremogone congesta, Erigeron compositus, Eriogonum racemosum, Eriogonum umbellatum* var. *umbellatum, Elymus elymoides, Heterotheca pumila, Ipomopsis aggregata* var. *aggregata, Koeleria macrantha, Mirabilis linearis, Potentilla hippiana* var. *hippiana, Rosa blanda, Saxifraga bronchialis* var. *austromontana,* and *Sedum lanceolatum*. The MT community is bordered by aspen forest (G222) to the south and east, dry grassland (G268) to the east, a rocky cliff (G565) to the west, and limber pine woodland (G221) to the north.

The unusual MT community appears to be the result of a fire, though perhaps not one in living memory. Several large, dead trees, probably *Pseudotsuga menziesii*, can be found atop the mesa. If the mesa top had been completely forested in the past, a fire may have been ignited by lightning strikes, which are common on ridges in the area.

G219 Rocky Mountain subalpine dry-mesic spruce-fir woodland group

(*Abies bifolia, Juniperus communis, Picea engelmannii, Populus tremuloides*)

G221 Rocky Mountain subalpine-montane limber pine-bristlecone pine woodland

(*Berberis repens, Juniperus communis, Pinus flexilis, Sedum lanceolatum*)

G222 Rocky Mountain subalpine-montane aspen forest and woodland group

(*Arctostaphylos uva-ursi, Populus tremuloides*, *Pteridium aquilinum, Rosa blanda*)

G225 Rocky Mountain mesic white fir-Douglas-fir-blue spruce mesic forest

(*Abies bifolia, Linnaea borealis, Oreochrysum parryi, Pseudotsuga menziesii, Symphoricarpos rotundifolius*)

G226 Southern Rocky Mountain white fir-Douglas-fir dry forest

(*Abies bifolia, Arctostaphylos uva-ursi, Paxistima myrsinites, Picea engelmannii, Pseudotsuga menziesii*)

G268 Southern Rocky Mountain montane-subalpine grassland group

(*Carex siccata, Danthonia parryi, Festuca arizonica, Festuca thurberi, Poa fendleriana*)

G277 Southern Rocky Mountain Gambel oak-mixed montane shrubland

(*Amelanchier alnifolia, Artemisia tridentata, Quercus gambelii, Symphoricarpos rotundifolius*)

G304 Intermountain mountain big sagebrush steppe and shrubland

(*Artemisia cana* ssp. *viscidula, Artemisia tridentata* ssp. *vaseyana*, *Festuca* spp.)

G506 Rocky Mountain-Great Basin montane riparian and swamp forest

(*Mertensia ciliata, Picea engelmannii, Populus tremuloides, Saxifraga odontoloma*)

G521 Vancouverian-Rocky Mountain montane wet meadow and marsh group

(*Cardamine cordifolia, Carex utriculata, Deschampsia caespitosa, Veratrum californicum*)

G527 Western montane-subalpine riparian and seep shrubland group

(*Alnus incana, Carex* spp., *Salix* spp.)

G544 Western North American temperate freshwater aquatic vegetation group

(*Callitriche palustris, Lemna minor, Ranunculus hyperboreus*)

G565 Rocky Mountain cliff, scree and rock vegetation group

(*Ribes* spp., *Saxifraga bronchialis, Sedum lanceolatum, Senecio atratus*)

MT Dry mesa top open shrub and forb community

(*Ceanothus fendleri, Comandra umbellata, Elymus elymoides, Juniperus communis, Koeleria macrantha, Rosa blanda*)

Abundance abbreviations

c common: abundant, with many populations of at least 25 individuals distributed throughout surveyed area

i infrequent: isolated, small populations of 10 to 25 individuals, present at two or more collection sites

o occasional: locally abundant, with populations of at least 25 individuals, present at three or more collection sites

r rare: isolated, with only one known population, or two populations with fewer than 10 individuals each

Symbols

***** new taxon record for Gunnison County

+ uncommon taxon in Colorado, according to Ackerfield (2015)

++ rare taxon in Colorado, according to Ackerfield (2015) or CNHP (https://cnhp.colostate.edu/ourdata/trackinglist/vascular_plants/)

taxon on CNHP watchlist

taxon fully tracked by CNHP

! non-native taxon

!! non-native taxon listed as a noxious weed in Colorado (https://www.colorado.gov/pacific/agconservation/noxious-weed-species)

§ observed and documented in the course of this study, but not collected

% not observed or collected in the course of this study, but previous presence suggested or confirmed by either Ackerfield (2016, pers. comm.) or Arnett (2002)

@ observed by Jennifer Ackerfield in study area in 2015 (2016, pers. comm.)

~ collected by Melanie Arnett on BLM portion of study area in 1999 (Arnett, 2002)

© observed by Charles Maurer in study area in 2016

Checklist entry format

Genus species Authority rank *infraspecific epithet* Infraspecific Authority; property on which taxon was collected or documented; codes for habitat(s) in which taxon was collected or documented; code for abundance of taxon according to my observations; elevation range of collections (in feet); **[collection number(s)] symbols**

Example:

Sambucus racemosa L. var. *microbotrys* (Rydb.) Kearn. & Peeb.; BLM, M; G219, G222, G527; c; 9008-9203'; **[20, 242] @**

Collection numbers refer to my own collections unless otherwise specified. Co-collectors of my specimens were Jennifer Ackerfield (*M. Maher et al. 1-55*), Vinit Mahida (*M. Maher & V. Mahida 168-234, 476-504*), Jens Pentenrieder (*M. Maher et al. 271-278, 578-605*), and Charles Maurer (*M. Maher et al. 1-55, 271-278, 578-605; M. Maher & C. Maurer 56-94, 106-167, 235-270, 411-463, 505-508*).

CHECKLIST

L Y C O P H Y T E S

SELAGINELLACEAE

Selaginella densa Rydb.; M; G565; i; 9919’ **[604]**

M O N I L O P H Y T E S

DENNSTAEDTIACEAE

Pteridium aquilinum (L.) Kuhn var. *pubescens* Underw.; M; G222; o; 9914'; **[277]**

DRYOPTERIDACEAE

Cystopteris fragilis (L.) Bernh.; BLM, M; G219, G222, G268, G506, G521; o; 9144-9416'; **[235, 506, 560]**

EQUISETACEAE

Equisetum arvense L.; BLM, M; G506, G521, G527; c; 8967-9121'; **[62, 69, 231, 438, 488]**

G Y M N O S P E R M S

CUPRESSACEAE

Juniperus communis L. var. *depressa* Pursh; BLM, M; G219, G222, G225, G226, G268, G304, G565, MT; c; 9426-9900'; **[82, 257, M. Arnett 7166] ~**

PINACEAE

Abies bifolia A. Murray; BLM, M; G219, G225, G226, G506; c; 9452'; **[569]**

Picea engelmannii Parry ex Engelm. var. *engelmannii*; BLM, M; G219, G225, G226, G506, G521, G527; c; 9121-9900'; **[332, 465, 490, M. Arnett 7167] ~**

Pinus flexilis E. James; M; G221, MT; r; 9919'; **[157]**

Pseudotsuga menziesii (Mirb.) Franco var. *glauca* (Beissn.) Franco; BLM, M; G219, G222, G225, G226, G506; c; 9478-9900'; **[526, M. Arnett 7168] ~**

A N G I O S P E R M S

ADOXACEAE

Sambucus racemosa L. var. *microbotrys* (Rydb.) Kearn. & Peeb.; BLM, M; G219, G222, G527; c; 9008-9203'; **[20, 242] @**

ALLIACEAE

Allium geyeri S. Watson var. *tenerum* M.E. Jones; BLM, M; G521, G527; c; 9508'; **[84]**

APIACEAE

Angelica ampla A. Nelson; BLM, M; G527; i; 9052'; **[496] @**

Conioselinum scopulorum (A. Gray) J.M. Coult. & Rose; BLM, M; G521, G527; c; 9144-9482'; **[189, 278, 457, 478]**

Cymopterus lemmonii (J.M. Coult. & Rose) Dorn; BLM, M; G219, G222, G226, G268, G304, G527; c; 9121-9900'; **[3, 270, 330, M. Arnett 7156, M. Arnett 7157] @ ~**

Heracleum maximum Bartr.; BLM, M; G222, G506, G521, G527; c; 9144'; **[153] @**

Ligusticum porteri J.M. Coult. & Rose; BLM, M; G222, G268; i; 9180'; **[458]**

Osmorhiza depauperata Phil.; BLM, M; G219, G222, G225, G226, G506; c; 9121-9190'; **[40, 328] @**

Oxypolis fendleri (A. Gray) Heller; BLM, M; G219, G226, G506; c; 9508-9629'; **[106, 248]**

ARACEAE

Lemna minor L.; M; G544; o; 8996'; **[459] @**

ASTERACEAE

Achillea millefolium L.; BLM, M; G219, G222, G268, G304, G527, MT; c; 9797-9900'; **[104, M. Arnett 7139] @ ~**

Agoseris aurantiaca (Hook.) Greene var. *aurantiaca*; BLM, M; G222, G268, G521, G527; c; 9181'; **[151]**

Agoseris aurantiaca (Hook.) Greene var. *purpurea* (A. Gray) Cronquist; BLM; G268; r; 9012'; **[572]**

Agoseris glauca (Pursh) Raf. var. *dasycephala* (Torr. & A. Gray) Jeps.; BLM, M; G219, G268, G521; c; 9314-9900'; **[193, M. Arnett 7133] ~**

Agoseris parviflora (Nutt.) D. Dietr.; BLM; G268; i; 9391'; **[19]**

Anaphalis margaritacea (L.) Benth. & Hook.; BLM, M; G219, G222; c; 9744'; **[171]**

Antennaria microphylla Rydb.; BLM, M; G219, G222, G304; c; 9182'; **[25]**

Antennaria parvifolia Nutt.; BLM, M; G219, G222, G304; c; 9008-9182'; **[22, 24]**

Antennaria rosea Greene; BLM, M; G219, G222, G268; o; 9182-9919'; **[261b, M. Arnett 7137] @ ~**

Arnica chamissonis Less.; BLM, M; G521; c; 8967-9400'; **[197, 489, 495]**

Arnica cordifolia Hook.; BLM, M; G219, G222, G226; c; 9337-9662'; **[10, 470]**

Artemisia cana Pursh ssp. *viscidula* (Osterh.) Beetle; BLM, M; G268, G304; c; 9121'; **[274]**

Artemisia dracunculus L.; BLM, M; G219, G268, MT; o; 9950'; **[210, M. Arnett 7140] ~**

Artemisia ludoviciana Nutt. var. *incompta* (Nutt.) Cronquist; BLM; G268, G527; i; 9006'; **[551]**

Artemisia ludoviciana Nutt. var. *ludoviciana*; BLM, M; G219; i; 9026'; **[272] @**

Artemisia tridentata Nutt. var. *vaseyana* (Rydb.) B. Boivin; BLM, M; G219, G225, G226, G268, G304; c; 9121-9629'; **[556, 557, 545, 275] @**

Bahia dissecta (A. Gray) Britton; BLM, M; G268, G277; o; 8999-9012'; **[241, 260]**

Carduus nutans L.; BLM, M; G222, G268, G304, G527; c; 9415'; **[198] !! @**

Chaenactis douglasii (Hook.) Hook. & Arn. var. *douglasii*; BLM, M; G277; i; 9180'; **[152]**

Cirsium arvense (L.) Scop.; BLM, M; G219, G226, G268, G304, G521, G527; c; 9012-9144'; **[236, 570, 571, 579, 592] !! @**

Cirsium clavatum (M.E. Jones) Petr. var. *americanum* (A. Gray) D.J. Keil; BLM, M; G268, G304, G521, G527; c; 9452'; **[567]**

Cirsium clavatum (M.E. Jones) Petr. var. *clavatum*; BLM, M; G268, G304, G521, G527; c; 9144-9919'; **[158, 594]**

Cirsium parryi (A. Gray) Petr.; M; G219, G226, G268, G521; o; 9340-9478'; **[201, 493, 524]**

Cirsium scariosum (Poir.) Nutt. **% @**

Dieteria bigelovii (A. Gray) D.R. Morgan & R.L. Hartm. var. *bigelovii*; BLM, M; G304; o; 9182'; **[497]**

Ericameria nauseosa (Pall. ex Pursh) G.L. Nesom & G.I. Baird var. *graveolens* (Nutt.) Reveal & Schuyler; BLM, M; G268, G304; r; 9416'; **[558]**

Ericameria parryi (A. Gray) G.L. Nesom & G.I. Baird var. *parryi*; M; G268, G304, G527; o; 9006-9121'; **[276, 552]**

Erigeron compositus Pursh; M; G565; i; 9919'; **[600]**

Erigeron coulteri Porter; BLM, M; G521, G527; c; 8967-9629'; **[107, 161, 393, 435, 464] @**

Erigeron divergens Torr. & A. Gray; M; G277; r; 8999'; **[441]**

Erigeron eximius Greene; BLM; G219; 9800-9900'; **[M. Arnett 7135] % ~**

Erigeron flagellaris A. Gray; BLM, M; G219, G221, G222, G268, G277, G304, MT; c; 8786-9919'; **[21, 49, 142, 399, 445, M. Arnett 7142] @ ~**

Erigeron formosissimus Greene; BLM, M; G268, G304; i; 9006-9895'; **[111, 437]**

Erigeron speciosus (Lindl.) DC.; BLM, M; G219, G222, G226, G268, G277; c; 8999-9900'; **[212, 439, 554, M. Arnett 7132] @ ~**

Erigeron subtrinervis Rydb. ex Porter & Britton; BLM; G219, G222; i; 9452'; **[484]**

Helianthella quinquenervis (Hook.) A. Gray; BLM; G268; r; 9012'; **[120]**

Heliomeris multiflora Nutt.; BLM, M; G219, G222, G268; c; 9686-9900'; **[214, M. Arnett 7138] ~**

Heterotheca pumila (Greene) Semple; M; G221, MT; i; 9919'; **[133]**

Hymenoxys hoopesii (A. Gray) Bierner; BLM, M; G219, G222, G304, G268, G527; c; 8996'; **[54] @**

Lactuca serriola L.; M; G277; o; 8999'; **[546] !**

Leucanthemum vulgare (Vaill.) Lam.; BLM, M; G268, G521, G527; c; 9340'; **[261, 598] !! @**

Madia glomerata Hook.; BLM, M; G268, G521; c; 9055-9340'; **[186, 517] !**

Matricaria discoidea DC.; M; G521; o; 9340'; **[178] !**

Oreochrysum parryi (A. Gray) Rydb.; BLM, M; G219, G268, G304, G565; c; 9452-9900'; **[252, 483, M. Arnett 7141] ~**

Packera fendleri (A. Gray) W.A. Weber & Á. Löve **% @**

Packera neomexicana (A. Gray) W.A. Weber & Á. Löve var. *mutabilis* (Greene) W.A. Weber & Á. Löve; M; G219, G222, G226, G268, MT; c; 9718-9919'; **[144, 208, 338, M. Arnett 7134]**

Senecio atratus Greene; M; G565; r; 9898'; **[254]**

Senecio bigelovii A. Gray var. *hallii* A. Gray; BLM, M; G219, G222, G226, G268; i; 9480'; **[196] @**

Senecio eremophilus Richardson var. *kingii* (Rydb.) Greenm.; M; G268, G304; r; 9478'; **[200]**

Senecio integerrimus Nutt.; BLM, M; G219, G304; c; 9182'; **[28, 30]**

Senecio serra Hook. var. *admirabilis* (Greene) A. Nelson; M; G506; i; 9584'; **[253]**

Senecio triangularis Hook.; BLM; G521; c; 9144'; **[154]**

Solidago multiradiata Ait. var. *scopulorum* A. Gray; M; G521; c; 9508'; **[110] @**

Solidago simplex Kunth var. *simplex*; BLM, M; G219, G222, G226, G268; c; 9744-9900'; **[166, M. Arnett 7136] ~**

Symphyotrichum foliaceum (D.C.) G.L. Nesom var. *parryi* (D.C. Eaton) G.L. Nesom; BLM, M; G521, G527; i; 9006-9452'; **[549, 583]**

Symphyotrichum spathulatum (Lindl.) G.L. Nesom; M; G268, G521; r; 9430-9482'; **[203, 536] +**

Taraxacum officinale F.H. Wigg; BLM, M; G219, G222, G226, G268, G277, G304, G521, G527; c; 9340'; **[91] ! @**

Tetraneuris acaulis (Pursh) Greene var. *arizonica* (Greene) Parker; M; G219, G304; i; 9182'; **[33] +**

Tragopogon dubius Scop.; BLM; G268, G521, G527; c; 9144'; **[149] !**

Tragopogon pratensis L.; BLM; G268, G527; r; 9012'; **[448] !**

BERBERIDACEAE

Berberis repens Lindl.; BLM, M; G219, G222, G268; c; 9391-9900'; [18, M. Arnett 7150] ~

BETULACEAE

Alnus incana (L.) Moench ssp. *tenuifolia* (Nutt.) Brietung; BLM, M; G527; c; 9012'; **[449]**

BORAGINACEAE

Cynoglossum officinale L.; BLM, M; G222, G268, G506, G527; r; 8926'; **[41] !!**

Hackelia floribunda (Lehm.) I.M. Johnst.; BLM, M; G219, G222, G226, G268, G277, G527, MT; c; 9919'; **[138] @**

Lappula occidentalis (S. Watson) Greene; BLM, M; G277; c; 8999'; **[402] !**

Mertensia ciliata (James ex Torr.) G. Don; M; G219, G222, G226, G521, G527; c; 9370-9452'; **[97, 543] @**

Mertensia fusiformis Greene; BLM, M; G219, G226, G268, G304; c; 9121-9508'; **[86, 89, 334]**

Plagiobothrys scouleri (Hook. & Arn.) I.M. Johnst. var. *hispidulus* (Greene) Dorn; BLM; G521, G527; o; 9006'; **[516]**

BRASSICACEAE

Boechera grahamii (Greene) Windham & Al-Shehbaz; BLM; G219, G222, G226, G506, G521, G527; r; 9524'; **[56]**

Boechera stricta (Graham) Al-Shehbaz; BLM, M; G219, G222, G268, G304, G527; c; 9006-9900'; **[32, 59, 232, 343, M. Arnett 7151] @ ~**

Capsella bursa-pastoris (L.) Medik; BLM, M; G219, G222, G304, G521; c; 9340-9584'; **[317, 341] !**

Cardamine cordifolia A. Gray; BLM, M; G521; c; 8786-9452'; **[47, 98, 406]**

Descurainia incana (Bernh. ex Fisch. & C.A. Mey.) Dorn; BLM, M; G268; c; 9942'; **[226] @**

Descurainia incisa (Engelm. ex A. Gray) Britton ssp. *incisa*; M; G222; c; 8786'; **[125]**

Draba albertina Greene; BLM; G268, G521; o; 9121'; **[329]**

Draba rectifructa C.L. Hitchc.; M; G219, G268, G521; o; 9300-9800'; **[7, 383] ++ #**

Draba spectabilis Greene; M; G219, G226, G304; o; 9508'; **[85]**

Erysimum capitatum (Douglas ex Hook.) Greene; M; G277, G304; o; 9508'; **[108]**

Noccaea fendleri (A. Gray) Holub ssp. *glauca* (A.Nelson) Al-Shehbaz & M. Koch; BLM, M; G219, G222, G226, G565; c; 9107-9662'; **[11, 58, 321]**

Rorippa curvipes Greene; BLM, M; G219, G521, G527; r; 9347-9629'; **[216, 566]**

CAMPANULACEAE

Campanula parryi A. Gray var. *parryi* ; BLM, M; G268, G304, G521; c; 9340'; **[187] @**

Campanula rotundifolia L.; BLM, M; G268, G304; c; 9629-9883'; **[223] @**

CAPRIFOLIACEAE

Linnaea borealis L. var. *longiflora* Torr.; M; G219, G225; o; 9898'; **[131]**

Symphoricarpos rotundifolius (L.) S.F. Blake; BLM, M; G219, G222, G268, G277; c; 8999-9177'; **[122, 400] @**

CARYOPHYLLACEAE

Cerastium fontanum Baumg. ssp. *vulgare* (Hartm.) Greuter & Burdet; BLM; G268, G521, G527; o; 9121-9196'; **[333, 408] !**

Eremogone congesta (Nutt.) Ikonn. var. *congesta*; BLM, M; G219, G268, G304; c; 9797-9900'; **[105, M. Arnett 7153] ~**

Moehringia macrophylla (Hook.) Fenzl; BLM, M; G219, G222; o; 9337'; **[322]**

Silene drummondii Hook. ssp. *drummondii*; M; G268, G304, G521; o; 9482'; **[531] @**

Silene scouleri Hook.; BLM, M; G219, G222, G268; c; 9006-9416'; **[243, 559]**

Stellaria calycantha (Ledeb.) Bong.; M; G219, G521; i; 9508'; **[453] +**

Stellaria longifolia Muhl. ex Willd.; BLM, M; G521; c; 9144'; **[146]**

Stellaria longipes Goldie ssp. *longipes* ; BLM, M; G268; c; 9052-9508'; **[71, 409, 454, 491]**

CELASTRACEAE

Paxistima myrsinites (Pursh) Raf.; BLM, M; G219, G226; c; 9347-9452'; **[337, 565]**

CHENOPODIACEAE

Chenopodium atrovirens Rydb.; BLM, M; G219, G268, G521; c; 9482-9914'; **[175, 204, 529, M. Arnett 7169] ~**

Chenopodium fremontii S. Watson; BLM; G219, G506, G521; i; 9006'; **[573]**

Chenopodium overi Aellen; BLM, M; G219, G226, G527; o; 9347'; **[555, 564]**

Monolepis nuttalliana (Schult.) Greene; M; G268, G521; r; 9340'; **[342]**

CLUSIACEAE

Hypericum scouleri Hook. ssp. *nortoniae* (M.E. Jones) J. Gillett; M; G521; i; 8996'; **[494]**

CRASSULACEAE

Sedum lanceolatum Torr.; BLM, M; G219, G565, MT; c; 9800-9919'; **[135, M. Arnett 7155] ~**

Rhodiola rhodantha (A. Gray) H. Jacobsen **% @**

CYPERACEAE

Carex aquatilis Wahlenb.; BLM, M; G521, G527; c; 9452-9629'; **[205, 511, 533, 574] @**

Carex aurea Nutt.; M; G521, G527; o; 9340-9452'; **[503, 576]**

Carex disperma Dewey; M; G506, G521; o; 9452-9482'; **[469, 514]**

Carex geyeri W. Boott; BLM, M; G219, G222, G226; c; 9190'; **[37]**

Carex microptera Mack.; M; G268, G506, G521; c; 9340-9629'; **[186b, 199, 220, 250b] @**

Carex nebrascensis Dewey; M; G521; o; 9055'; **[239]**

Carex pachystachya Cham. ex Steud.; M; G219, G506, G521; o; 9629'; **[250a]**

Carex pellita Muhl. ex Willd. **% @**

Carex petasata Dewey; M; G304; o; 9182'; **[498]**

Carex raynoldsii Dewey; M; G268; o; 9797'; **[476]**

Carex saxatilis L.; M; G521; o; 9508'; **[537]**

Carex siccata Dewey; BLM, M; G268; r; 9797-9900'; **[101, M. Arnett 7163] ~**

Carex tahoensis Smiley; M; G521; i; 9629'; **[265] +**

Carex utriculata Boott; BLM, M; G521, G527; c; 9012-9629'; **[188, 509, 575, 580] @**

Eleocharis palustris (L.) Roem. & Schult.; M; G521; o; 9629'; **[264]**

ELAEAGNACEAE

Shepherdia canadensis Nutt.; M; G219, G225, G226; r; 9898'; **[258]**

ERICACEAE

Arctostaphylos uva-ursi (L.) Spreng.; BLM, M; G222, G226; c; 9718'; **[339] @**

Orthilia secunda (L.) House; M; G219, G222, G226, G506; o; 9551'; **[481]**

Pyrola asarifolia Michx.; M; G521, G527; o; 9452'; **[577]**

Pyrola chlorantha Sw.; BLM, M; G219, G222, G226; c; 9144'; **[126]**

Pyrola picta Sm.; BLM, M; G226; r; 9150-9650'; **[578] * ++ #**

Vaccinium myrtillus L.; BLM, M; G219, G225, G226; c; 9452-9662'; **[336, 394]**

FABACEAE

Lathyrus lanszwertii Kellogg var. *leucanthus* (Rydb.) Dorn; BLM, M; G219, G222, G268, G304; c; 8999-9840'; **[8, 78] @**

Lupinus argenteus Pursh var. *argenteus*; M; G304; c; 8996'; **[53] @**

Lupinus argenteus Pursh var. *rubricaulis* (Greene) S.L. Welsh; BLM, M; G219, G304; c; 9508-9900'; **[530, M. Arnett 7152] @ ~**

Lupinus polyphyllus Lindl. var. *prunophilus* (M.E. Jones) L. Phillips; BLM, M; G222, G268; c; 9662'; **[14]**

Thermopsis rhombifolia (Pursh) Richardson var. *divaricarpa* (A. Nelson) Isely **% @**

Trifolium hybridum L.; BLM, M; G268, G527; o; 9006-9914'; **[176, 550] !**

Trifolium kingii S. Watson var. *kingii* ; M; G222, G506; r; 8600-9100'; **[51] * ++ ##**

Trifolium longipes Nutt.; BLM, M; G268, G527; c; 9012'; **[446]**

Trifolium pratense L.; BLM, M; G268, G527; o; 8967'; **[486] ! @**

Trifolium repens L.; BLM, M; G304; o; 9182'; **[26] ! @**

Vicia americana Muhl. ex Willd. var. *americana*; BLM, M; G219, G222, G225, G226, G268, G506; c; 8786-9900'; **[44, 48, M. Arnett 7146, M. Arnett 7147] @ ~**

FAGACEAE

Quercus gambelii Nutt.; M; G277; o; 8999'; **[72]**

FUMARIACEAE

Corydalis aurea Willd. ssp. *aurea*; BLM, M; G219, G222, G226; c; 9391'; **[17]**

GENTIANACEAE

Gentiana parryi Engelm.; M; G222, G268; c; 9883'; **[246]**

Gentianella acuta (Michx.) Hiitonen; BLM, M; G219, G226, G268, G521; c; 9744-9898'; **[168, 170]**

Swertia perennis L.; M; G506, G521; c; 9360-9508'; **[192, 532]**

GERANIACEAE

Erodium cicutarium (L.) L'Hér. ex Ait.; M; G277; r; 8999'; **[403, 591] !!**

Geranium richardsonii Fisch. & Trautv.; BLM, M; G219, G222, G268, G304, G527; c; 8786-9182'; **[27, 50, 436] @**

GROSSULARIACEAE

Ribes cereum Douglas; M; MT; r; 9919'; **[605]**

Ribes inerme Rydb.; M; G226, G521; r; 9380'; **[167]**

Ribes lacustre (Pers.) Poir.; M; G219, G225, G565; r; 9898'; **[256, 462]**

Ribes wolfii Rothr.; BLM, M; G219, G222, G226; c; 9452-9662'; **[12, 335]**

HYDROPHYLLACEAE

Phacelia heterophylla Pursh; BLM, M; G219, G222, G268; c; 9012-9452'; **[112, 485, 507] @**

IRIDACEAE

Iris missouriensis Nutt. **% @**

Sisyrinchium montanum Greene var. *montanum*; M; G521; r; 9340'; **[500] @**

JUNCACEAE

Juncus alpinoarticulatus Chaix; M; G521; i; 9629'; **[217b]**

Juncus arcticus Willd. var. *balticus* (Willd.) Trautv.; BLM, M; G268, G304, G521, G527; c; 9055-9629'; **[218, 519] @**

Juncus confusus Coville; M; G268, G304; c; 8996-9340'; **[262, 502]**

Juncus ensifolius Wikstr.; M; G521, G527; c; 9314'; **[194]**

Juncus longistylis Torr.; M; G521; c; 9314'; **[195]**

Juncus nevadensis S. Watson; M; G521; c; 9629'; **[217a, 219] + @**

Luzula parviflora (Ehrh.) Desv.; BLM, M; G506, G521, G527; o; 9012-9508'; **[444, 452]**

LAMIACEAE

Agastache urticifolia (Benth.) Kuntze; M; G268, G506; o; 8786'; **[124]**

Dracocephalum parviflorum Nutt.; BLM, M; G222, G268, G277, G527; c; 8999-9452'; **[79, 582] @**

Prunella vulgaris L. **% @**

Scutellaria galericulata L.; M; G521, G527; r; 9055'; **[237, 521]**

LILIACEAE

Calochortus gunnisonii S. Watson; M; G268; c; 9895'; **[172]**

Erythronium grandiflorum Pursh **% @**

LINACEAE

Linum lewisii Pursh; M; G222, G268; c; 9850'; **[164] @**

MALVACEAE

Iliamna rivularis (Douglas) Greene; BLM; G219, G226; r; 9300-9800’; **[165] ++ @**

Sidalcea candida A. Gray; BLM, M; G521, G527; c; 9340'; **[180]**

MELANTHIACEAE

Veratrum californicum T. Durand; BLM, M; G521; c; 8786'; **[137] @**

Zigadenus elegans Pursh; BLM, M; G268, G521; c; 9629-9852'; **[129, 159] @**

MONTIACEAE

Lewisia pygmaea (A. Gray) B.L. Rob. var. *pygmaea*; BLM, M; G268, G521; c; 9121-9852'; **[6, 323]**

Montia chamissoi (Ledeb. ex Spreng.) Greene; M; G521; o; 9314'; **[480]**

NYCTAGINACEAE

Mirabilis linearis (Pursh) Heimerl var. *linearis*; M; G277, MT; o; 8999-9919'; **[271, 471]**

ONAGRACEAE

Chamerion angustifolium (L.) Holub; M; G268, G565; o; 9850'; **[251] @**

Epilobium ciliatum Raf. var. *glandulosum* (Lehm.) Dorn; BLM, M; G521; o; 9144'; **[455]**

Epilobium halleanum Hausskn.; BLM, M; G521; i; 9144'; **[148]**

Epilobium hornemannii Rchb. var. *hornemannii*; BLM, M; G506, G521; c; 9052-9797'; **[70, 109, 461] @**

Epilobium hornemannii Rchb. var. *lactiflorum* (Hausskn.) D. Löve; BLM, M; G268, G521; c; 9121-9629'; **[92, 324, 460]**

Epilobium saximontanum Hausskn.; M; G521; i; 9629'; **[160]**

Gayophytum diffusum Torr. & A. Gray ssp. *parviflorum* F.H. Lewis & Szweyk.; BLM, M; G268, G304, G521; c; 8999-9883'; **[113, 547] @**

Oenothera flava (A. Nelson) Garrett; BLM, M; G268, G521; o; 9012-9340'; **[118, 447] @**

Oenothera villosa Thunb. ssp. *strigosa* (Rydb.) W. Dietr. & Raven **% @**

ORCHIDACEAE

Calypso bulbosa (L.) Oakes var. *americana* (R. Br. ex Ait. f.) Luer; BLM, M; G219, G226; r; 9144'; **[68]**

Corallorhiza maculata (Raf.) Raf.; M; G219, G225, G226; c; 9950'; **[132] @**

Goodyera oblongifolia Raf.; BLM, M; G219, G225, G226; c; 9144-9551'; **[240, 240b]**

Platanthera huronensis (Nutt.) Lindley; BLM, M; G521; c; 9144-9314'; **[67, 67b, 450, 456] @**

Spiranthes romanzoffiana Cham.; BLM; G527; r; 8967'; **[596]**

OROBANCHACEAE

Castilleja linariifolia Benth.; M; G277, G304; o; 8999'; **[405]**

Castilleja miniata Douglas ex Hook.; BLM, M; G219, G222, G226; c; 9052-9900'; **[35, 474, M. Arnett 7154] @ ~**

Castilleja rhexifolia Rydb.; BLM; G527; r; 9012'; **[442]**

Castilleja sulphurea Rydb.; BLM, M; G268, G304, G521; c; 9340-9797'; **[100a, 100b] @**

Orobanche fasciculata Nutt.; M; G304; r; 9629'; **[173]**

Orthocarpus luteus Nutt.; BLM, M; G268, G304, G521; c; 9629'; **[221]**

Pedicularis groenlandica Retz.; M; G521; o; 9314'; **[477] @**

Pedicularis procera A. Gray; BLM, M; G219, G222, G506; c; 9827'; **[169] @**

PHRYMACEAE

Mimulus guttatus DC.; BLM, M; G521; c; 9144-9196'; **[145, 407] @**

PLANTAGINACEAE

Callitriche palustris L.; M; G544; o; 9482'; **[207]**

Penstemon strictus Benth. ssp. *strictus*; BLM, M; G268, G277, G304; c; 8999-9177'; **[123, 440] @**

Plantago major L.; BLM, M; G219, G226, G506; c; 9629'; **[249] !**

Veronica americana Schwein. ex Benth.; BLM; G521, G527; c; 9006'; **[548]**

Veronica anagallis-aquatica L.; BLM, M; G521, G527; o; 9019-9144'; **[147, 473] !**

Veronica peregrina L. var. *xalapensis* (Kunth) Pennell; M; G521, G527; o; 9055'; **[518] @**

Veronica serpyllifolia L. var. *humifusa* (Dicks.) Syme; BLM, M; G521; o; 9121-9482'; **[88, 325b]**

Veronica wormskjoldii Roem. & Schultes; M; G521, G527; o; 9452'; **[466]**

POACEAE

Achnatherum lettermanii (Vasey) Barkworth; BLM, M; G268; c; 9880-9914'; **[174, 213]**

Achnatherum nelsonii (Scribn.) Barkworth; BLM; G219; 9800-9900'; **[M. Arnett 7160] % ~**

Agrostis exarata Trin.; BLM, M; G506, G521; o; 9144'; **[593] !**

Agrostis idahoensis Nash; BLM, M; G521; c; 9482'; **[202]**

Anthoxanthum hirtum (Schrank.) Y. Schouten & Veldkamp; BLM, M; G521, G527, G268; c; 9006-9452'; **[96, 434]**

Bromus carinatus Hook. & Arn.; M; G521; i; 9340'; **[184]**

Bromus ciliatus L.; BLM; G219; 9800-9900'; **[M. Arnett 7164] % ~**

Bromus inermis Leyss.; BLM, M; G268, G521, G527; c; 8926-9340'; **[43, 182] @ !**

Bromus porteri (J.M. Coult.) Nash; BLM, M; G219, G222, G226 ; c; 9337'; **[508]**

Bromus tectorum L.; M; G277; o; 8999'; **[404] !!**

Calamagrostis canadensis (Michx.) P. Beauv.; BLM, M; G521; c; 9340-9629'; **[183, 225a]**

Dactylis glomerata L.; BLM, M; G219, G222, G268, G304, G506, G521, G527; c; 8926-9900'; **[42, 206, M. Arnett 7159] ! ~**

Danthonia intermedia Vasey; BLM; G219; 9800-9900'; **[M. Arnett 7161] % ~**

Danthonia parryi Scribn.; BLM, M; G268, G304; c; 9883'; **[245]**

Deschampsia cespitosa (L.) P. Beauv.; BLM, M; G521, G527; c; 9340-9629'; **[181, 512, 525]**

Elymus elymoides (Raf.) Swezey; M; MT; o; 9919-9950'; **[143, 209, 211]**

Elymus glaucus Buckley ssp. *glaucus*; M; G521; c; 9629'; **[513]**

Elymus repens (L.) Gould; M; G521; o; 9629'; **[224] !**

Elymus trachycaulus (Link) Gould; BLM, M; G521; c; 9340'; **[185]**

Festuca arizonica Vasey; BLM, M; G219, G226, G268, MT; c; 9416'; **[561]**

Festuca thurberi Vasey; BLM, M; G219, G268, G304, G521, MT; c; 9478-9900'; **[267, 492, M. Arnett 7165] ~**

Glyceria striata (Lam.) Hitchc.; M; G521; i; 9629'; **[510]**

Hordeum brachyantherum Nevski; BLM, M; G521; c; 9629'; **[266]**

Hordeum jubatum L.; M; G304; o; 9182'; **[234]**

Koeleria macrantha (Ledeb.) Schult.; BLM, M; G219, G268, G277, G565, MT; c; 9800-9919'; **[139, M. Arnett 7162] ~**

Phleum alpinum L.; BLM, M; G268, G304, G521; c; 9340-9883'; **[117, 191]**

Phleum pratense L.; BLM, M; G219, G222, G268, G304, G521, G527; c; 9121-9340'; **[60, 190] !**

Poa compressa L.; BLM, M; G268, G521, G527; o; 9340'; **[340] !**

Poa fendleriana (Steud.) Vasey ssp. *fendleriana*; BLM, M; G219, G226, G268, G304; c; 9662-9852'; **[9, 13, 57]**

Poa pratensis L.; BLM, M; G219, G222, G268, G304, G521, G527, MT; c; 9182-9895'; **[34, 102, 116, 225b] !**

POLEMONIACEAE

Collomia linearis Nutt.; BLM, M; G277, G268, G304, MT; c; 9895-9919'; **[115, 130] @**

Ipomopsis aggregata (Pursh) V.E. Grant ssp. *aggregata*; BLM, M; G219, G221, G277, G268, MT; c; 8999-9900'; **[73, M. Arnett 7144] @ ~**

Polemonium occidentale Greene ssp. *occidentale*; M; G521; o; 9452'; **[95] @**

POLYGONACEAE

Bistorta bistortoides (Pursh) Small; M; G521; c; 9340-9452'; **[99, 155]**

Bistorta vivipara (L.) A. Gray; M; G521; c; 9314'; **[479]**

Eriogonum racemosum Nutt.; BLM, M; G277, G304; c; 9023'; **[150] @**

Eriogonum umbellatum Torr. var. *aureum* (Gandoger) Reveal; M; MT; r; 9919'; **[141] @**

Eriogonum umbellatum Torr. var. *majus* Hook.; BLM, M; G219, G277, G304; i; 8999-9900'; **[77, M. Arnett 7148] @ ~**

Polygonum aviculare L.; BLM, M; G219, G222, G226, G268, G506, G521, G527; c; 9055-9900'; **[247, 520, 541, M. Arnett 7170] ! ~**

Polygonum douglasii Greene; BLM, M; G219, G268, G506; c; 9370-9914'; **[177, 542]**

Polygonum sawatchense Small ssp. *sawatchense*; M; G268, G521; i; 9508'; **[538]**

Rumex acetosella L.; BLM, M; G268, G521, G527; o; 9426'; **[81] !**

Rumex crispus L.; BLM; G268, G527; r; 9006'; **[233] !**

Rumex densiflorus Osterh.; M; G521; o; 9452'; **[156] @**

Rumex triangulivalvis (Danser) Rech. f.; BLM, M; G521, G527; o; 9006-9629'; **[482, 553] @**

PRIMULACEAE

Androsace septentrionalis L.; BLM, M; G219, G222, G226, G268, G304, G565, MT; c; 9121-9852'; **[1, 327] @**

Dodecatheon pulchellum (Raf.) Merr.; M; G222, G506; r; 8786'; **[52]**

RANUNCULACEAE

Aconitum columbianum Nutt.; BLM, M; G222, G506, G521; c; 8786'; **[136] @**

Anemone patens L. var. *multifida* Pritz.; M; MT; r; 9919'; **©**

Aquilegia coerulea James var. *coerulea*; BLM, M; G219, G222, G565; c; 9686'; **[119] @**

Aquilegia coerulea James var. *ochroleuca* Hook.; M; G268, G565; r; 9340'; **§**

Aquilegia elegantula Greene; BLM, M; G219, G222, G226; c; 9008'; **[23, 398] @**

Caltha leptosepala DC.; BLM, M; G506, G521; c; 9340'; **[90]**

Clematis columbiana (Nutt.) Torr. & A. Gray var. *columbiana*; BLM, M; G219, G225, G226; r; 9662'; **[15] @**

Clematis hirsutissima Pursh; BLM; G268; o; 9391'; **[16]**

Delphinium barbeyi (Huth) Huth **% @**

Delphinium nuttallianum Pritz.; M; G222, G304; c; 9182-9686'; **[31, 319, 320]**

Delphinium occidentale (S. Watson) S. Watson; M; G222; r; 9190'; **[522]**

Ranunculus inamoenus Greene var. *inamoenus*; BLM, M; G268, G521; c; 9121-9482'; **[61, 325, 534]**

Ranunculus alismifolius Geyer ex Benth. var. *montanus* S. Watson; M; G506, G521; o; 9797'; **[93]**

Ranunculus aquatilis L. var. *diffusus* With.; M; G544; r; 9052'; **[475]**

Ranunculus hyperboreus R. Br.; M; G544; r; 9052'; **[433]**

Thalictrum fendleri Engelm. ex A. Gray; BLM, M; G222, G225; c; 9662'; **[14] @**

RHAMNACEAE

Ceanothus fendleri A. Gray; M; MT; r; 9919'; **[140]**

ROSACEAE

Amelanchier alnifolia (Nutt.) Nutt. ex M. Roem. var. *utahensis* (Koehne) M.E. Jones; M; G277; o; 8999'; **[80]**

Fragaria virginiana Mill.; BLM, M; G219, G222, G225, G268, G304, G506, G521, G527; c; 9452-9852'; **[2, 468] @**

Geum aleppicum Jacq.; BLM, M; G521; i; 9144'; **[66]**

Geum macrophyllum Willd. var. *perincisum* (Rydb.) Raup; BLM, M; G521, G527; c; 9012-9797'; **[104b, 443, 523] @**

Geum rivale L.; M; G521; o; 9340-9452'; **[467, 499] @**

Geum triflorum Pursh; BLM, M; G268, G304, G521; c; 9107'; **[63] @**

Holodiscus dumosus (Nutt. ex Hook.) A. Heller; BLM, M; G268, G277, G565; r; 9144'; **[505]**

Potentilla arguta Pursh; BLM; G219, G226, G506; r; 9347'; **[562] +**

Potentilla fissa Nutt.; M; G277; o; 8999'; **[75]**

Potentilla fruticosa Pursh; M; G521; c; 9340-9629'; **[94, 179]**

Potentilla gracilis Douglas ex Hook. var. *elmeri* (Rydb.) Jeps.; M; G521; c; 9370'; **[544]**

Potentilla hippiana Lehm. var. *hippiana*; BLM, M; G219, G268, MT; c; 9800-9919'; **[602, M. Arnett 7149] @ ~**

Potentilla hippiana Lehm. × *pulcherrima* Lehm.; M; G277; c; 8999'; **[74, 401]**

Potentilla pulcherrima Lehm.; BLM, M; G219, G222, G268, G304; c; 8996-9744'; **[29, 55, 163] @**

Prunus virginiana L. var. *melanocarpa* (A. Nelson) Sarg.; M; G222, G506; o; 8926'; **[45]**

Rosa acicularis Lindl. ssp. *sayi* (Schwein.) W.H. Lewis; BLM, M; G222, G268, G521; o; 9144'; **[595]**

Rosa blanda Ait.; BLM, M; G219, G222, G268, G277; c; 9452-9900'; **[128, 568, M. Arnett 7158] @ ~**

Rubus idaeus L. var. *strigosus* (Michx.) Maxim.; BLM, M; G219, G222, G268, G527; c; 8967-9006'; **[244, 487]**

RUBIACEAE

Galium boreale L.; BLM, M; G219, G222, G226, G268, G304; c; 9895-9900'; **[114, M. Arnett 7145] @ ~**

Galium trifidum L. var. *subbiflorum* Wiegand; BLM, M; G521, G527; c; 9340'; **[504]**

RUSCACEAE

Maianthemum racemosum (L.) Link ssp. *amplexicaule* (Nutt.) LaFrankie; BLM, M; G219, G222, G225, G226; c; 9190'; **[39]**

Maianthemum stellatum (L.) Link; BLM, M; G219, G222, G225, G226; c; 9190'; **[38] @**

SALICACEAE

Populus tremuloides Michx.; BLM, M; G219, G222, G225, G226, G506; c; 9800-9914'; **[463, M. Arnett 7143] @ ~**

Salix drummondiana Barratt ex Hook.; BLM; G527; c; 9006-9019'; **[65, 396a, 397]**

Salix geyeriana Andersson; BLM, M; G527; c; 8967-9452'; **[584a, 587, 590]**

Salix lasiandra Benth. var. *caudata* (Nutt.) Sudw.; BLM; G527; i; 9006'; **[64]**

Salix lasiandra Benth. var. *lasiandra*; BLM; G527; c; 8967-9019'; **[472, 586]**

Salix monticola Bebb; BLM; G527; c; 8967-9019'; **[396b, 589]**

Salix planifolia Pursh; M; G521, G527; o; 9452-9508'; **[535, 584b]**

Salix wolfii Bebb var. *wolfii*; M; G521, G527; o; 9452'; **[585]**

SANTALACEAE

Comandra umbellata (L.) Nutt. ssp. *pallida* (A. DC.) Piehl; M; G221, MT; o; 9919'; [134]

SAXIFRAGACEAE

Heuchera parvifolia Nutt.; BLM, M; G268; o; 9797'; **[103] @**

Lithophragma glabrum Nutt.; BLM, M; G268, G521; o; 9121'; **[326]**

Lithophragma tenellum Nutt.; M; G268, G304; o; 9182'; **[36]**

Micranthes odontoloma (Piper) A. Heller; M; G506; o; 9508'; **[451]**

Micranthes rhomboidea (Greene) Small; M; G268, G521; c; 9629-9852'; **[5, 384]**

Saxifraga bronchialis L. var. *austromontana* (Wiegand) Piper; M; G565, MT; o; 9898'; **[255]**

SCROPHULARIACEAE

Scrophularia lanceolata Pursh; M; G268, G277, G304; o; 9023'; **[127] @**

Verbascum thapsus L.; BLM, M; G222, G268, G277; i; 9003'; **[273] !!**

TYPHACEAE

Sparganium emersum Rehmann; M; G521, G544; r; 9629'; **[215]**

Typha latifolia L.; BLM, M; G521, G527; o; 9144'; **[238]**

URTICACEAE

Urtica dioica L. ssp. *gracilis* (Aiton) Selander; BLM, M; G219, G222, G268, G506, G521, G527; c; 9482-9629'; **[162, 268]**

VALERIANACEAE

Valeriana edulis Nutt.; BLM, M; G268, G304; c; 9883'; **[263] @**

Valeriana occidentalis A. Heller; BLM, M; G219, G226, G268, G506, G521; c; 9508'; **[83] @**

VIOLACEAE

Viola adunca J. Sm.; BLM, M; G219, G222, G225, G226, G268, G304, G506, G521; c; 8786-9852'; **[4, 46, 331]**

Viola canadensis L.; BLM, M; G219, G222, G506; o; 9019-9584'; **[318, 395] @**

Viola nuttallii Pursh **% @**

Viola palustris L.; M; G506, G521; o; 9508'; **[87]**

APPENDIX B:
PLANT COMMUNITIES TRACKED BY THE COLORADO NATURAL HERITAGE PROGRAM AND FOUND IN THE STUDY AREA

Table B.1 lists the plant communities tracked by the Colorado Natural Heritage Program (CNHP) and found in the study area, the sites at which they occur (Fig. 1.6), and their global and state conservation status (https://cnhp.colostate.edu/ourdata/trackinglist/plants_communities/). Property owners are abbreviated as follows: 'M' for Maurer family, and 'BLM' for Bureau of Land Management. The species names in the list have been modified from CNHP's plant-community tracking list to match the taxonomy in the *Flora of Colorado* (Ackerfield, 2015). A conservation status of GU or SU indicates that insufficient data has been gathered to assign a status. Conservation status ranks between G1 and G3 (globally critically imperiled to vulnerable) or between S1 and S3 (state critically imperiled to vulnerable) have been highlighted in red. Communities marked with an asterisk are suspected, but not confirmed, to occur in the study area. Similarly, sites marked with an asterisk are suspected to include the community in question, but this has not been confirmed.

Table B.1. Full list of plant community types in the study area that are tracked by the Colorado Natural Heritage Program (CNHP).

CNHP community description (tree species / understory species)	Global conservation status	State conservation status	CNHP tracking status	Site numbers	Property owner
Abies bifolia – Picea engelmannii / Calamagrostis canadensis swamp forest*	G5	S2	full	9*	M
Abies bifolia – Picea engelmannii / Mertensia ciliata swamp forest	G5	S5	partial	9	M
Abies bifolia – Picea engelmannii / moss forest	G4	SU	full	9, 20, 41	M

CNHP community description (tree species / understory species)	Global conservation status	State conservation status	CNHP tracking status	Site numbers	Property owner
Abies bifolia – Picea engelmannii / Ribes (montigenum, lacustre, inerme) forest	G5	S3	partial	13*, 21	BLM, M
Abies bifolia – Picea engelmannii / Vaccinium myrtillus forest	G5	S5	partial	41	BLM, M
Abies bifolia / Carex aquatilis swamp forest*	G4	SU	full	9 *	M
Abies bifolia / Erigeron eximius forest *	G5	S4	partial	23 *	BLM
Alnus incana – Salix (monticola, lasiandra, eriocephala) wet shrubland	G3	S3	full	24, 25, 26	BLM, M
Alnus incana – Salix drummondiana wet shrubland	G3	S3	full	24, 25, 26	BLM, M
Alnus incana / Equisetum arvense wet shrubland	G3	S1	full	25, 26	BLM, M
Alnus incana / mesic forbs wet shrubland	G3	S3	full	24, 25, 26	BLM, M
Alnus incana / mesic graminoids wet shrubland	G3	S2	full	24, 25, 26	BLM, M
Artemisia cana ssp. *viscidula / Festuca thurberi* shrubland	G2G3	S2S3	full	1, 3, 4, 8, 9, 10, 11, 14	M
Artemisia tridentata ssp. *vaseyana / Festuca thurberi* shrubland*	G3G4	S1S2	full	33*, 36*	M
Calamagrostis canadensis western wet meadow	G4	S4	partial	1*, 9, 10	M
Caltha leptosepala wet meadow	G4	S4	partial	7, 13, 14	M
Carex aquatilis - Carex utriculata wet meadow	G4	S4	partial	1, 7, 9, 10, 14, 24, 26, 40	BLM, M
Carex aquatilis wet meadow	G5	S5	partial	9, 40	BLM, M
Carex microptera wet meadow	G4	S1	full	1, 14	M
Carex nebrascensis wet meadow	G4	S4	partial	30	M
Carex utriculata wet meadow	G5	S5	partial	1, 7, 24, 26, 40	BLM, M

CNHP community description (tree species / understory species)	Global conservation status	State conservation status	CNHP tracking status	Site numbers	Property owner
Deschampsia caespitosa wet meadow	G4	S4	partial	7, 14	M
Eleocharis palustris marsh	G5	S5	partial	1	M
Festuca thurberi – (Lathyrus lanzwertii var. *leucanthus, Potentilla* spp.*)* grassland	G4	S4	partial	22, 23, 24, 25, 40, 41	BLM, M
Juncus arcticus var. *balticus* wet meadow	G5	S5	partial	1, 3	M
Picea engelmannii / Caltha leptosepala swamp forest	G3	S1	full	2	M
Picea engelmannii / Equisetum arvense swamp forest	G4	S1	full	2	M
Picea engelmannii / Saxifraga bronchialis scree sparse vegetation	G4	SU	full	21	M
Pinus flexilis / Arctostaphylos uva-ursi woodland	G4	S1	full	22	M
Pinus flexilis / Juniperus communis woodland	G5	S5	partial	22	M
Populus tremuloides / Carex geyeri forest	G4	S4	partial	32, 36	M
Populus tremuloides / Festuca thurberi forest*	G4	S4	partial	41*	BLM, M
Populus tremuloides / Pteridium aquilinum forest	G4	S4	partial	21	M
Populus tremuloides / Shepherdia canadensis forest	G3G4	S1	full	21	M
Populus tremuloides / Thalictrum fendleri forest	G5	S5	partial	16, 17, 37	M
Populus tremuloides / Veratrum californicum riparian forest	G3	S1	full	35	M
Pseudotsuga menziesii / Carex geyeri forest	G4	S4	partial	18, 36	M
Pseudotsuga menziesii / Juniperus communis forest	G4	S1	full	15	M
Pseudotsuga menziesii / Paxistima myrsinites forest*	G2G3	S2	full	41*	BLM, M
Quercus gambelii / Amelanchier alnifolia var. *utahensis* shrubland	G3G5	S2	full	28	M

CNHP community description (tree species / understory species)	Global conservation status	State conservation status	CNHP tracking status	Site numbers	Property owner
Salix drummondiana / Carex utriculata wet shrubland	G4	S2	full	24, 25, 26	BLM, M
Salix drummondiana / mesic forbs wet shrubland	G4	S4	partial	24, 25, 26	BLM, M
Salix geyeriana / Carex aquatilis wet shrubland	G3	S2	full	7	M
Salix geyeriana / Carex utriculata wet shrubland	G3	S2	full	7	M
Salix geyeriana / mesic forbs wet shrubland	G3	S2	full	7	M
Salix geyeriana / mesic graminoids wet shrubland	G3	S2	full	7	M
Salix lasiandra var. *caudata* wet shrubland	G3	S2	full	25	BLM
Salix monticola / Carex aquatilis wet shrubland	G3	S2	full	26	BLM, M
Salix monticola / Carex utriculata wet shrubland	G3	S3	full	26	BLM, M
Salix monticola / mesic forbs wet shrubland	G4	S4	partial	26	BLM, M
Salix monticola / mesic graminoids wet shrubland	G3	S3	full	26	BLM, M
Salix planifolia / Carex aquatilis wet shrubland	G5	S5	partial	7, 9, 10	M
Salix planifolia / Carex utriculata wet shrubland	GU	S2	full	7, 9, 10	M
Salix planifolia / Deschampsia caespitosa wet shrubland	G2G3	S2	full	7	M
Salix planifolia / mesic forbs wet shrubland	G4	S2	full	7, 9, 10	M
Salix wolfii / Carex aquatilis wet shrubland	G4	S3	full	7	M
Salix wolfii / Carex utriculata wet shrubland	G4	S1	full	7	M
Salix wolfii / mesic forbs wet shrubland	G3	S3	full	7	M
Typha (latifolia, angustifolia) western marsh	G5	S5	partial	30, 31	M

APPENDIX C:
LABELMAKER USER GUIDE

How to install and run Labelmaker and supporting software

1. Ensure Python (version 3.0 or higher) is installed on your computer. If not, install it. A convenient way to install Python is installing Anaconda (http://www.anaconda.com/download), which includes the most recent Python distribution, and has versions available for use on Windows, MacOS, or Linux. You also need to install the pystache Python package, which can be downloaded by typing `pip install pystache` in the command line (after installing Python).
2. Download the whole Labelmaker repository (https://github.com/wundalous/labelmaker), ensuring you save all of its contents in a single folder.
3. Create a CSV (comma-separated value) file containing your label data. Use any spreadsheet software (such as Microsoft Excel, Google Sheets, and OpenOffice Calc) to do this. Ensure that all field names (column headings) are the same as in the sample CSV file provided in the repository (sample_input_file.csv). Note: Labelmaker will automatically italicize the contents of the fields *genus*, *specificEpithet*, and *infraspecificEpithet*. If you want to include italicized text in other fields, the current version requires you to put the HTML italics tags `<i></i>` around the text to be italicized. For example, an entry for *habitat* might read "Growing in loamy soil in shady spruce-fir forest with `<i>`Aconitum columbianum`</i>`."
4. Save the CSV file in the same folder as the repository files. (Let's say you name it MyLabels.csv.)
5. Once you have written the content of your labels, run Labelmaker by opening a terminal window, navigating to the folder in which you've saved the repository files and your CSV file, and typing the following: `python v3labelmaker.py -i MyLabels`. Make sure to type

in just the name of the CSV file, without the '.csv' file extension. (If the '.csv' file extension is included, the program will look for a file called 'MyLabels.csv.csv'.) Hit 'Enter' to run the program.

6. If run successfully, Labelmaker will print a message stating the number of labels generated, the name of the HTML file generated, and the processing time taken to complete the operation. For instance: "`Done. 530 labels printed to file MyLabels.html. Job completed in 0.20 seconds.`" To verify that the program worked, check the contents of the directory you have been working in. There should now be a file called MyLabels.html. (Another file, MyLabels.json, will also be in the directory. This is the file the program uses to generate the HTML file.)
7. Open MyLabels.html in a browser. Each label will appear to be the whole width of the page on your screen. When you print the page or view it in print preview, however, the labels will be resized so that six will fit on one page, in two columns of three.
8. Print the page from the browser.